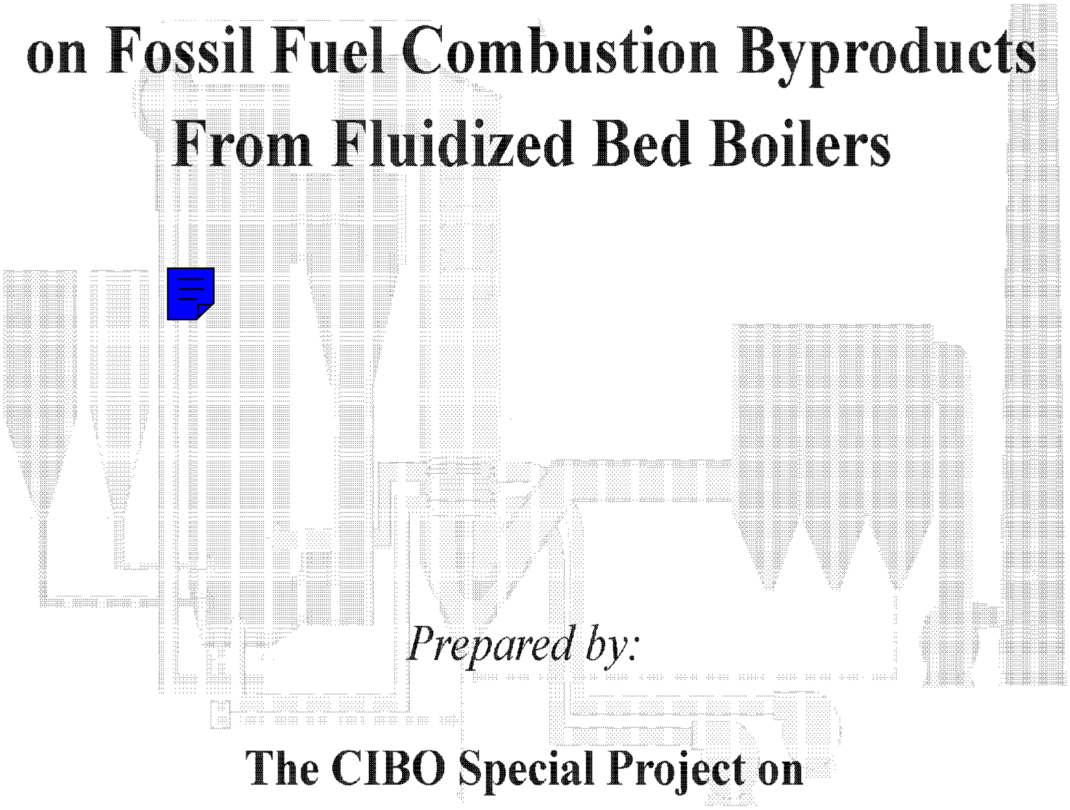
Report to the
U.S. Environmental Protection Agency
on Fossil Fuel Combustion Byproducts
From Fluidized Bed Boilers



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The CIBO Special Project would also like to acknowledge the US Environmental Protection Agency Office of Solid Waste personnel who helped provide guidance for the project, helping us to avoid duplication of efforts and to collect the data that would be most beneficial and useful to the Agency. Their guidance was appreciated by all participating in the production of this document.

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November, 1997

EXECUTIVE SUMMARY

This document is the product of an effort by the CIBO Special Project on Non-Utility Fossil Fuel Ash Classification, an *ad hoc* committee of the Council of Industrial Boiler Owners (CIBO), to develop and provide to the U.S. Environmental Protection Agency (EPA) certain facts, analyses, and perspectives that bear upon a forthcoming EPA decision regarding the regulation of fossil fuel ash under the Resource Conservation and Recovery Act (RCRA). Fossil fuel ash is one of the so-called "Special Wastes" identified in the statute for which EPA is required to complete a Report to Congress and formal regulatory determination in advance of regulating or exempting them as hazardous wastes under Subtitle C of RCRA. The Special Project has prepared this report on its own initiative, in the belief that by providing to EPA detailed information on byproducts from fluidized bed combustion of fossil fuels (hereafter FBCBs), EPA will be in a better position to make a regulatory determination that will provide cost-effective protection of human health and the environment, in accord with the spirit of the Bevill Amendment, than would be possible otherwise.

The Special Project has developed and employed data collection approaches, analytical methods, and reporting conventions that closely parallel previous EPA Special Waste studies, in order to make the resulting information as relevant and accessible as possible. To that end, we have conducted a detailed survey of all known U.S. operators of FBC units that burn fossil fuels, as well as a survey of state-level agencies addressing regulation of disposal of fossil fuel ash in landfills and surface impoundments. In addition, the Special Project has conducted a number of on-line literature searches, research addressing documented cases of damage caused by FBCBs, and detailed analyses of byproduct management practices, potential impacts of these practices on human health and the environment, and the cost and economic impacts of potential RCRA regulatory alternatives, among others. In addition, the Special Project facilitated an EPA tour of four FBC installations and several FBCB beneficial reuse projects, to familiarize Agency staff with the technology and its benefits.

While this report is focused on fluidized bed combustion, comparisons and contrasts to conventional technologies (pulverized fuel and stokers) have been made. These comparisons and contrasts allow a comparative qualitative analysis to be made between the previously studied coal combustion byproducts and management practices from electric utilities and the analogous combustion byproducts and management practices of non-utility sources.

The results of our studies are illuminating in several important respects. FBC use, and along with it, FBCB generation, have grown rapidly in recent years, as the benefits of this relatively new technology have become more widely understood. The Special Project estimates that approximately 9.4 million short tons of FBCBs are generated annually (as of 1995). Most of the FBCBs generated are put to productive use rather than disposed. Reclamation of coal mines and mined lands is the predominant productive use, though significant quantities of FBCBs are used for waste stabilization and geotechnical and agricultural applications. FBCBs that are disposed generally are delivered to on-site landfills or surface impoundments, almost all of which have been designed and constructed since the emergence of waste management controls under RCRA and analogous state programs. Waste disposal unit features vary, but typically include several different types of contaminant release controls. Both disposal and productive use of FBCBs are often addressed under state-level regulations.

Concerted efforts by the Special Project to find and analyze any cases of documented damages to human health and the environment posed by FBCB management yielded no unambiguous examples of such damages. None of the instances of environmental contamination at or adjacent to FBC-equipped facilities that have been identified by the Special Project can be definitively linked to FBCB management practices, and none meet EPA's established "tests of proof" for documented damage.

As part of this study, the Special Project conducted screening-level and comparative risk analyses, which confirmed that FBCBs pose very low intrinsic hazards. Moreover, comparison with analogous materials generated by the electric utility industry that have been analyzed in depth by EPA indicates that FBCBs pose a similar, or lower, degree of risk. EPA has chosen not to remove Special Waste status from the utility industry byproducts.

In the event of an EPA decision to remove FBCBs from the Special Waste exclusion, the Agency would presumably either regulate these materials as hazardous wastes under Subtitle C of RCRA, or possibly attempt to impose new industrial solid waste controls under RCRA Subtitle D. The Special Project has evaluated the operational practices that would be required to comply with these two scenarios, and projected the cost and economic consequences of each. Imposition of Subtitle C controls would render the independent power producers that employ FBC non-economic, leading to facility closure. Extensive Subtitle D controls also would threaten the continued survival of many of these operations. Industrial users of FBC technology would experience more variable impacts, though most would either close or abandon the technology in favor of new sources of electricity and/or steam, rather than absorb significant new FBCB management costs.

In EPA's two most recent regulatory determinations for Bevill wastes (applied to cement kiln dust and utility fossil fuel combustion wastes, respectively), the Agency has employed a three step decision making process to sequentially evaluate the most critical Bevill study factors in a consistent and logical manner. The Special Project endorses this general approach, and offers its views on the salient facts viewed within this context.

In Step 1, EPA asks, "Does management of FBCBs pose human health and environmental problems? Might current practices cause problems in the future?" Upon reviewing the results of a search for documented cases of damage to human health and the environment, performing screening-level and comparative risk assessments, and evaluating the results of laboratory analyses of a large number of FBCB samples, the Special Project has concluded that risks associated with current methods of FBCB disposal and beneficial use are low. Indeed, the available evidence suggests that if anything, appropriate FBCB use may often lead to environmental improvements, particularly through reclaiming mined lands, stabilizing waste materials, and improving fill or soil quality.

In the view of the Special Project, should EPA decide to follow its traditional three step decision making methodology in determining the Special Waste status of FBCBs, that evaluation should logically conclude at this juncture, given the absence of past or current impacts and low predicted risks, and therefore, any justification for new regulatory controls.

Were EPA to continue to Step 2, it would ask "Is more stringent regulation necessary or desirable?" The Special Project believes that the information presented in this Report suggests that additional or more stringent regulation of FBCBs is neither necessary nor desirable. Extensive information developed and reported by the Special Project leads to the conclusion that both disposal and productive use of FBCBs are already extensively (and often intensively) regulated. It is unclear that additional waste management controls at the federal level would impart significant improvements in protection of human health or the environment. Indeed, to the extent that such controls were to discourage productive use of the material, they might actually lead to a decline in environmental quality in certain locations.

Finally, in Step 3, EPA would ask "What would be the operational and economic consequences of a decision to regulate FBCBs under Subtitle C?" As briefly mentioned above, imposition of Subtitle C management controls on FBCBs would almost certainly lead to closure of all independent power producers that generate these materials. Similarly, impacts of mandating the MSW landfill "default" landfill design and operating standards would threaten the economic viability of many of these operations. Because operation of an FBC unit is not necessarily central to their core business, industrial operators would experience less severe impacts than the IPPs. Nonetheless, they would likely need to expend significant resources (human and financial) arranging for alternative sources of electricity and/or steam.

In conclusion, the Special Project believes that it has provided sufficient factual bases upon which EPA can make its regulatory determination for Fluidized Bed Combustion Byproducts with confidence that it is adequately protecting human health and the environment and fulfilling its primary mission. We believe that the evidence provided in this Report fully supports the continued and permanent exclusion of FBCBs from RCRA Subtitle C under the auspices of the Bevill Amendment.

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GLOSSARY

ACRONYMS

ABMA	American Boiler Manufacturers' Association
ABMA tests	Emission and Efficiency Performances of Industrial Coal Stoker Fired Boilers, published by the American Boiler Manufacturers Association in 1981
AEO97	Energy Information Administration report *Annual Energy Outlook 1997*
AFBCR	Atmospheric Fluidized Bed Combustion Residue
ALEC	American Legislative Exchange Council
ARIPPA	Anthracite Region Independent Power Producers Association
ASTM	American Society for Testing and Materials
ASTM C-618	Standard Specification for fly ash and raw or calcined natural pozzolan for use as a mineral admixture in Portland cement concrete
AWQC	Ambient Water Quality Criteria
AWQCS	Ambient Water Quality Control Standards
BACT	Best Available Control Technology
BFB	bubbling fluidized bed
BMR	Bureau of Mining and Reclamation
BTU	British Thermal Unit
BUD	beneficial use determination
CAA	Clean Air Act and its amendments
CaO	calcium oxide, or lime
$CaCO_3$	calcium carbonate, limestone, or mineral calcite
$CaMg(CO_3)_2$	dolomite
$Ca(OH)_2$	hydrated lime
Ca/S	calcium/sulfur ratio
$CaSO_4$	calcium sulfate, or gypsum
CBC	Case by case
CCB	Coal Combustion Byproduct

ACRONYMS (continued)

CCLs	ceiling concentration limits
CCSEM	Computer controlled scanning electron microscopy
CDFA	California Department of Food and Agriculture
CERCLA or Superfund	Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (P.L. 96-510)
CFB	circulating fluidized bed
CFB conditions	fast fluidization or lean phase fluidization
CIBO	Council of Industrial Boiler Owners
CIWMB	California Integrated Waste Management Board
CKD	cement kiln dust
CO	carbon monoxide
CO_2	carbon dioxide
CSF	cancer slope factors
CPG	Comprehensive Procurement Guideline
CPL	Cumulative pollution loading
CPLRs	cumulative pollutant loading rate limits
C_v	coefficients of variation
CWA	Clean Water Act
DEC	Department of Environmental Conservation
DOE	Department of Energy
DRI	Data Resources, Inc.
DWS	Drinking Water Standards
EIA	Energy Information Administration
EP	Extraction Procedure (EPA Method 1310)
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act of 1992

ACRONYMS (continued)

EPCRA	Emergency Planning and Community Right to Know Act
ERDA	Energy Research and Development Administration
ESP	electrostatic precipitator
EWG	exempt wholesale generator
FBAC's	Fluidized bed ash coolers
FBC	Fluidized Bed Combustion
FBCBs	fluidized bed combustion byproducts
FC	fixed carbon
FeS	pyrrhotite
FFCB	fossil fuel combustion byproducts
FGD	flue gas desulfurization
FHWA	Federal Highway Administration
FML	flexible membrane liner
ft	feet
ft^3	cubic feet
fuel NO_x	oxidation of nitrogen and/or nitrogen components in the fuel
GNP	Gross National Product
GRI	Gas Research Institute
HAPs	hazardous air pollutants
HDPE	high density polyethylene
HSWA	Hazardous and Solid Waste Amendments of 1984
ICCR	industrial combustion coordinated rulemaking
ID	induced draft
IPP	independent power producer
IRIS	Integrated Risk Information System (EPA)
LAER	Lowest Achievable Emission Rate

ACRONYMS (continued)

lb	pound
LCS	leachate collection systems
LFA	Lime-fly ash
LVCC	large-volume coal combustion wastes
m	meter
MCL	Maximum Contaminant Levels
mg	milligram
$MgCO_3$	magnesium carbonate
MSW	municipal solid waste
MWe	Megawatts electric
N_2	nitrogen (elemental)
NAAQS	National Air Ambient Quality Standards
Na_2CO_3	sodium carbonate
Na_2SO_4	sodium sulfate
NCSL	National Conference of State Legislators
NESHAP	National Emission Standards for Hazardous Air Pollutants
NH_3	ammonia
Nm^3	normal cubic meters
NO_2	nitrogen dioxide
NODA	Notice of Data Availability
NOx	nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
NPRM	Notice of Proposed Rulemaking
NSPS	New Source Performance Standards
NSR	New Source Review
O_2	oxygen (elemental)

ACRONYMS (continued)

O_3	ozone
O&M	operating and maintenance
OSW	Office of Solid Waste
OTC	Ozone Transport Commission
PABMR	Pennsylvania Department of Environmental Protection, Bureau of Mining and Reclamation
PADEP	Pennsylvania Department of Environmental Protection
PC	pulverized coal
PCL	pollution concentration limits
PDWS	Primary Drinking Water Standards
PFBC	pressurized FBC
PM	particulate matter
PM_{10}	particulate matter-ten microns
PPA	power purchase agreement
PPA	Pollution Prevention Act of 1990
ppm	parts per million
PRPs	potentially responsible parties
PSD	Prevention of Significant Deterioration
PSIG	Pounds per square inch gauge
PUCHA	Public Utility Holding Company Act of 1935
PURPA	Public Utility Regulatory Policy Act of 1978 (P.L.95-617)
PVC	polyvinyl chloride
QF's	PURPA-defined qualifying facilities
RCC	Roller compacted concrete
RCRA	Resource Conservation and Recovery Act
RfD	non-cancer reference dose

ACRONYMS (continued)

RTC	Report to Congress
RTG	regional transmission group
s	second
SCR	selective catalytic reduction
SDWA	Safe Drinking Water Act
SDWA	Solid Waste Disposal Act Amendments of 1980
sec	second
SEM	scanning electron microscopy
SIC	Standard Industrial Classification
SIP	state implementation plan
SNCR	selective non-catalytic reduction
SO_2	sulfur dioxide
SOx	Sulfur oxides (commonly referring to sulfur dioxide)
SPP	small power producer
SPLP	Synthetic Precipitation Leaching Procedure (EPA method 1312)
STLC	Soluble Threshold Limit Concentration
TC	toxicity characteristic
TCLP	Toxicity Characteristic Leaching Procedure (EPA method 1311)
TDS	total dissolved solids
thermal NO_x	oxidation of nitrogen in the air
TIFs	thermally-induced fractures
tph	tons per hour
TSP	total suspended particulates
US90	1990 National Interim Emission Inventory
USWAG	Utilities Solid Waste Activities Group
Vepco	Virginia Electric and Power Company

VM	volatile matter
WEFA	WEFA group
WET	waste extraction test, California
XRD	X-ray diffraction

CHAPTER ONE

INTRODUCTION

1.0 Introduction

This report has been prepared by the Council of Industrial Boiler Owners, Special Project on Non-Utility Fossil Fuel Ash Classification ("CIBO Special Project") to provide the United States Environmental Protection Agency ("EPA") with data and information on fossil fuel-fired fluidized bed combustion ("FBC") and its associated byproducts. The EPA is currently conducting studies, as required by the Bevill[1] Amendment to the Resource Conservation and Recovery Act ("RCRA", 42 U.S.C. §6901 *et seq*.), that will lead to a regulatory determination relating to fossil fuel combustion byproducts from FBC and other combustion technologies.

This introductory chapter is organized into the following five (5) sections: Section 1.1 discusses the significant role that energy plays in the United States economy and several important legislative initiatives that affect energy production and use, and the environment. Section 1.2 provides a description of the Council of Industrial Boiler Owners and the CIBO Special Project. Section 1.3 provides a brief introduction on the current regulatory status of fossil fuel combustion byproducts under RCRA. Section 1.4 discusses information sources and methods used to analyze the collected

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[1] In October 1980 the Congress passed the Solid Waste Disposal Act Amendments that, among other things, temporarily exempted from regulation as hazardous waste several large volume wastes, Section 3001(b)(3)(A)(i-iii) of RCRA (42 U.S.C. §§ 6921(b)(3)(A)(i-iii)), the "Bevill Amendment." The Bevill wastes include: fly ash waste, bottom ash waste, slag waste, and flue gas emission control waste generated primarily from the combustion of coal or other fossil fuels; solid waste from the extraction, benefication, and processing of ores and minerals; and cement kiln dust waste. The Bevill Amendment also imposed the requirement for the EPA to conduct a study of these special wastes and prepare a Report to Congress. Additionally, the EPA Administrator is required to complete a regulatory determination within six months of completing the Report to Congress. The Bevill Amendment designated crude oil and natural gas wastes as high-volume, low-toxicity "special wastes," but reserved Subtitle C regulatory treatment for certain drilling muds and production brines. In 1980, however, Congress passed the Bentsen Amendment to RCRA which exempted drilling fluids, produced waters, and other wastes associated with the exploration, development, or production of crude oil, natural gas, or geothermal energy until such time as a study was completed and recommendations made. 42 U.S.C. §6921(b)(2)(A); see *Amer. Steel Inst. v EPA*, 886 P.2d 390, 394 (D. C. Cir. 1989), cert. denied, 497 U.S. 1003 (1990). As in the case of the Bevill Amendment, the Bentsen Amendment was passed because Congress feared that the application of Subtitle C to energy wastes could produce unique and adverse consequences for the economy and the security of the nation. Also, given the high volumes and relatively benign profiles of the wastes, Congress believed the exclusion was environmentally appropriate. For an explanation of the legislative history of these energy exclusions, see David M. Flanery & Robert E. Lannan, *Hazardous Waste - The Oil and Gas Exemption*, 89 W. Va. L. Rev. 1089, 1096 (1987).

information contained in this report. Lastly, section 1.5 provides an overview of the content of the report and its organization.

1.1 Energy and Environmental Policy Considerations for Fossil Fuel Use

The significance of the role of energy in the United States economy was noted by the U.S. House of Representatives during debate on the Energy Policy Act of 1992 (P.L. 102-486):

> The role of energy in the U.S. economy is clear. The U.S. economy is the largest in the world, producing a vast array of goods and services. Energy is needed to produce these goods and services in the end use sectors of the economy, as well as to produce electricity that feeds back into the end use sectors. Nationally, our annual expenditure on energy represents a significant portion of the GNP [Gross National Product]. DOE [Department of Energy], in its 1992 update on the National Energy Strategy, noted that the annual U.S. energy bill now totals nearly $440 billion, or 8.5 percent of the gross national product, representing a bill of about $1,750 for every man, woman, and child. Given our current growth patterns and economic progress of the developing countries, energy will be a key fact in our national economic growth and international competitiveness well into the 21st century.[2]

During the period from 1949 to 1973 U.S. energy consumption more than doubled from 30.46 quadrillion Btu to 74.28 quadrillion Btu with the U.S. economy growing at about the same rate.[3] In the period from 1973 to 1995 energy consumption has continued to increase by about a quarter, to a record 90.62 quadrillion Btu[4] while the economy has nearly doubled.

Energy consumption is, however, only half of the picture; energy production is the other. Consider the following statements from 1975:

> Through the first half of this century, the United States was energy self-sufficient; in fact, a net exporter of energy supplies. But in succeeding years growth in demand began to exceed domestic production. By 1973 consumption had reached 75 quadrillion Btu's--more than double the 37 quadrillion Btu's consumed in 1950...
>
> ...It is significant to keep in mind that coal production in the United States remains at levels achieved in the 1940's. Natural gas consumption began exceeding new discoveries in 1968. And domestic crude oil production has been declining since 1970.

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[2] Hse. Rpt. No. 102-474(II), 102 U.S.C. C.A.N., pp. 2132-2133 (1992)

[3] Annual Energy Review 1995, Energy Information Administration, Washington, D.C., July 1996, p. 1.

[4] *Ibid*. Exhibit 1.1

> The gap between the production and consumption...is entirely filled by petroleum imports. In 1974, approximately 37 percent of petroleum products were imported at a negative trade balance of $25 billion....[5]

The 1973 Arab oil embargo (which affected about 14 percent of U.S. petroleum consumption and precipitated a $10- to $20-billion drop in GNP[6]) brought into sharp focus the need to develop a new direction in energy policy. The 1973 embargo ushered in a new era with the federal government taking an increased role in energy policy and taking an active role not only in "...research and development aspects of energy policy, but also the demonstration of promising, near-term technologies."[7] Prior to the new energy awareness, concern over the effects of energy use on the environment had surfaced, and in tandem with changing energy policy resulted in a significant body of new federal law that affected energy decisions (such as fuel choices, energy conversion technology, and pollution control equipment).

Federal Energy Policy

In response to the 1973 oil embargo, Congress in 1974 began adopting laws that addressed the multidimensional aspect of energy policy and the desired reduction in the dependence on oil imports by encouraging the utilization of the nation's coal resources. These legislative initiatives attempted to address the national security, economic consequences, and the environmental protection aspects of energy policy. The first suite of laws, the Federal Energy Administration Act of 1974 (P.L. 93-275), the Energy Supply and Environmental Coordination Act of 1974 (P.L. 93-319), and the Energy Reorganization Act (P.L. 93-438), began the development of a coordinated energy policy.

The Energy Research and Development Administration ("ERDA") was created in 1974 in order to "consolidate the Federal Government's fragmented and uncoordinated energy research and development functions..."[8] Specifically, ERDA was conceived to foster energy conversion technologies, such as fluidized bed combustion. One mission of ERDA was summarized as follows: "For example, significant emphasis will be placed on fossil fuels, e.g., coal gasification, liquefaction, and clean combustion systems devices, etc., since this area appears to be promising based on current resource reserves and research technologies."[9] The Energy Supply and Environmental Coordination Act encouraged the broader use of the Nation's coal resources by prohibiting "... as its primary energy source, the burning of natural gas or petroleum products by any major fuel-burning installation (including any existing electric powerplants) which, on the date of enactment of this legislation, has

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[5] Hse. Rpt. No. 94-340, 94 U.S.C. C.A.N., p. 1764 (1976).

[6] *Ibid*. p.1765.

[7] 94020: Fossil Energy Research and Development: Whiter Coal?, Congressional Research Service Issue Brief, November 20, 1996, available at http://www.cnie.org/nle/eng-19.html.

[8] Sen. Rep. No. 93-980, 93 U.S.C. C.A.N., p. 5470 (1974).

[9] *Ibid*. p. 5481.

the capability and necessary plant equipment to burn coal..."[10] A similar prohibition was included for new facilities in the early planning stages that required these facilities to have the capability to burn coal. The prohibition of using oil or natural gas was conditioned on the following factors: meeting variances to certain specific Clean Air Act requirements; availability of coal and coal transportation facilities; and the maintenance of reliability of service in a given service area.

Since the prohibition on using oil and natural gas as the primary energy source in major fuel-burning facilities contained in the Energy Supply and Environmental Coordination Act was an emergency act with only a one year authorization, the Congress in 1975 passed the Energy Policy and Conservation Act (P.L. 94-163). This law continued the prohibition on the use of oil and natural gas as a primary energy source until June 30, 1977 and extended the period for the enforcement of any coal conversions ordered under the Energy Supply and Environmental Coordination Act requirements until December 31, 1984. The Act instituted price controls on all domestic crude oil production, and established a regulatory program to bring about measured savings in consumption of energy by improving efficiency of products and cars. Other portions of the Act granted additional powers to the President to manage the vital needs of the nation in the event of another embargo or other supply interruption and provisions were made for the development of a strategic reserve of petroleum products.

The Congress and the President continued strengthening the Nation's energy policy making capability in 1977 with the enactment of the Department of Energy Organization Act (P.L. 95-91) and Executive Order 12009. The U.S. Department of Energy ("DOE") was a consolidation of the major Federal energy functions into one cabinet-level agency. Generally, DOE advances energy policy by providing "the framework for a comprehensive and balanced national energy plan through the coordination and administration of the energy functions of the federal government.[11] An explicit part of this mission is responsibility for "research and development programs involving fossil fuels -- coal, petroleum, and gas," including management of the Clean Coal Technology program.[12]

In 1978 two important laws were enacted that affected energy policy, namely: the Power Plant and Industrial Fuel Use Act of 1978 (P.L. 95-620) and the Public Utility Regulatory Policy Act of 1978 (P.L. 95-617). The Power Plant and Industrial Fuel Use Act was an amendment to the Energy Supply and Environmental Coordination Act of 1974, as amended. The Power Plant and Industrial Fuel Use Act basically created a permanent prohibition on the use of oil or natural gas in major fuel burning facilities. Specific exemptions (both temporary and permanent) could be granted provided certain conditions could be met. The rationale for this legislation was to foster greater coal utilization to enhance "energy independence." The previous 1974 legislation and its amendments had established

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[10] Hse. Rpt. No. 93-1013, 93 U.S.C. C.A.N., p. 3294 (1974).

[11] Nat'l Archives and Records Adm., *The United States Government Manual* (1990) , p.276.

[12] *Ibid*. p. 280.

a process that "...has proven to be cumbersome and time-consuming, and its effectiveness is yet to be demonstrated."[13]

The Public Utility Regulatory Policy Act of 1978 (P.L.95-617) ("PURPA") was a continuation of efforts to reduce dependency on oil imports, stimulate the use of renewable energy sources in power production, and spur conservation efforts and efficiency improvements in electricity generation and use. PURPA created an entirely new class of electric power generators called "Qualifying Facility" that either provided cogeneration (sequential use of energy for electricity production and other useful purposes) or used alternative fuels such as bio-mass or other wastes (small power production). A qualifying cogeneration facility had to meet certain efficiency standards while small power production facilities had fuel use and size restrictions. This legislation was the impetus for the development of an entirely new industry that has now become known as independent power production. Refer to Chapter 2 for additional details on PURPA and independent power production.

While the national policy remained to encourage the development of coal as a primary energy source instead of oil or natural gas, there was a growing national and international concern over acid rain brought on from sulfur dioxide and nitrogen oxide emissions and their effects on the environment. In 1985 the U.S. and Canada appointed Special Envoys on Acid Rain to study ways of resolving the transboundary problems of acid rain. During the time that the Special Envoys were conducting their studies, the Congress, in 1985, concerned about acid rain and the high costs and/or major economic dislocations to regions dependent on high sulfur coal for electric power production or economic stability, was searching for ways to accomplish an improved environment without sacrificing economic growth. Although technologies were emerging from government and industry laboratories that could control sulfur dioxide and nitrogen oxide emissions,

> ...the Nation lacked a mechanism for moving these technologies into the commercial marketplace. The role of Government in technology development at the time was limited to support of basic, high risk research. With a risk averse, regulated utility industry as the major potential customer of clean coal technologies, the Nation lacked a mechanism for moving these technologies into the commercial marketplace. To help fill that gap, Congress directed the Department of Energy to initiate a unique Government/industry partnership by providing $400 million (from funds previously earmarked for the Synthetic Fuels Corporation) to cost share in the construction and operation of a number [of] commercial scale clean coal technology demonstration facilities. These first-of-a-kind demonstrations are intended, when successful, to lead to widespread commercial use of the most promising technologies.[14]

In January 1986 the Special Envoys issued their recommendations which affirmed the conclusion already made by Congress that a cost shared demonstration of clean coal technologies would be the key to bring these technologies to the market place and resolving acid rain concerns. The Congress subsequently appropriated in advance over the next several years, an additional $2.35 billion to

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[13] Sen. Rpt. No. 95-361, 95 U.S.C. C.A.N., p. 8176 (1978).

[14] Comprehensive Report to Congress, Clean Coal Technology Program Completing the Mission, DOE/FE-0309P, U.S. Department of Energy, Washington, D. C., May 1994, p. II-1.

complete the Clean Coal Technology Program.[15] The Clean Coal Technology Program included sub-programs for Advanced Electric Power Generation Systems, Environmental Control Devices, Coal Processing for Clean Fuels, and Industrial Applications. Examples of Advanced Electric Power Generation Systems projects are the Nucla Circulating Fluidized Bed Demonstration Project, the Tidd Pressurized Circulating Fluidized Bed Demonstration Project, and the Pinon Pine Integrated Gasification Combined Cycle Power Project.

In the ensuing years several market and policy changes occurred that effected energy policy. For instance, consumers and utilities had very actively responded to market prices and conservation efforts and the rate of growth for electricity generation had decreased from the 7.1 percent annual growth rate of the 1949 - 1980 period to an annual growth rate of 1.8 percent in the 1980 to 1995 period.[16] Since the mid-1970's, coal and nuclear fuels have provided an increased share of fuel input for electricity generation, displacing substantial quantities of petroleum and to a lesser extent natural gas.[17] Federal price controls on crude oil and natural gas were removed, and the start of federal deregulation of various economic sectors had begun. These changes resulted in 1987 in the enactment of the Powerplants and Industrial Fuel Use Act of 1978 Amendment (P.L. 100-42), which changed the standard to require only that all new baseload electric generation plants and major fuel-burning installations have the design capability to be converted to coal or other alternative fuel, instead of the physical capability. This amendment was intended to preserve the coal option while allowing energy consumers to make their energy decisions in the increasingly deregulated energy marketplace and encourage competition between oil, natural gas, and coal on their own merits.

The most recent major legislation in energy policy was the Energy Policy Act of 1992 (P.L. 102-486). This legislation was again directed at "... a comprehensive national energy policy that gradually and steadily increases U.S. energy security in cost-effective and environmentally beneficial ways."[18] One provision of this legislation increased the competition in the wholesale electricity power market (with the goal of improving efficiency and securing the lowest possible costs for consumers) and removed constraints on the growth of the independent power production market that was created under PURPA. Other provisions of the law encouraged the most efficient and environmentally sound utilization of coal and established programs to export both conventional and clean coal technologies to developing countries. Recognizing that large volumes of coal exist in abandoned mine lands and refuse piles, incentives were provided for industry to extract and reprocess these materials in an environmentally sound manner. Chapter 2 contains a more complete discussion of the Energy Policy Act of 1992's effect on competition in the wholesale electricity power market and removal of constraints on independent power production market.

Federal Environmental Protection Policy

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[15] *Ibid.* p. II-2.

[16] *Ibid*. p. 1.

[17] *Ibid*. p. 1.

[18] Hse. Rpt. No. 102-474(I), 102 U.S.C. C.A.N., p. 1955 (1992).

There are many federal and state environmental laws that affect the generation and management of fossil fuel combustion byproducts and will be more fully discussed in Chapter 8 of this report. The following discussion only touches on those laws that have a major impact on the generation and management of fossil fuel combustion byproducts.

The Clean Air Act ("CAA") has been a feature of American environmental law for over thirty years. Initially, with the adoption of the Air Quality Act of 1967,[19] the federal government established a goal to enhance the quality of the Nation's resources so as to promote the public health and welfare and the productive capacity of its population. Other goals included stimulating appropriate research, providing technical and financial assistance to the states, and encouraging regional approaches to control. See §101(b). One of the most important elements of the 1967 approach was the development by the Department of Health, Education and Welfare of air quality "criteria" for the most widespread pollutants. See §107(b), 110. Despite this important federal research and development role, use of clean air regulations remained primarily at the discretion of the states and localities until the adoption of the centerpiece of modern clean air regulation, the Clean Air Act (CAA) of 1970.[20]

The 1970 CAA marked an important step in the process of greater federal control over clean air policy. To overcome the disappointments of the 1967 Act, the federal government was now authorized to move beyond establishing mere criteria and to promulgate National Ambient Air Quality Standards to be implemented by the states at the direction of the newly formed U.S. Environmental Protection Agency. CAA regulations have imposed limitations on particulate matter emissions that have increased the volume of fly ash that is collected and subsequently managed. Restrictions on the emissions of other criteria pollutants such as Sulfur Dioxide (commonly referred to as SOx) and Nitrogen Oxides (NOx) have not only influenced fuel choices, combustion technology, and flue gas clean-up technology options but also can affect both the quantity and, in some cases, the quality of the combustion byproducts.

The Resource Conservation and Recovery Act of 1976 (P.L. 94-580), as amended, is the primary federal statute governing the management of solid and hazardous waste. The principal objectives of RCRA are to:

- Promote the protection of human health and the environment from potential adverse effects of improper solid and hazardous waste management;
- Conserve material and energy resources through source reduction and waste recycling;
- Reduce or eliminate the generation of hazardous waste as expeditiously as possible; and
- Improve solid waste management practices.

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[19] Air Quality Act of 1967, Public Law 90-148, 42 U.S.C. §§ 1857 *et seq*. (1967).

[20] Clean Air Act (as amended), Public Law 91-604, 42 U.S. C. §§ 1857 *et seq*. (1970).

Special requirements for hazardous wastes are found in Subtitle C of RCRA. Subtitle C provides a statutory framework for tracking all hazardous and toxic wastes from "cradle to grave," that is, from their generation to their final disposal, destruction, or recycling. Subtitle D provides the framework for a state based program for the management of non-hazardous solid wastes.[21]

RCRA as originally enacted did not distinguish the regulatory treatment for the large volume of wastes that are typically associated with the combustion of solid fossil fuels. To address this issue, the Solid Waste Disposal Act Amendments of 1980 (P.L.96-482), including the "Bevill Amendment" which is more fully discussed in Section 1.3 of this chapter, were enacted by the Congress. RCRA was further amended by the Hazardous and Solid Waste Amendments of 1984 (P.L.98-3221) to give the U.S. Environmental Protection Agency flexibility in the promulgation of regulations under Subtitle C that considered the unique characteristics of some large-volume wastes, including fossil fuel combustion wastes.

With the Pollution Prevention Act of 1990 (P.L.101-593) Congress reaffirmed the hazardous waste reduction policy set forth as a national objective in the 1984 Hazardous and Solid waste Amendments to RCRA. The Pollution Prevention Act ("PPAct") stated a simple order of preference for environmental management techniques: reduce; reuse or recycle; treat; dispose. Most of the previous environmental regulations had imposed technology-based standards for control at the "end-of-pipe" without regard to cross-media impacts. The PPAct recognizes that often times control technologies encouraged under one set of regulations may produce a waste that must be managed under another. The PPAct sought to shift the policy making focus and industrial management practices toward the most preferable environmental management technique.[22]

While the national policy is to reduce the volume of material being disposed, there are other statutes that potentially discourage recycling or beneficial use of fossil fuel combustion byproducts. One important example is the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (P.L. 96-510) ("CERCLA" or Superfund). CERCLA authorizes the federal government to respond to the release or threatened release of hazardous substances, pollutants, or contaminants into the environment and establishes a fund to finance the government's response activities. The federal government may conduct a clean-up of the site, and sue potentially responsible parties ("PRPs") to recover the cost of clean-up. Alternatively, the federal government may order the PRPs to conduct the clean-up action themselves. PRPs can include a facility owner, operator, generator, or transporter of the hazardous substance. Fossil fuel combustion byproducts are not specifically listed as CERCLA hazardous substances, although some combustion byproducts may contain small amounts of constituents such as arsenic, cadmium, chromium, and selenium that are CERCLA hazardous substances.

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[21] The preceding discussion of RCRA was adapted from <u>Report to Congress on Cement Kiln Dust, Methods and Findings</u>, EPA530-R-94-001, U.S. Environmental Protection Agency, Washington, D. C., December 1993, page 7.20.

[22] Adapted from <u>Cogeneration of Steam and Electric Power: Pollution Prevention Opportunities and Options, Report 49-1</u>, Commonwealth of Virginia Department of Environmental Quality, Richmond, VA, September 1994, p. iv.

The U.S. economy has responded to the developing national energy and environmental policy in ways that have allowed for continued economic expansion. PURPA has spurred the development of independent power producers ("IPP"). For instance, in 1978 there were no IPPs other than self-generating industrial companies. By 1985, IPPs accounted for approximately 2 percent of all installed generating capacity. By 1996, this percentage had grown to 7.8 percent.[23] Equally significant is the fact that independent power's share of installed generating capacity added each year has grown steadily since 1988, peaking at 67 percent in 1994 and averaging about 50 percent throughout the 1990s.[24] The IPPs have used a wide variety of combustion technologies and fuels, including fluidized bed combustion (a clean coal technology). Fuels have included coal, waste coal from refuse piles at mine sites, petroleum coke, and many forms of biomass. Fluidized bed combustion use has grown from research sized facilities to being fully commercially viable with 84 plants representing approximately 4,551 MWe in operation in the U.S. in 1996. The use of cogeneration has increased the energy conversion efficiency of many electric power plants from around 35 percent to in excess of 50 percent. Moreover, the clean coal and conventional technologies that have been improved through the clean coal technology program are now being deployed in developing countries to improve the efficiency of combustion of coal and other fossil fuel derivatives (such as petroleum coke), while protecting the environment.

1.2 The Council of Industrial Boiler Owners and the CIBO Special Project

The Council of Industrial Boiler Owners ("CIBO") is a broad-based association of industrial boiler owners, architect-engineers, related equipment manufacturers, industrial byproduct managers, and university affiliates consisting of over 100 members representing 20 major industrial sectors. CIBO members have facilities located in every region and state of the country. The organization has a representative distribution of almost every type of boiler and fuel combination currently in operation. CIBO was formed in 1978 to promote the exchange of information within industry and between industry and government relating to energy and environmental equipment, technology, operations, policies, laws, and regulations affecting industrial boilers. Since its formation, CIBO has taken an active interest in the development of technically sound, reasonable, and cost-effective energy and environmental regulations for industrial boilers.

The CIBO Special Project was established to specifically address regulatory treatment of fluidized bed combustion byproducts under RCRA. The participants in this CIBO Special Project have a direct interest in the pending regulatory determination. The CIBO Special Project is operated autonomously from CIBO under its own bylaws. The purpose of the CIBO Special Project is "...to bring together CIBO member companies and other interested parties in a program to characterize and assess the impact of management of non-utility fossil fuel combustion byproducts. The Special Project will also evaluate the economic and environmental consequences of reclassifying combustion byproducts under the terms of a pending Bevill determination by the U.S. Environmental Protection Agency under the terms of the Resource Conservation and Recovery Act." The CIBO Special Project is an

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[23] Profile X -- Global Independent Power Market: 1996 Status and Trends, Hagler Bailly Consulting, Inc., Arlington, VA, April 1996, p. 3W3. 1995 Statistical Yearbook of the Electric Utility Industry, Edison Electric Institute; Washington, D.C.

[24] Profile X, Hagler Bailly Consulting, Inc., p. 3W4.

amalgamation of 38 FBC (fluidized bed combustion) and conventional technology plant owners, three (3) combustion byproduct management contractors, two (2) limestone suppliers, and one (1) boiler manufacturer who have voluntarily provided funding for this project. Exhibit 1-1 provides a listing of the financial sponsors of the CIBO Special Project.

In achieving its purpose, the CIBO Special Project has prepared this report to provide data and other information to the EPA to assist EPA in its fact-finding regarding the appropriate regulatory status of FBC byproducts under RCRA. In establishing a factual basis for decision making, the CIBO Special Project anticipates that EPA will prepare a Supplemental Report to Congress. Section 8002(n) of RCRA states "... the Administrator shall, as he deems appropriate, ...invite participation by other concerned parties, including industry... with a view towards avoiding duplication of

EXHIBIT 1-1
FINANCIAL PARTICIPANTS IN CIBO SPECIAL PROJECT

FBC and Conventional Technology Plant Owners:

- The Anthracite Region Independent Power Producers Association (ARIPPA) & its affiliated plants:
  - Archbald Power Company - Archbald, PA
  - Ebensburg Power Company - Ebensburg, PA
  - Foster Wheeler Mt. Carmel - Mt. Carmel, PA
  - Gilberton Power Company - Frackville, PA
  - Inter-Power/Ahlcon Partners - Colver, PA
  - Northeastern Power Company - McAdoo, PA
  - Northampton Generating Company, L.P. - Northampton, PA
  - Panther Creek Partners - Nesquehoning, PA
  - Schuylkill Energy Company - Frackville, PA
  - Scrubgrass Generating Company, L.P. - Kennerdell, PA
  - Westwood Energy Properties - Joliet, PA
  - Wheelabrator Frackville Energy Company - Frackville, PA
- AES Barbers Point, Inc. - Honolulu, HI
- AES Shady Point, Inc. - Porteau, OK
- AES Thames, Inc. - Uncasville, CT
- ACE Cogeneration Company - Trona, CA
- Air Products and Chemicals, Inc. - Ebensburg, PA
- Air Products and Chemicals, Inc. - Stockton, CA
- Archer Daniels Midland Company - Cedar Rapids, IA
- Archer Daniels Midland Company - Decatur, IL
- Archer Daniels Midland Company - Des Moines, IA
- Archer Daniels Midland Company - Lincoln, NE
- Archer Daniels Midland Company - Mankato, MN
- Black River Limited Partnership - Watertown, NY
- Cedar Bay Generating Company, L. P. - Jacksonville, FL
- Colmac Energy - Palo Alto, CA
- Fort Howard Corporation - Green Bay, WI
- Fort Howard Corporation - Rincon, GA
- GWF Power Systems - Walnut Creek, CA
- Michigan State University - East Lansing, MI
- Mt. Poso Cogeneration Company - Bakersfield, CA
- Piney Creek - Clarion, PA
- POSDEF Power Company, L.P. - Stockton, CA
- R. J. Reynolds Tobacco Company - Winston-Salem, NC
- Rio Bravo Poso - Bakersfield, CA
- Rio Bravo Jasmin - Bakersfield, CA
- Ross Products - Sturgis, MI

Combustion Byproduct Management Companies:

- ReUse Technologies, Inc. - Kennesaw, GA
- JTM Industries, Inc. - Kennesaw, GA
- Wallace Industries, Inc. - Ithaca, NY

Limestone Suppliers:

- Meckley's Limestone Products, Inc. - Herndon, PA
- Rohrer's Quarry, Inc. - Lititz, PA

Boiler Manufacturer:

- Foster Wheeler Energy Corporation - Clinton, NJ effort...."[25] Industry participation in the previous Bevill determinations has been universal and the CIBO Special Project is a continuation of this effort.

1.3 RCRA Regulatory Context

Fossil fuels are used by many sectors of the United States economy as a source of energy. Each type of fossil fuel, with the exception of gaseous fuels, has a unique solid combustion byproduct (waste) that may be subject to regulation under various state and federal laws or regulations. The Resource Conservation and Recovery Act specifically addresses combustion byproducts from fossil fuels. The legislative and procedural history of the application of RCRA regulation to fossil fuel combustion byproducts is described in 58 *Federal Register* 42466-42467, August 9, 1993 and will not be repeated in this report except as necessary to establish why this report has been prepared.

Section 3001(b)(3)(A)(i) of RCRA excludes "[f]ly ash waste, bottom ash waste, slag waste, and flue gas emission control waste generated primarily from the combustion of coal or other fossil fuels" from regulation under Subtitle C of RCRA pending completion of a Report to Congress required by Section 8002(n) of RCRA[26] and a determination by the Environmental Protection Agency Administrator to either promulgate regulations under Subtitle C or that such regulations are unwarranted.[27] In partial fulfillment of these requirements, the EPA in February 1988 issued a Report to Congress: Wastes from the Combustion of Coal by Electric Utility Power Plants (EPA/530-SW-88-002) ("Report to Congress") and in August 1993 issued a regulatory determination that "...regulation under Subtitle C of RCRA is inappropriate for the four waste streams that were studied [in the Report to Congress]..."[28] This regulatory determination was limited to "...coal-fired units at steam electric utility power plants in the United States, including independent power producers not engaged in any other industrial activity..."[29]

The 1993 regulatory determination was specific to the following coal combustion byproducts studied in the 1988 Report to Congress: fly ash, bottom ash, boiler slag, and flue gas scrubber waste. The determination did not address: i) utilities burning other fossil fuels or wastes from non-utility boilers burning any type of fossil fuel;[30] ii) fluidized bed combustion wastes;[31] and iii) co-management, co-

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[25] 42 U.S.C. §6982(n).

[26] 42 U.S.C. §6982(n). While these waste streams are exempt from RCRA Subtitle C regulation they remain subject to regulation under other applicable provisions of Federal or State law.

[27] RCRA Section 3001(b)(3)(C).

[28] 58 Federal Register 42466, August 9, 1993.

[29] *Ibid* at 42469.

[30] *Ibid* at 42467; Note that as cited in the previous paragraph, utility boilers were indicated to include independent power producers not engaged in any other industrial activities, so that the quote to which this footnote applied, when referring to "non-utility boilers" is actually referring to (continued...)

treatment, or co-disposal of the four high volume wastes studied in the Report to Congress with other wastes generated in conjunction with the combustion of coal or other fossil fuels.[32] These categories of waste are referred to by EPA as "remaining wastes" and are the subject of an ongoing study by EPA that will provide the factual basis for a regulatory determination, which is scheduled to be completed by April 1, 1998.[33]

Because the 1993 regulatory determination applies only to coal combustion byproducts and is of limited scope, many commercial, institutional and industrial facilities, utilities, and independent power producers have been left without certainty as to the long term regulatory status of their combustion byproducts under RCRA. To further complicate matters, the 1993 regulatory determination specifically identified a single combustion technology, fluidized bed combustion, for additional study. The 1993 regulatory determination postponed a final determination on FBC technology using the following rationale:

> ...FBC is a relatively new combustion technology that allows for the removal of sulfur without an end-of-pipe scrubber. The wastes generated by this technology were not studied in the RTC [Report to Congress] , and only limited information regarding their characteristics and management has been collected to date. The information that is available has not provided EPA with enough evidence to conclude that waste generated from FBC units is substantially similar to conventional boiler wastes...Because of the current lack of data, the potential of the co-firing of limestone to have a significant effect on the characteristics of the wastes produced and the potential for increased utilization of the technology, the Agency [EPA] has decided to defer a decision on these wastes until further information from the growing number of facilities can be examined....[34]

Since EPA commenced the study of fossil fuel combustion byproducts in about 1978, the number of FBC units using fossil fuels has increased from about 4 commercial and research plants with 4 boilers to 84 commercial plants representing 123 boilers as of December 1996. These FBC units are used in the combustion of a variety of fossil fuels and are used by utilities, independent power producers, and institutional and industrial facilities.

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[30](...continued)
non-electric generating boilers in the industrial, commercial, and institutional sectors.

[31] *Ibid* at 42469.

[32] *Ibid* at 42470.

[33] On October 30, 1997, the U.S. EPA, Edison Electric Institute, and the Bull Run Coalition jointly petitioned the U.S. District Court for a one year extension to complete this regulatory determination.

[34] *Ibid* at 42469.

The remaining wastes affect a large cross section of the United States economy and present many technically complex issues with a relatively short time for EPA to collect and analyze data and complete a regulatory determination. Accordingly, various organizations and other state and federal agencies are voluntarily cooperating with the EPA to provide data and information on the remaining wastes to assist EPA in developing a factual basis for a regulatory determination. For instance, the Utilities Solid Waste Activities Group ("USWAG") is sponsoring studies on co-management or co-disposal of high and low volume wastes, co-combustion of various fossil fuels and other opportunity fuels with coal, and characteristics and management of oil ash. The CIBO Special Project was initiated to focus on FBC byproducts because of the ownership of FBC boilers by its members. We also considered the conventional technologies (stoker and pulverized coal) used by the non-utility sector by making simple comparisons between FBC units and the conventional technologies that EPA had previously studied for the utilities. It is hoped that the EPA will find the information provided by USWAG and the CIBO Special Project helpful in augmenting its own studies, in developing a Supplemental Report to Congress as the factual basis for the pending regulatory determination.

1.4 General Methods and Information Sources

To prepare this report the CIBO Special Project has used several information sources to provide site specific and industry wide data. First, the CIBO Special Project developed a survey instrument (Appendix A) that was sent to every fossil fuel fired FBC plant (i.e., both utility and non-utility) in the United States for voluntary completion. The list of these plants was developed from boiler manufacturers reference lists, a CIBO 1990 publication, Worldwide List of Fluid Bed Boiler Installations, and several commercial data bases. The CIBO Special Project Survey was designed to collect information on all eight Bevill study factors. In developing this survey, the CIBO Special Project consulted with EPA to ensure that the information collected would be complete and useful to EPA.

Information gathered in the CIBO Special Project survey was entered into a data base using Access[35] computer software by ICF Kaiser Consulting Group, the CIBO Special Project's contractor. This data base was also made available to the EPA for its analysis and utilization. From this database, the information tables contained in this report were developed. Statistical analyses of the data from the survey were accomplished using SAS[36] computer software.

Information on state and federal regulatory programs was developed by review of published reports by trade associations, the EPA, and a CIBO Special Project survey of the states' solid waste disposal regulations. Interviews of personnel representing environmental regulatory agencies in selected states were conducted to provide additional in-depth information on the regulation of FBC byproducts. This survey information was also provided to the EPA.

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[35] A trademark of Microsoft Corporation.

[36] A trademark of The SAS Institute.

Where additional information was required a literature search was conducted. Documents reviewed included published technical papers from conferences, trade or professional journals, and reports from a variety of governmental agencies.

The CIBO Special Project Survey contained questions to solicit information on environmental damage cases. Additionally, the LEXIS[37] data base was searched to locate environmental damage cases associated with the disposal or use of FBC byproducts.

To evaluate the potential danger, if any, to human health or the environment posed by management of FBC byproducts ICF Kaiser Consulting Group conducted a detailed comparison of the physical and chemical characteristics of FBC by-products and analogous, high volume coal combustion wastes generated by electric utilities that had previously been studied in-depth by EPA. These studies included screening comparative analyses in support of state regulations. Due to the great similarities between these two categories of materials, the CIBO Special Project believes that the comparison provides meaningful and relevant results.

The CIBO Special Project facilitated a tour for EPA officials of four FBC combustion plants to familiarize the EPA with FBC technology. In connection with these familiarization tours, three projects in Pennsylvania were visited where FBC byproducts were being used in mine reclamation and in an FBC byproduct monofill. One project was visited in California where FBC byproducts were being used in agricultural applications (for lime value and as a construction material) and as an ingredient in an alternative daily cover in a commercial municipal solid waste landfill.

1.5 Contents and Organization of Report

This report provides information that will allow EPA to address in its Supplemental Report to Congress the eight study factors required by the Bevill Amendment relative to FBC byproducts. The eight study factors that the CIBO Special Project has gathered information on are:

(1) The source and volumes of such material generated per year;

(2) Present disposal and utilization practices;

(3) Potential danger, if any, to human health and the environment from the disposal and reuse of such materials;

(4) Documented cases in which danger to human health or the environment from surface runoff or leachate has been proved;

(5) Alternatives to current disposal methods;

(6) The cost of such alternatives;

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[37] A trademark of Reed Elsevier Properties Inc.

(7) The impact of those alternatives on the use of coal and other natural resources; and

(8) The current and potential utilization of such materials.

This report also contains an update of applicable state and federal regulations to identify any duplication of existing regulations in any regulatory decision. A comprehensive glossary of terms used throughout this report is included.

This report consists of two volumes, as follows:

<u>Report to the U.S. Environmental Protection Agency on Fossil Fuel Combustion Byproducts from Fluidized Bed Boilers</u>

- <u>Chapter 1</u>, **Introduction**, summarizes the purpose and scope of the report, summarizes the emergence of the independent power industry and the history of environmental regulation, and describes the general methods and information sources used by the CIBO Special Project in preparing this report.

- <u>Chapter 2</u>, **The United States Economy's Use of Fossil Fuels, Economic Differences Between Various Economic Sectors and Description of the Study Population**, provides information on the widespread use of fossil fuels by the United States economy and its various economic sectors (i.e., utilities, independent power producers, and commercial, institutional, and industrial steam and/or power generators). A description of the significant economic differences between the various economic sectors is provided as well as information on the study population.

- <u>Chapter 3</u>, **Fossil Fuel Combustion Technologies and Air Pollution Control Technologies** provides a review of conventional and fluidized bed combustion technology. A review of various air pollution control technologies that affect fossil fuel combustion byproducts also is included.

- <u>Chapter 4</u>, **Fossil Fuel Combustion Byproduct Generation and Characteristics**, provides a description of significant process inputs (fuel and limestone) used in FBC systems, as well as a physical and chemical description of the combustion byproducts, and the volumes of materials generated. A discussion of low volume (associated wastes) generated during fossil fuel combustion and co-managed with the primary byproduct(s) also is included.

- <u>Chapter 5</u>, **Current Management Practices for Fossil Fuel Combustion Byproducts**, describes the current disposal and beneficial use of the FBC byproducts, including quantities reporting to each management method, and environmental protection measures employed by management unit operators.

- <u>Chapter 6</u>, **Environmental Damages from Management of Fossil Fuel Combustion Byproducts** provides a discussion of the results of an effort to identify any documented damages caused by FBC byproduct management practices.

- Chapter 7, **Potential Danger to Human Health and the Environment**, addresses the potential for future environmental or human health impacts resulting from current disposal and utilization practices.

- Chapter 8, **Existing Regulatory Controls on Fossil Fuel Combustion Byproducts**, provides a synopsis of existing applicable federal and state regulatory programs.

- Chapter 9, **Alternative Fossil Fuel Combustion Byproduct Management Practices and Potential Utilization and Cost Impacts of Alternatives**, provides a discussion of alternative disposal methods. The potential costs and economic impacts imposed by alternative disposal practices under several regulatory scenarios also are addressed.

- Chapter 10, **Study Findings and Regulatory Implications**, provides a summary of this study's findings for each of the eight Bevill study factors and provides the industry's view of how these findings should affect the regulation of FBC combustion byproducts.

Report to the U.S. Environmental Protection Agency on Fossil Fuel Combustion Byproducts from Fluidized Bed Boilers: Appendices

- **Appendix A**: 1996 Survey of Fossil Fuel Fluidized Bed Combustion Byproducts

- **Appendix B**: Non-utility Electric Power Generation

- **Appendix C**: Comparison of Utility and Non-utility Fossil Fuel Uses, Technology, and Combustion Byproduct Management Practices

- **Appendix D**: Boiler Input Formation and Processing

- **Appendix E**: Estimate of Industry-wide FBCB Generation Rates

- **Appendix F**: USDA Manual for Applying Fluidized Bed Combustion Residue to Agricultural Lands

- **Appendix G**: FBCB Risk Screening Criteria and Results

- **Appendix H**: CIBO Special Project Survey of State Waste Management Controls

- **Appendix I**: Tabulated Results of CIBO Special Project Survey of State Waste Management Controls
- **Appendix J**: ACAA Report on CCB Use Regulations
- **Appendix K**: New York State Beneficial Use Determination
- **Appendix L**: 1/25/97 Pennsylvania Bulletin
- **Appendix M**: Draft Pennsylvania Certification Guidelines for Beneficial Uses of Coal Ash
- **Appendix N**: Draft Pennsylvania Guidance for Beneficial Uses of Coal Ash
- **Appendix O**: Draft Pennsylvania Report on Beneficial Use of Coal Ash at Coal Mine Sites
- **Appendix P**: CIWMB Meeting Minutes
- **Appendix Q**: Tabulated Cost Analysis Results

CHAPTER TWO

THE UNITED STATES ECONOMY'S USE OF FOSSIL FUELS, ECONOMIC DIFFERENCES BETWEEN VARIOUS ECONOMIC SECTORS, AND DESCRIPTION OF THE STUDY POPULATION COVERED IN THIS REPORT

2.0 Introduction

This chapter will provide an overview of the use of energy by the United States, with a focus on fossil fuels use. Historical and forecasted energy use patterns will be described which affect the volume of fossil fuel combustion byproducts generated and managed within the United States economy. Traditionally, there have been significant economic differences between the utility industry and non-utility sectors of the economy. This chapter will provide a synopsis of the economic difference between the electric utility sector previously studied by the EPA and the non-utility sector, along with emerging trends that are affecting both sectors. Lastly, this chapter will describe the study population that is the subject of this report.

2.1 United States Energy Use

Section 1.1 of this report described the significant impact that energy has historically had in the United States economy. This section will review the historical use of energy and projections for energy consumption to assess the future generation of fossil fuel combustion byproducts. The projections for energy use are based on the United States Department of Energy's Energy Information Administration ("EIA") report *Annual Energy Outlook 1997 with Projections to 2015*, reference case. The forecast report is based on EIA's "...National Energy Modeling System which examines the total energy system, including all energy-producing and consuming sectors and the most significant macroeconomic indicators that affect or are affected by the energy system." The EIA has chosen a 20-year period for a forecast because "... EIA believes that the most important characteristics of energy consumption and production are sufficiently well understood for credible projections to be developed in considerable detail." This time period provides sufficient time for impacts that changes in energy policy or technology would cause to be fully developed, allows short-term phenomena (which generally do not affect longer term trends) to be put into perspective when compared with long-term historical trends, and can alert the public to future issues that will need to be addressed. An example of a future issue that will affect energy decisions is the likely retirement of a number of nuclear generating plants and the need to replace these plants with new plants using natural gas, coal, or renewable fuels.[38]

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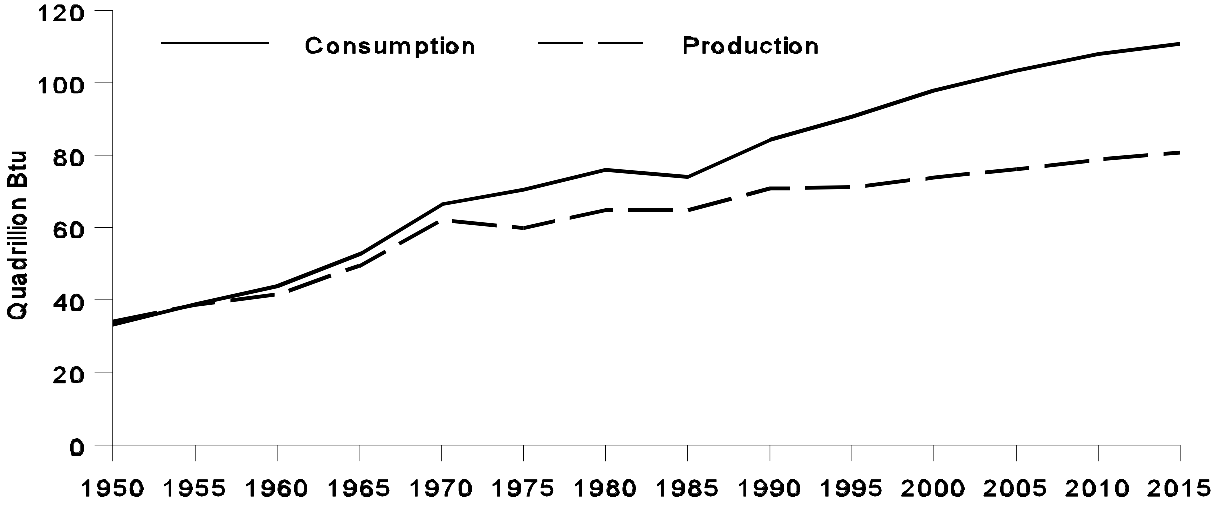
[38] The foregoing was adapted from Energy Information Administration, *Annual Energy Outlook 1997 with Projections to 2015*, DOE/EIA-0383(97), Washington, D.C., December 1996, p. ix.

EXHIBIT 2-1

Energy Consumption and Production

1950 - 2015



The EIA forecasts that total energy consumption and production will continue to grow through the period 1995-2015. Exhibit 2-1 shows the historical and projected total energy consumption and production for the period 1950 through 2015. During this 65 year period total energy consumption will more than triple, from 33.076 Quadrillion Btu[39] to a forecasted 110.87 Quadrillion Btu.[40] For the 20 year energy forecast, the growth in energy consumption is 21.9 percent, or an annual growth rate of about 1 percent.[41] The domestic production of energy during the 65 year period will more than double from 33.983 Quadrillion Btu[42] to a forecasted 80.75 Quadrillion Btu.[43] For the 20 year energy forecast, the growth in domestic energy production is about 12.8 percent, or an annual growth rate of about 0.6 percent. As has been the historical case, the shortfall in domestic energy production and consumption will be filled by imports of energy, principally crude oil, petroleum products, and natural gas.

The consumption of energy in its various forms has undergone significant changes and will continue to change through the 20 year energy forecast period (1995 - 2015). Exhibit 2-2 illustrates the historical and forecast consumption of energy from the various sources of energy.

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[39] Energy Information Administration, *Annual Energy Review 1995*, DOE/EIA-0384(95), Washington, D.C., July 1996, Table 1-3, p. 9.

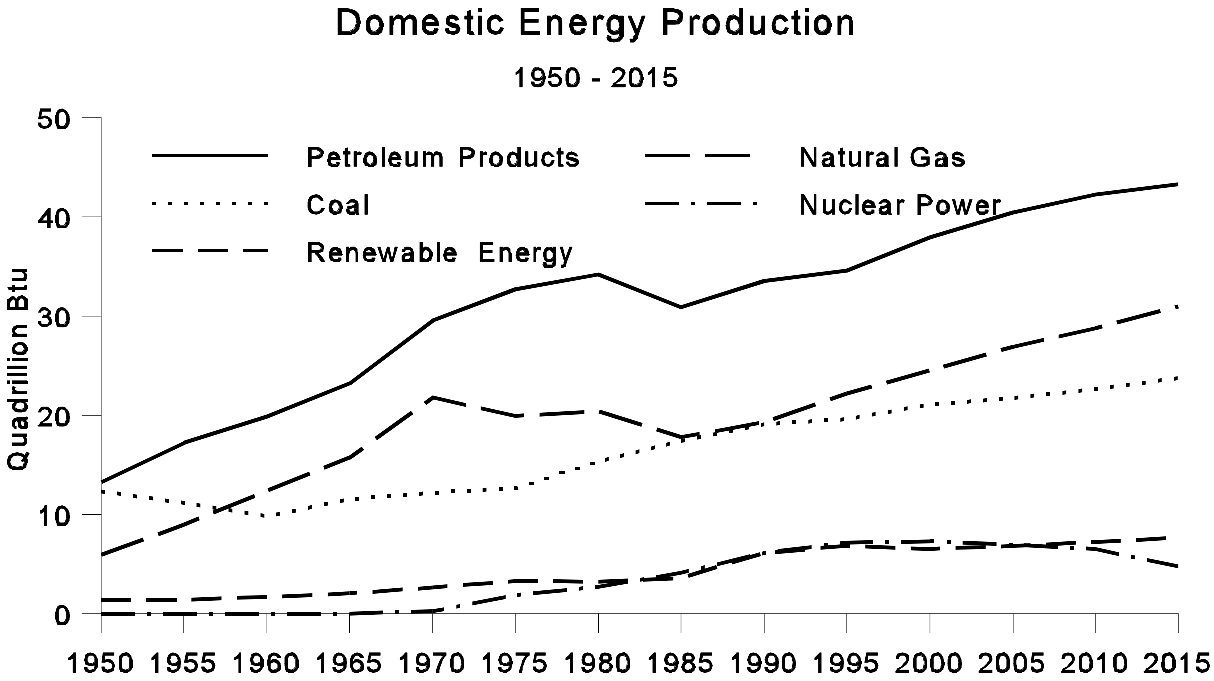
[40] *Annual Energy Outlook*, Table 1, p. 6.

[41] *Ibid.*, Table A1, p. 96.

[42] *Annual Energy Review*, Table 1-2, p. 7.

[43] *Annual Energy Outlook*, Table A1, p. 96.

EXHIBIT 2-2



Examination of this figure shows that those derived from fossil fuels (petroleum, natural gas, and coal) will continue to increase but at different annualized rates (1.1 percent, 1.7 percent, and 0.9 percent, respectively).[44] Nuclear power will decrease by an annualized rate of 2.0 percent while renewable energy will grow at an annualized rate of 1.0 percent.[45] The reasons for these varying growth rates are summarized below:

- The forecasted increase in natural gas consumption is mainly because of growth in gas-fired electricity generation. Gas consumption by electric generators, excluding cogenerators, is forecast to more than double (3.5 trillion cubic feet in 1995 to 7.5 trillion cubic feet in 2015).

- Coal is forecast to remain the primary fuel for electricity generation. The share of coal-fired generation (excluding cogenerators), however, will decline to about 50 percent in 2015 principally due to the increased use of natural gas. Total coal consumption is forecast to grow by 0.9 percent per annum with 90 percent of the coal consumption being for electricity generation in 2015.[46]

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[44] *Ibid.*

[45] *Ibid.*

[46] *Ibid.*, p. 4.

- Petroleum consumption is projected to grow at an annual rate of 1.1 percent per year. More than two-thirds of the petroleum products are used in transportation. Increases in miles traveled by light-duty vehicles will more than offset the increases in vehicle efficiency during the forecast period. Sustained economic growth also will lead to continued increases in the use of petroleum for freight, travel, and shipping.[47]

- Renewable fuel use, including hydropower, is projected to increase at an average annual rate of 1.0 percent. About 60 percent of the renewable fuels are used for electricity generation and the remainder for dispersed heating and cooling, industrial use, and blending into vehicle fuels. Hydropower generation, the major source of renewable energy, will decline during the forecast period due to regulatory actions limiting capacity at existing sites and the fact that no large new sites are available for development.[48]

- Nuclear power generation is forecast to decrease because many nuclear plants will be near the end of their forty-year operating licenses by the end of the forecast period. Of the approximately 100 gigawatts of nuclear capacity available in 1996, 38 gigawatts are assumed to be retired by 2015 -- primarily during the last 10 years of the forecast.[49]

The mix of energy sources and users of these energy sources will undergo significant changes. Exhibit 2-3 illustrates energy consumption by the various sectors of the United States economy. In this graph, the "Utility" sector has been charged with all energy consumption associated with the production of electricity (i.e., the electricity consumption, transmission, and other losses that are allocated to other economic sectors by the Department of Energy's Energy Information Administration). By presenting economic sector energy consumption data in this manner, it is easier to discern the relationship between the use of fossil fuels and the volumes of combustion byproducts generated by the various sectors.

Within sectors of the economy, the fuels of choice also have been changing, and will continue to do so. For example, in 1950 the transportation sector of the economy consumed 70.2 million tons of coal, about 14.5 percent of total coal consumption.[50] By 1975 the transportation sector was using less than 0.05 million tons,[51] effectively zero percent of total coal consumption. In contrast to the transportation sector, the utility sector in 1950 consumed 91.9 million tons of coal or about 18.6 percent of total coal consumption. By 1995 the utility sector was consuming 829.2 million tons[52]

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[47] *Ibid.*

[48] *Ibid.*

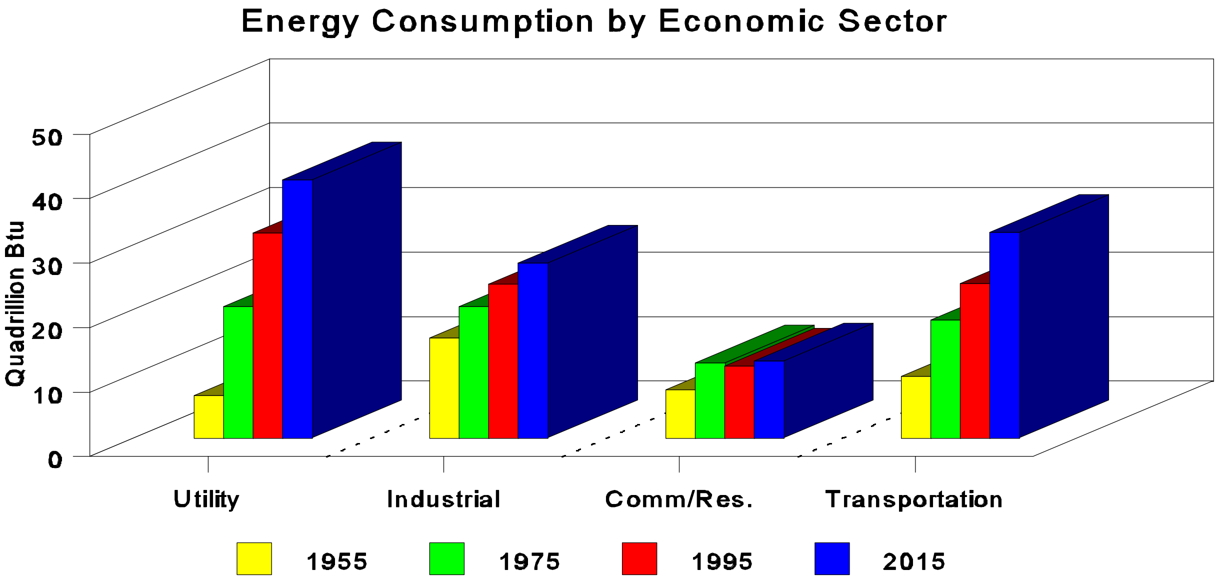
[49] *Ibid.*

[50] *Annual Energy Review*, Table 7-3, p. 215.

[51] *Ibid.*

[52] *Ibid.*

EXHIBIT 2-3



of coal or about 88.1 percent of total coal consumption with this percentage expected to increase to about 90 percent[53] in the year 2015.

It should be noted that not all consumption of ash-containing fuels (energy) will produce a combustion byproduct. For instance, coal may be used to produce heat and to generate electricity. In these uses, the coal that contains ash produces a solid waste combustion byproduct. An ash-containing fuel also may be used as a raw material input to the manufacturing process, for instance fuel for a cement kiln. In this case, the fuel ash becomes a part of the manufactured product, Portland cement, and no solid waste or combustion byproduct is generated.

Market Trends

Electricity Generation

Electricity generation by utilities and cogenerators is the major consumer of coal, the fossil fuel that generates the majority of combustion byproducts. These uses will continue to be the major generators of fossil fuel combustion byproducts through 2015. The increase in the consumption of electricity has undergone considerable change; in "... the 1960s, electricity demand grew by more than 7 percent a year, nearly twice the rate of economic growth.... In the 1970s and 1980s, however, the ratio of electricity demand growth to economic growth decline to 1.5 and 1.0 respectively. A continued decline is expected through the forecast [i.e., 2015]."[54] "Cogenerators in 1995 produced 132 billion kilowatt-hours for their own use in industrial and commercial processes, such as petroleum

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[53] *Annual Energy Outlook*, p. 4.

[54] *Ibid.*, p. 48.

refining and paper manufacturing.... By 2015, these producers are expected to maintain about the same share of total generation, increasing their own use-generation to 181 billion kilowatt-hours...."[55]

Other factors in this market area that will affect the production of fossil fuel combustion byproducts and when they will be generated include the following:

- The forecasted reduction in baseload nuclear capacity after 2010 and the attendant need for new capacity.
- New plant installation. The last five years of the forecast (2011 - 2015) represent only 25 percent of the forecast period, however, during this period 32 percent of the forecasted new combined-cycle and 42 percent of the new coal capacity for the entire 20 year forecast are expected to be brought into service.[56]
- Before building new capacity, utilities are expected to use other options to meet demand growth -- life extension and repowering of existing plants, power imports, demand-side management, and purchase from cogenerators. Even so, assuming an average plant capacity of 300 megawatts, a projected 1,063 new plants with a total of 319 gigawatts of capacity will be needed by 2015 to meet growth in demand and to offset retirements. Of the new capacity, 81 percent is projected to be combined-cycle or combustion turbine technology fueled by natural gas or both oil and natural gas.[57]
- Utility generators continue to dominate capacity ownership, increasing from 703.7 gigawatts in 1995 to 724.7 gigawatts (7.47 percent of the total) in 2015. However, cogenerators and other non-utilities significantly increase their share of the market, accounting for 57.6 percent of total capacity by 2015.[58]
- Oil prices to utilities are expected to increase by 27 percent during the forecast period. Even so, greater utilization of plants for which oil is the primary fuel is expected to lead to a 1.4 percent increase in oil-fired generation by 2015. However, oil currently accounts for only 2.1 percent of total generating, and that share is expected to decline to 1.6 percent by 2015 as oil-fired steam generators are replaced by gas turbine-based technologies.[59]
- Concerns about the environmental impacts of coal plants, combined with their relatively long construction lead times and the availability of economical natural gas, make it unlikely that

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[55] *Ibid.*

[56] *Ibid.*, p. 49.

[57] *Ibid.*

[58] *Ibid.*

[59] *Ibid.*, p. 50.

many new coal plants will be built before 2000. Nevertheless, slow demand growth and huge investment in existing plants will keep coal in its dominant position.[60]

- Current construction costs for a typical 300-megawatt plant range from $400 per kilowatt for combined-cycle technologies to $1,465 per kilowatt for coal-steam technologies. These costs, combined with the difficulty of obtaining permits and developing new generating sites, make refurbishment of existing power plants (at $260 per kilowatt) a profitable option for utility resource planners. Between 1995 and 2015, utilities are expected to refurbish 770 coal-, 172 gas-, and 74 oil-fired generating units.[61]

Coal Consumption

Several changes are occurring in coal production and consumption that will affect the quantity of coal combustion byproducts generated. The most significant change that is occurring is a shifting of coal production from eastern mines to western mines Western mines have the advantage of lower production costs and lower sulfur content. The eastern share of national production, which fell from 93 percent in 1970 to 53 percent in 1995, is projected to be 46 percent in 2015.[62] "The shift from eastern to western coals has been led by midwestern and southeastern utilities, which have reduced fuel costs while switching from high-sulfur eastern sources to coal from Wyoming, Colorado, and Utah. Low-sulfur, low-cost subbituminous coal from Wyoming can displace eastern bituminous coal in many larger, newer boilers. Consumers with smaller, older boilers often purchase suitable low-cost, low-sulfur bituminous coal from Colorado or Utah."[63]

Several other factors will affect coal consumption during the forecast period:

- Domestic coal demand rises by 197 million tons in the forecast, from 959 million tons in 1995 to 1,156 million tons in 2015 principally because of the increased use for electricity generation. Coal demand in other domestic end-use sectors increases by 5 million tons, as reduced coking coal consumption is offset by coal demand for industrial cogeneration.[64]

- Coal consumption for electricity generation (excluding industrial cogeneration but including independent power producers) rises from 847 million tons in 1995 to 1,039 million tons in 2015, due to increased utilization of existing generation capacity and in later years, additions of new capacity. The average utilization rate for coal-fired power plants increases from 63 to 74 percent between 1995 and 2015. Coal consumption (in tons) per kilowatt-hour of generation is higher for subbituminous and lignite coals than for bituminous coal. Thus, the

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[60] *Ibid.*, p. 51.

[61] *Ibid.*, p. 53.

[62] *Ibid.*, p. 67.

[63] *Ibid.*

[64] *Ibid.*, p. 70.

shift to western coal increases the tonnage per kilowatt-hour of generation in midwestern and southeastern regions In the east, generators shift from higher to lower sulfur Appalachian bituminous coals that contain more energy (Btu) per short ton.[65]

- In the non-electricity sectors, an increase of 18 million tons in industrial steam coal consumption between 1995 and 2015 (1.1 percent annual growth) is offset by a decrease of 13 million tons in coking coal consumption. Increasing consumption of industrial steam coal results primarily from increased use of coal in the chemical and food processing industries and from increased use of coal for cogeneration.[66]

- While delivered energy consumption in the residential and commercial sectors grows by 0.8 percent and 0.9 percent a year, respectively, most of the growth is captured by electricity and natural gas. Coal consumption in these sectors remains constant, accounting for less than 1 percent of total U.S. coal demand.[67]

Summary of market trends

The above discussion of energy projections was based on the Department of Energy's, Energy Information Administration report *Annual Energy Outlook 1997* ("AEO97"). In the AEO97 a comparison was made between the AEO97 forecasts and those made by other organizations that produce comprehensive energy projections with a similar time horizon. The AEO97 compared its projections to those of Data Resources, Inc. ("DRI"), the WEFA Group (WEFA), and the Gas Research Institute ("GRI"). Comparison of all these forecasts for total energy consumption showed remarkable similarity.[68] For coal, the GRI, DRI, and WEFA forecasts production in 2010 at levels more comparable with that in the AEO97 high growth case than that in the reference case, primarily due to higher forecast of electricity sector coal consumption after 2000. Exhibit 2-4 shows the comparison on forecasted coal consumption in year 2015.

Through 2015, coal will continue its dominance in the generation of electricity with about 19 percent of the forecasted new capacity additions being coal-fired The forecast increased use of coal is by utilities and other economic sectors. Several factors will affect the total volume of additional coal combustion byproducts produced, among them is a shift towards more western coals that require more tons per kilowatt-hour of electricity generation, and the increased use of coal by cogeneration facilities while non-combustion byproduct uses (e.g., coking) are forecast to decrease. Coal consumption by the commercial and residential sectors is forecast to remain constant and will account for less than 1 percent of the total United States coal demand.

EXHIBIT 2-4

Comparison of Coal Production, Consumption, and Exports in 2015

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[65] *Ibid.*

[66] *Ibid.*

[67] *Ibid.*

[68] *Ibid.*, p. 76.

(millions of short tons)

	AEO97			Other Forecasts		
Projection	Reference	Low Economic Growth	High Economic Growth	WEFA	GRI	DRI
Production	1,268	1,197	1,399	1,484	1,415	1,412
Consumption by Sector:						
Electricity generation	1,039	987	1,155	1,289	1,218	1,177
Coking plants	20	20	20	32	29	24
Industrial/other	97	84	112	84	97	114
Total	1,560	1,091	1,288	1,405	1,354	1,315
Net coal exports	112	112	112	88	62	95

Source: Annual Energy Outlook 1997, Table 22.

While the principal fossil fuel being used in electricity generation that produces a solid waste (ash or FGD material) is coal, other fossil fuels also are used. Petroleum coke is currently an "opportunity fuel," i.e., an alternative fuel that has a lower cost, that is being used or considered for use by both the utility and non-utility sectors. Many trade publications are reporting the substitution of up to 20 to 30 percent petroleum coke for coal in utility units that have FGD systems. The primary reason for this substitution is a lower total fuel cost for the electricity generator. In the non-utility sector, the Special Project has identified ten power plants using FBC technology that are using only petroleum coke as a fuel source and several other FBC plants that are burning blends of petroleum coke and coal. In addition to the opportunity fossil fuels, other opportunity fuels, such as tire chips and wood also are being used by both the utility and non-utility sectors. As more experience is gained with opportunity fuels and with continued pressure to control fuel costs, it is expected that the use of opportunity fuels will increase in the future.

2.2 Important Economic Characteristics of the Utility and Non-utility Sectors

Since the early 1900s there has been a significant difference in economic regulation of the utility and non-utility sectors. The electric utility industry is dominated by investor-owned utilities that have traditionally been regulated by both federal and state entities in such areas as rates that could be charged and the return that investors could earn on their investment. In contrast, the non-utility sector of the economy is made up of enterprises that are largely non-regulated in the economic sense. In the non-utility sector there are typically no federal or state entities that dictate such areas as rates charged for products or the rate of return on investments. This significant economic difference needs to be fully understood as part of this Bevill determination of the "remaining wastes."

Utilities

Traditionally, utilities have operated as regulated monopolies with exclusive service territories and captive customers and, in return, an obligation to serve. Under this traditional model the utilities have evolved into a vertically integrated service of generation, transmission, and distribution of electricity. The regulators (either state or federal) typically allow the utilities to recover, through rates charged to customers, the expenses they incur to provide electric service. As part of the rates charged to customers, the utilities have the opportunity to earn a predetermined rate of return on capital investments made. The expenses that a utility can recover through rates must be prudently incurred. Likewise, capital assets included in the calculation of rate of return must be found to be necessary for the public convenience or necessity. Under this traditional model, new costs due to, for instance, pollution abatement, could be fully recovered through the rates charged.

Today, the utility industry is undergoing sweeping changes, i.e., "restructuring" and is entering a competitive era. How the restructured industry will look in the future is still uncertain. Some of the costs that are incurred will still be recovered through regulated rates with some costs at least partially recovered by competitive sales. Appendix B contains a more complete discussion of the forthcoming utility restructuring and the non-utility electricity generation industry.

Non-utilities

Due to the diversity and the limited economic regulation of this sector only a synopsis of significant differences from the traditional regulated utility will be made. The independent power production (IPP) business provides one example of a significant difference that may be examined. Further discussion of electric power generation by non-utility entities is provided in Appendix B.

The IPP business initially emerged in the late 1970's as the product of the Public Utilities Regulatory Policy Act of 1978. PURPA was formulated to promote renewable sources of power and sequential uses of energy in response to the oil shortage of the 1970's. The types of powerplants contemplated under PURPA (called qualifying facilities or "QF's") included those powered by wind, solar, geothermal, biomass, and waste coal as well as cogeneration facilities. PURPA was formulated to promote the sale of electricity at wholesale to utilities that would displace existing utility sources of non-renewable, less environmentally friendly generation. Many of the CFB boilers now in use were developed as waste fuel and cogeneration applications promoted by PURPA. Almost all of the IPP projects developed between the late 1970's until the last several years[69] depended upon long-term fixed price power sale contracts as the sole or major source of revenue for the project.

The QF had basically two choices for pricing from the utility. It could receive a fixed price over the term of its contract with the utility based on prices estimated at the inception of the contract or it could receive a variable price which was dependent upon and varied with the cost the utility actually saved in not having to generate its own electricity. In either instance, there is no provision for increasing the price paid for the electricity to pay for such unanticipated events such as the cost associated with new regulations. The QF plants have often been heavily financed with non-recourse debt secured solely by the particular plant. The margin of profit after paying debt service and operating expenses is often quite limited. These circumstances can be contrasted to a utility, where debt is raised on a company-wide basis and rates on the sale of electricity to its customers are set at a level to pay debt, expenses, and profit to the stockholders (investors). In such a framework, the

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[69] The Energy Policy Act of 1992, whose regulations were not implemented until 1993, is an alternative to PURPA for developing IPP facilities.

cost of regulatory change is accommodated through a requested rate increase to the ratepayers (customers).

Other segments of the non-utility sector may be in a similar circumstance as an IPP project when incurring additional regulatory costs for competitive reasons. For instance, if two companies both manufacture the same product and one company incurs an additional regulatory cost while the other one does not, the company incurring the added cost can either increase the product price, at the expense of losing part of its customer base, or absorb the added expense, thus reducing its profit margin.

2.3 Description of the Study Population Addressed in this Report

The non-utility sector of the United States economy is very diverse in that it covers all aspects of economic (commercial and industrial) activity except for the electric utilities. This sector has a large range of sizes, from a one-person enterprise working out of a small office to major manufacturing enterprises (e.g., General Motors) with thousands of employees located at scores of locations. This huge range in sizes of the business enterprise means that energy needs are equally diverse. These energy needs may be met by simply having a utility provide electric service to the business unit to meet all of its energy needs. On the other hand, a large manufacturing facility may purchase none or only a portion of its energy needs in the form of electricity from a utility, generate all or the balance of its electricity needs, and/or produce internally energy to meet its thermal needs. The manufacturing facility may use only one fossil fuel, e.g., natural gas, or may use multiple fossil fuels (coal, petroleum coke, natural gas, petroleum products) in multiple energy conversion units.

The U.S. EPA is currently conducting an "industrial combustion coordinated rulemaking" ("ICCR"). As part of this work, the ICCR work group has identified 50,487 water-tube boilers by capacity and fuel type. The size range of these 50,487 water-tube boilers is from 400,000 Btu/hr to 1,500,000,000 Btu/hr heat input. Out of the total population of water-tube boilers 37,696 boilers were identified as being "industrial boilers." Exhibit 2-5 summarizes the number of water-tube boilers by type of fossil fuel used. The ICCR also is developing updated information addressing non-utility boilers. As of this writing (November 1977), however, this information had not been finalized.

A review of Exhibit 2-5 shows that about 58 percent (heat input basis) of the industrial boilers have the potential to emit solid combustion byproducts (i.e., fly ash, bottom ash, and FGD material). Because very few of the industrial oil-fired boilers have particulate control systems, and the volume of ash that would be generated would be low (due to a low ash content, typically less than 0.1 percent) this report is focused on solid fossil fuels (coal and petroleum coke).

EXHIBIT 2-5

Population of Industrial Water-Tube Boilers In the United States, 1979

Fuel	Number of Boilers	Percent of Total	Heat Input (MMBtu/hr)	Percent of Total
Coal	5,876	15.6	551,700	25.3

Residual Oil	11,872	31.5	601,160	27.6
Distillate Oil	4,609	12.2	87,360	4.0
Natural Gas	15,339	40.7	939,320	43.1
Total	37,996	100.0	2,179,540	100.0

Adapted from: Pedco, Inc. 1979, Table 2-9. Population Characteristics of Industrial/ Commercial Boilers.

The EPA Office of Solid Waste ("OSW"), as part of its efforts in this Bevill determination, has attempted to characterize the universe of non-utility fossil fuel use. In developing its study population the OSW used the EPA-prepared 1990 National Interim Emission Inventory ("US90") data base to gather characteristic information. This data base was based on the 1985 National Acid Precipitation Assessment Program inventory data base that includes information on all major stationary sources of criteria pollutant emissions permitted under the Clean Air Act. The US90 data base is the only comprehensive National Emission Inventory that includes criteria pollutants for all 50 States and reflects the estimated 1990 emissions. The US90 data base does not include information on small boilers and furnaces, however, other EPA studies reportedly have indicated that the vast majority of the non-utility fossil fuel combustion universe that is excluded from the major source category represents a small percentage of the total capacity of the entire non-utility universe. These same studies have shown that these small boilers are less likely to generate significant quantities of solid wastes because the small boilers are disproportionately populated by natural gas- and oil-fired units. Additionally, these small boilers are less likely to be fitted with air pollution control devices which further decreases their generation of solid waste combustion byproducts.[70]

From the US90 data base the OSW determined general population statistics for the non-utility (industrial, commercial, and institutional) fossil fuel users. Exhibit 2-6 provides a summary of the findings.

Comparison of Exhibits 2-5 and 2-6 shows a good correlation between the industrial boilers (Exhibit 2-5) and the entire non-utility population developed by the OSW.

EXHIBIT 2-6

Distribution of Non-Utility Boilers by Fuel Type

Fuel Type	Total Number of Boilers	Percent of Boilers	Total Capacity (MMBtu/hr)	Percent of Capacity
Coal	2,262	14.5	325,043	21.6
Oil	5,245	33.6	556,489	37.0

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[70] Science Applications International Corporation, Non-Utility Fossil Fuel Combustion: Sources and Volumes. Submitted to U.S. EPA, Office of Solid Waste, McLean, VA, December 1996.

Natural Gas	6,907	44.3	477,662	31.8
Other	1,178	7.6	144,336	9.6
Total	15,592	100.0	1,503,530	100.0

Adapted from: Pedco, Inc. 1979, Table 2-9. Population Characteristics of Industrial/Commercial Boilers.

In addition to the general statistics shown in Exhibit 2-6 above, the OSW has determined the distribution of boilers by boiler type and fuel type. Exhibit 2-7 shows the distributions that the OSW has found.

EXHIBIT 2-7

Distribution of Non-utility Boilers by Type and Fuel

Fuel/Technology	Number of Boilers	Number of Facilities	Total Capacity (MMBtu/hr)	Percent of Non-utility Capacity
Coal				
Pulverized	512	255	149,915	9.97
Stoker	1,683	741	158,522	10.54
Cyclone	22	15	8,892	0.59
Fluidized Bed	7	7	1,273	0.08
Other	38	19	6,441	0.43
Total Coal	26,262	1,037	325,043	21.62
Oil-fired	5,245	2,179	556,489	37.01
Natural Gas-fired	6,907	3,345	477,662	31.77
Coke*	26	15	8,482	0.56
Other**	1,152	366	135,854	9.04
Total	15,592	6,942	1,503,530	100.00

* Coke derived from coal

** Other fuels consist of process gas, liquid petroleum gas, and liquid waste oil.

Adapted from: Pedco, Inc. 1979, Table 2-9. Population Characteristics of Industrial/Commercial Boilers.

Of the conventional fossil fuels (petroleum, natural gas, and coal), only natural gas produces a negligible volume of solid combustion byproducts. Petroleum products, while inherently low in non-combustible materials (the ash content typically being less than 0.1 percent), produce some combustion byproducts that represent a small percentage of the total combustion byproducts generated annually in the United States. For instance, the Utilities Solid Waste Activities Group estimates that the electric utility industry generated 23,000 tons of oil ash in 1995. To put this in perspective, the American Coal Ash Association reported that for the same year 92,172,424 tons[71] of coal combustion byproducts were generated by the electric utility industry, hence oil ash was only about 0.04 percent of the total utility combustion byproduct generation. Due to the nearly negligible contribution of oil ash to the total fossil fuel combustion byproducts, and the study work being conducted by the USWAG on oil ash, the Special Project has focused on the solid fossil fuels used by the non-utility sector.

As explained in Chapter 1, the Special Project is focusing on fluidized bed combustion primarily due to the lack of information that has been available to the EPA. Exhibit 2-7 illustrates the problem that the EPA has faced in gathering information on FBC combustion when compared to the information that the Special Project has developed. The US90 data base is an estimate of 1990 emissions based on the 1985 National Acid Precipitation Assessment Program. Since 1985 a number of new large stationary source FBC units have been placed in service. As part of its work, the CIBO special project has determined that as of December 1996 there were 84 facilities (plants) with 123 fossil fuel-based FBC boilers. The population of FBC units represents approximately 4,551 megawatts of equivalent, electrical generation capacity. Exhibit 2-8 provides a listing of the FBC units operating in December 1996.

From the FBC universe of 84 facilities and 123 boilers we have collected detailed information from 39 facilities and limited information from 6 facilities. The available information provides a study population that represents 52.4 percent of the number of facilities with a study population of 72 boilers (59.0 percent). This study population is geographically representative of the entire population as shown in Exhibit 2-9. Likewise, the study population is representative of the size of units in service, Exhibit 2-10. The study population covers five (5) primary Standard Industrial Classification (SIC) codes shown in Exhibit 2-11.

The fuels used by the study population cover the full range of recognized fossil fuels. Exhibit 2-12 summarizes the solid fossil fuels and opportunity fuels used by the study population. Natural gas, propane, and distillate fuel oil also are used by FBC unit operators for start-up purposes.

The 11,843,682 tons of coal (anthracite, bituminous, subbituminous, and lignite) consumed by the FBC study population represents about 1.3 percent of the total U.S. coal consumption in 1995. In comparison, the utility sector consumed about 91.4 percent of the total U.S. coal consumption in 1995, while the total non-utility sector consumed about 8.6 percent. The FBC study population represents about 15.1 percent of the non-utility 1995 coal consumption.

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[71] American Coal Ash Association, *1995 Coal Combustion Byproduct (CCB) - Production and Use (Short Tons)*, Alexandria, VA, 1996.

EXHIBIT 2-8

Active Fluidized Bed Combustion Facilities Burning Fossil Fuels - Sorted by Capacity (MWe)

Capacity Rank	Owner/Operator	Plant Name	City	State	No. Boilers	Capacity (MWe)	Survey Received
1	AES Shady Point	Shady Point	Poteau	OK	4	320	Y
2	U.S. Generating Company	Cedar Bay	Jacksonville	FL	3	250	Y
3	Nelson Industrial Steam Company		Westlake	LA	2	200	
4	AES Barbers Point, Inc.		Ewa Beach	HI	2	180	Y
5	AES Thames		Uncasville	CT	2	180	Y
6	Tennessee Valley Authority	Shawnee Power Plant	West Paducah	KY	1	160	
7	Archer Daniels Midland Company	East Plant	Decatur	IL	5	150	Y
8	Archer Daniels Midland	Power Plant	Cedar Rapids	IA	3	120	Y
9	U.S. Generating Company	Northampton Generating Station	Northampton	PA	1	110	Y
10	ACE Cogeneration Company		Trona	CA	1	106	Y
11	Texas-New Mexico Power Company	TNP One Power Plant	Bremond	TX	1	100	Y
12	Northern States Power	Black Dog Power Plant	Burnsville	MN	1	100	Y
13	Tri-State Generation and Transmission Association	NUCLA Generating Station	Nucla	CO	1	100	
14	Inter-Power Ahlcon Partners	Colver	Colver	PA	1	85	Y
15	Air Products and Chemicals, Inc.	Cambria Cogeneration Plant	Ebensburg	PA	2	85	Y
16	U.S. Generating Company	Scrubgrass Power Plant	Kennerdell	PA	2	83	Y
17	Panther Creek Partners	Panther Creek Energy Facility	Nesquehoning	PA	2	83	Y
18	Lake Resources	North Branch Power Plant	Bayard	WV	2	80	
19	American Bituminous Power Partners	Grant Town	Grant Town	WV	2	80	
20	Gilberton Power Company	John B Rich Power Plant	Frackville	PA	2	80	Y
21	Schuykill Energy Resources, Inc.	Saint Nichols Power Plant	Shenandoah	PA	1	80	
22	Boise Cascade	Rumford Cogeneration Company	Rumford	ME	2	80	
23	Montana Dakota Utilities Company	Heskett Station Unit 2	Mandan	ND	1	75	Y
24	Morgantown Energy	Morgantown Cogeneration Plant	Morgantown	WV	2	70	
25	Ashland Petroleum Company	Boiler Plant	Catlettsburg	KY	2	65	
26	Southeast Paper Mfg Company		Dublin	GA	1	60	
27	Yellowstone Energy Limited Partnership	Yellowstone Power Plant	Billings	MT	2	57	Y
28	Black River Limited Partnership	Fort Drum Power Plant	Watertown	NY	3	56	Y
29	NRG	Sunnyside Cogeneration Plant	Sunnyside	UT	1	55	Y
30	Kimberly Clark Corporation	Power Plant	Chester	PA	1	55	
31	Ebensburg Power Company		Ebensburg	PA	1	52	Y
32	Southern Electric International	UDG Niagara	Niagara Falls	NY	1	52	

EXHIBIT 2-8 (continued)

Active Fluidized Bed Combustion Facilities Burning Fossil Fuels - Sorted by Capacity (MWe)

Capacity Rank	Owner/Operator	Plant Name	City	State	No. Boilers	Capacity (MWe)	Survey Received
33	A.E. Stanley Manufacturing Company		Decatur	IL	2	50	
34	Mt. Poso Cogeneration Company		Bakersfield	CA	1	49.9	Y
35	POSDEF Power Company, L.P.		Stockton	CA	1	49.9	Y
36	Northeastern Power Company		McAdoo	PA	2	49.5	
37	Air Products & Chemicals Inc		Stockton	CA	1	49	Y
38	P.H. Glatfelter Company		Spring Grove	PA	1	44	
39	Wheelabrator Frackville Energy Co, Inc.		Frackville	PA	1	42	Y
40	Rosebud Energy	Colstrip Power Plant	Colstrip	MT	1	42	
41	Foster Wheeler Mount Carmel, Inc.	Mount Carmel Power Plant	Marion Heights	PA	1	40	
42	Iowa State University	Physical Plant	Ames	IA	2	40	
43	Fort Howard Paper Company		Rincon	GA	2	40	Y
44	Rio Bravo Jasmin	Jasmin Power Plant	Bakersfield	CA	1	37	Y
45	Rio Bravo Poso	Poso Power Plant	Bakersfield	CA	1	37	Y
46	Fort Howard Paper Company	French Island Station	Greenbay	WI	1	32	Y
47	Tampella Power Services	Pinion Creek Power Plant	Clarion	PA	1	30	Y
48	CRSS Capital	Wetwood Generating Station	Tremont	PA	1	30	Y
49	Michigan State University	Number 4 Power Plant	East Lansing	MI	1	30	Y
50	University of North Carolina	Chapel Hill Power Plant	Chapel Hill	NC	2	28	
51	General Motors Corporation	Power Plant	Pontiac	MI	1	26	
52	Quaker State Oil	Congo Refinery	Newell	WV	2	24	
53	Purdue University	Physical Plant	West Lafayette	IN	1	23	Y
54	Archibald Power Corporation	Archibald Power Plant	Archibald	PA	1	21.5	Y
55	Mantiwoc Public Utilities		Mantiwoc	WI	1	20	
56	Tacoma Public Utilities	Steam Plant #2	Tacoma	WA	2	20	
57	University of Missouri	Energy Management Office	Columbia	MO	1	20	Y
58	Wyandotte Municipal Service Commission	Wyandotte Power Plant	Wyandotte	MI	1	20	Y
59	Lauhoff Grain Company		Danville	IL	1	20	
60	University of Iowa	Physical Plant	Iowa City	IA	1	20	Y
61	GWF Power Systems	Webber Road East	Antioch	CA	1	20	Y
62	GWF Power Systems	Webber Road East	Antioch	CA	1	20	Y
63	GWF Power Systems		Bay Point	CA	1	20	Y
64	GWF Power Systems		Hanford	CA	1	20	Y

EXHIBIT 2-8 (continued)

Active Fluidized Bed Combustion Facilities Burning Fossil Fuels - Sorted by Capacity (MWe)

Capacity Rank	Owner/Operator	Plant Name	City	State	No. Boilers	Capacity (MWe)	Survey Received
65	GWF Power Systems		Pittsburgh	CA	1	20	Y
66	GWF Power Systems		Pittsburgh	CA	1	20	Y
67	Worcester Energy Company, Inc	Down East Peat	Aurora	ME	3	14	
68	Idaho National Energy Lab		Idaho Falls	ID	2	13.6	
69	Abbott Laboratories		Casa Grande	AZ	1	13.6	
70	B.F. Goodrich Company		Henry	IL	1	12.5	
71	Archer Daniels Midland Company	Physical Plant	Lincoln	NE	1	9	Y
72	East Stroudsberg University		East Stroudsberg	PA	2	8	
73	Archer Daniels Midland Milling Company	Power Plant	Des Moines	IA	1	8	Y
74	University of Northern Iowa		Cedar Falls	IA	1	7.5	
75	Anderson Clayton Foods		Jacksonville	IL	1	7	
76	Iowa Beef Processors, Inc		Amarillo	TX	1	7	
77	archer Daniels Midland Company		Mankato	MN	1	6	Y
78	Central Soya Company		Marion	OH	1	4	
79	Griffin Industries, Inc.	Boiler Plant	Newberry	IN	1	4	
80	Midwest Brain Products		Pekin	IL	1	3.5	
81	General Motors Corporation	Power Plant	Warren	MI	1	3	
82	Correctional Facility		Danville	IL	3	3	
83	Georgetown University	Power Plant	Washington	DC	1	2.8	
84	Barton Brands Distillery		Bardstown	KY	1	1	
				Totals:	**123**	**4,591.3**	**45**

EXHIBIT 2-9

Study Population and Response Pattern

EXHIBIT 2-10

Capacity Rank of Survey Respondents

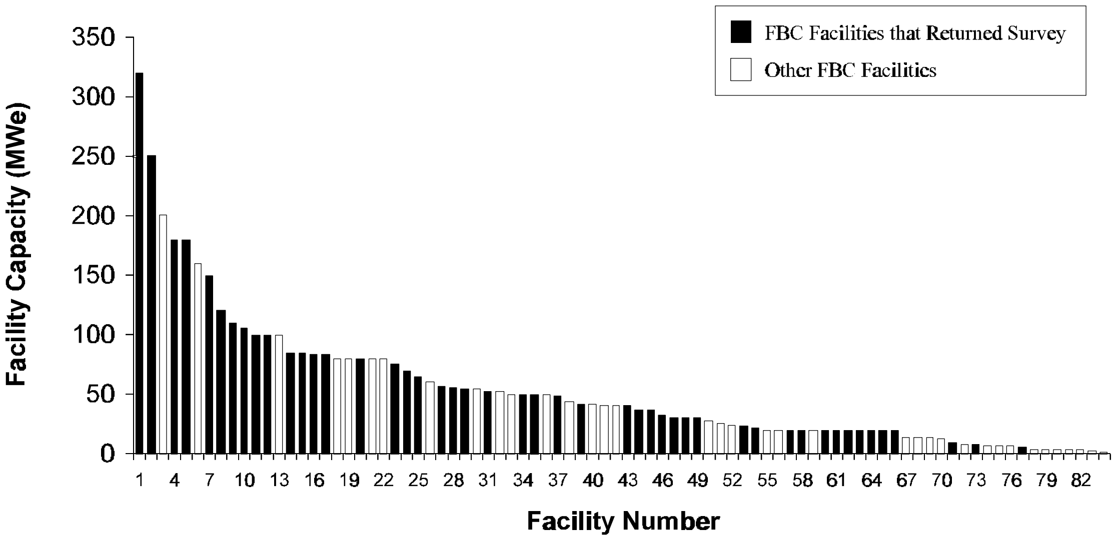

EXHIBIT 2-11

SIC Codes Contained in Study Population

SIC Code	Description	Number of Facilities
20	Food & Kindred Products	5
26	Paper & Allied Products	2
49	Electric Generation*	34
82	Universities	3
91	Municipal Government	1

* Includes both utility and non-utility electricity generation.

EXHIBIT 2-12

Solid Fuel Used in FBC Boilers (1995)

Fuel Description	Quantity (short tons)	Number of Facilities	Number of Boilers
Anthracite coal	536	2	4
Bituminous coal	7,450,009	23	49
Sub-bituminous coal	2,306,910	4	7
Lignite	2,086,227	2	3
Anthracite culm	5,568,000*	6	9
Bituminous gob	2,305,000* in PA	5	11
Petroleum coke	1,021,058	8	11
Tires	55,048	3	8
Wood	6,056	3	10

* ARIPPA SURVEY DATA (1997).

CHAPTER THREE

FOSSIL FUEL COMBUSTION TECHNOLOGIES AND AIR POLLUTION CONTROL TECHNOLOGIES

3.0 Introduction

The institutional, commercial and industrial sectors of the economy, referred to herein as the non-utility sector, employ a large number of boilers or heaters that consume a variety of fossil and non-fossil fuels. These boilers and heaters are used for product heating or to generate hot water or steam. In most applications, the steam is used for process heating, electrical or mechanical power generation, space heating, or any combination of these activities. This chapter discusses the various combustion technologies and air pollution control systems used by this non-utility sector.

A utility boiler and an industrial boiler are significantly different. Yet, because both generate steam, legislators and regulators have tended to treat them in the same fashion.

The major differences between industrial and utility boilers are in three principal areas:

- size,
- the application of the steam produced, and
- design.

The average new industrial boiler is a dwarf compared to the typical utility boiler. Today's typical utility unit produces 3.5 million pounds of steam per hour; the industrial boiler 100,000. In fact, most industrial boilers range in size from 10,000 pounds of steam per hour to 1,200,000. The size of the utility boiler allows its operator to enjoy significant economies of scale, especially in the control of flue gas emissions, that simply are not available to the owner of an industrial unit.

The Gas Research Institute estimates that there are approximately 54,000 non-utility boilers currently operating in the United States with about 200 new units being added each year.[72] Of the new units, about 80 percent are replacement units,[73] hence, only about 40 new boiler installations are added annually. In 1977, 12 percent of all non-utility boilers in the United States were coal-fired. Coal has not been utilized in the non-utility boilers as extensively as oil or natural gas, chiefly because of cost considerations for the smaller units (principally increased capital costs for coal handling equipment relative to the costs of the boilers). Nevertheless, a marked percentage increase in coal-fired non-utility boilers has occurred since the early 1970s. Of the total industrial boiler units purchased in 1971, only 0.5 percent were designed primarily for coal use. Following the oil embargoes of the 1970's, by 1980, coal-fired boilers claimed 13.7 percent of the new boiler market. Based on the latest American Boiler Manufacturers' Association statistics for 1996 boiler

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[72] Gas Research Institute, *Air Quality Primer: Boilers and Fired Heaters*, available at http://www.gri.org/tech/e+s/boilers/boiltop.htm.

[73] *Ibid*.

sales, there were 6 coal fired industrial watertube boilers sold out of a total of 287 units, or about 0.5 percent. When coal has been the fuel of choice, stoker firing dominates in units below about 250 million Btu/hr heat input capacity. Above this level, pulverized coal and FBC have dominated the coal fired non-utility boiler market.[74]

There are approximately 54,000 industrial boilers in use today, compared to approximately 4,000 utility boilers. Yet, all the small industrial units combined produce less steam than all the large utility boilers. In addition, the nation's utility boilers consume over 10 times as much coal as the industrial boilers.

A utility boiler has one purpose--to generate steam at a constant rate to power turbines that produce electricity. Industrial boilers, on the other hand, have markedly different purposes in different industries. Even at a single installation, the application of steam from an industrial boiler can change dramatically with the seasons, because the steam or hot water is often used for space heating, as well as from day to day and hour to hour, depending on the industrial activity or process underway at the moment and its demand for steam. The possibility of such widely fluctuating demand for steam in most industrial processes means that the industrial boiler does not, in the great majority of cases, operate steadily at maximum capacity. In general, the industrial boiler will have a much lower annual operating load or capacity factor than a typical base loaded utility boiler. This means any added system costs have a much greater effect on the final output steam cost.

In contrast, a typical base loaded utility boiler, because of a constant demand for steam, operates continuously at a rate close to maximum capacity. This basic difference in operation is reflected in proportionately lower operating costs than is the case for similarly equipped industrial boilers. Even in cases in which there are peaking units operated to meet utility load swings during the days or for seasonal peak demands, the utility units' load swings are more controlled and can be balanced over the complete electrical production and distribution grid.

In the event of an unscheduled period out of service, a utility will have a variety of backup systems available to meet its load, while industry rarely has a backup system for steam generation. Because of its desire to keep the costs for steam production as low as possible, industry has instead demanded a high level of reliability from its boilers; industrial boilers routinely operate with reliability factors of 98 percent. Any drop in reliability for an industrial system can mean irreplaceable production shortfalls and significant loss of revenues.

Utility boilers are primarily large, field erected pulverized coal, No. 6 oil, or natural gas fired high pressure, high temperature boilers with relatively uniform design and similar fuel combustion technologies. Industrial boilers, on the other hand, incorporate combustion systems that vary considerably. These industrial boilers provide either high pressure or low pressure, steam and/or hot water generation, are of large or small size, and may be field erected or shop assembled package boilers. They can be designed to burn just about anything that can be burned alone or along with conventional fossil fuels. Industrial boilers use many different types of combustion

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[74] Adapted from Gas Research Institute.

systems, including many different types of stokers, bubbling and circulating fluidized bed combustion systems, pulverized coal, and conventional, oil, and gas combustion systems. In fact, regardless of fuel or combustion type, the designs of individual industrial boilers can vary greatly, depending on the intended application of steam and the space limitations in a particular plant, while facilities at a utility plant are designed around the boilers and turbine(s).

3.1 Overview of Combustion Technologies

The goal of any combustion technology is to convert the chemical energy of a fuel in the presence of oxygen into useful thermal energy, in a controlled process. Various technologies are used to control this reaction, which require different fuel particle sizes; these, in turn, influence combustion temperatures and residence time for the fuel particle in the combustion zone. For the fossil fuels of interest in this regulatory determination, the principal combustible elements are carbon, hydrogen, and sulfur. "The combination of the combustible fuel elements and compounds in the fuel with all the oxygen requires *temperatures* high enough to ignite the constituents, mixing or *turbulence* to provide intimate oxygen-fuel contact, and sufficient *time* to complete the process, sometimes referred to as the three Ts of combustion."[75] This section will explain how these three Ts are accomplished in the various combustion systems and their effects on the combustion byproducts.

Regardless of the fuel being fired, or the actual combustion technique employed, boilers consist of several common systems and are frequently classified by their heat transfer configuration. The two major heat transfer configurations are firetube and watertube. The majority (over 98 percent) of non-utility boilers are watertube boilers. Moreover, electric utilities almost exclusively utilize watertube boilers due to the high temperatures and pressures that they offer, leading to greater efficiency. In a watertube boiler, combustion heat is transferred to water flowing through tubes lining the furnace (also referred to as the combustion chamber) walls and boiler passes. The furnace watertubes (waterwalls) absorb primarily radiant heat, while the watertubes in the heat recovery area gain heat by convective heat transfer. Non-utility boilers can be either shop fabricated or field-erected, depending on their size. In general, most units greater than 200 million Btu/hr heat input capacity are field-erected. Field-erected units are assembled onsite; these include all large multi-burner gas- and oil-fired boilers, and most pulverized coal ("PC"), stoker, and FBC units.[76]

In a firetube boiler, the hot combustion gases flow through tubes immersed in the boiler water, transferring heat to the water. Firetube boilers are typically small, with heat input capacities limited to less than 50 million Btu/hr, and steam pressures limited to 300 psig, with pressures of 150 psig being more common. Firetube boilers are used primarily where loads are relatively

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[75] S.C. Stutlz and L.B. Kitto, editors, *Steam: its generation and use, 40th Edition,* The Babcock & Wilcox Company, Barberton, Ohio, 1992, p. 9-1.

[76] Adapted from Gas Research Institute.

constant. Nearly all firetube boilers are sold as packaged units because of their relatively small size.[77]

All boiler systems use a fan system to provide the combustion air supply. Multiple fans may be used to provide the combustion air to different locations within the boiler for "staged combustion" for control of emissions or improved fuel conversion. Many non-utility and utility boilers using ash-containing fuels have particulate matter control systems such as electrostatic precipitators or fabric filters (baghouses). Other emission control systems also may be employed, such as flue gas desulfurization, to control gaseous emissions.

Depending on the size of the boiler, or the application in which the steam is used, a boiler also may be equipped with an economizer, superheater, or air preheater to increase the efficiency of converting the fuel (chemical energy) into high temperature and pressure steam (thermal energy). These devices are referred to as heat recovery devices and are located either in the boiler's furnace (combustion chamber) or after the furnace in the hot flue gas conveyances. The area of the boiler, outside of the furnace, where the hot flue gases contact these heating surfaces is referred to as the convection section or back-pass. Heat contained in the hot flue gas is transferred to water, steam, or air by convection. The economizer is a boiler feedwater heating device that is used to preheat the water before it enters the steam drum. An air preheater heats air that is used for combustion in the boiler. A superheater imparts additional thermal energy to the steam by raising the steam temperature above the saturation temperature. Exhibit 3-1 illustrates the major elements of a boiler system (without air emission control systems for simplicity).

This report is focused on fluidized bed combustion of coal, fuels derived from primary fossil fuels, and co-firing of fossil fuels with non-fossil fuels. To facilitate comparisons between FBC combustion and conventional technologies (stoker, pulverized coal, and cyclone) the following sections briefly describe each technology.

3.2 Conventional Combustion Technologies

This section provides a description of stoker, pulverized fuel and cyclone combustion systems that are used in both utility and non-utility boilers to convert chemical energy (fuel) into recoverable sensible heat. In the case of a boiler, the heat is used to produce hot water or steam to convey the thermal energy to the end use.

3.2.1 Stoker Combustion Technology

Stoker-fired systems account for approximately 90 percent of coal-fired watertube non-utility boilers. Stoker systems can be divided into three groups: underfeed stokers; overfeed stokers; and spreader stokers. These systems differ in how fuel is supplied to either a moving or stationary grate for burning. One important similarity among all stokers is that all design types use under fire air to combust the coal on the grate, combined with one or more levels of over fire air introduced above

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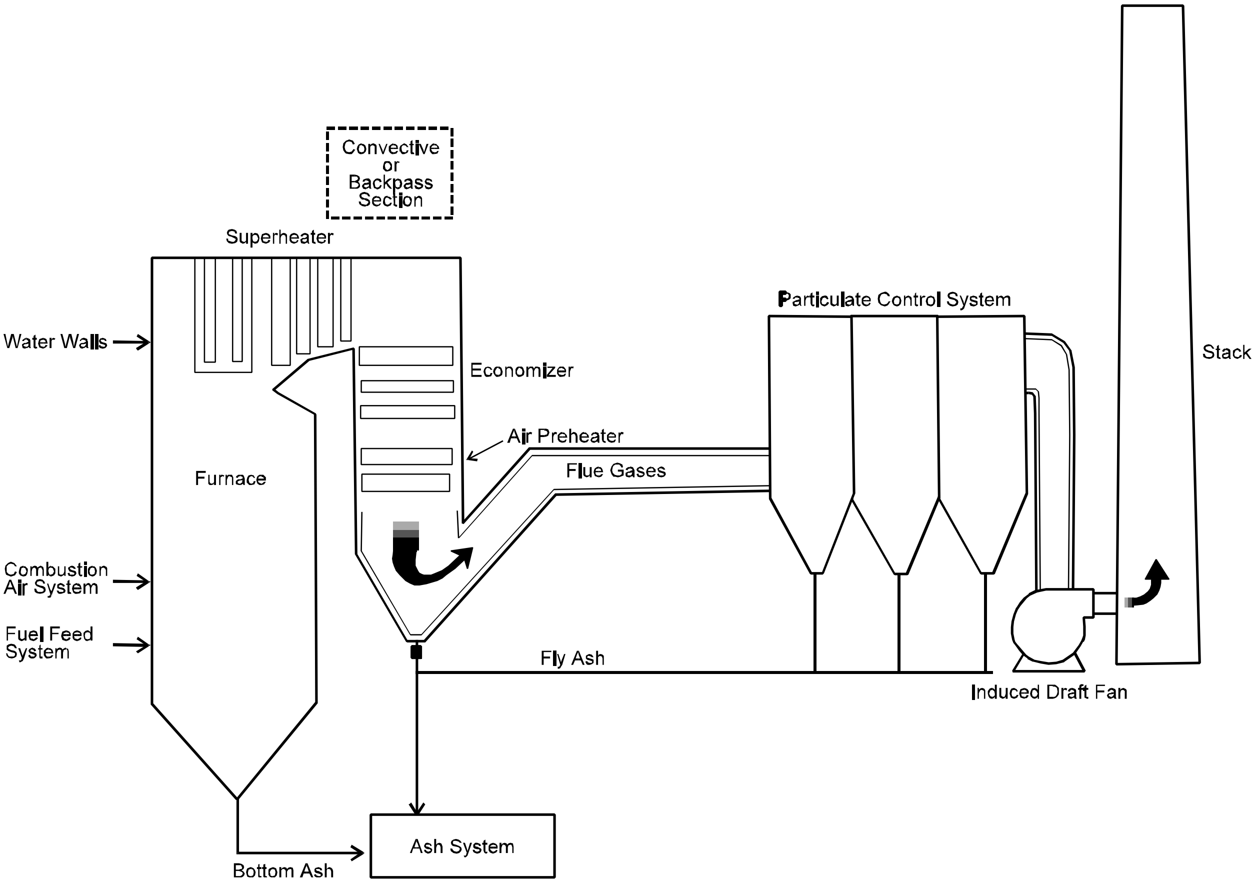
[77] Adapted from Gas Research Institute.

EXHIBIT 3-1
TYPICAL BOILER SYSTEM COMPONENTS



the grate. This helps ensure complete combustion of volatiles and low combustion emissions. Many stokers also utilize fly ash reinjection to minimize the unburned carbon content in the fly ash. Underfeed stokers were once the primary stoker type used in industrial and utility steam generation, but the specific coal feed size requirements, high costs of maintenance, and the slow response of these units to varying loads have made them less competitive in the present market. Spreader stokers, however, remain popular in industry today, due in part to their ability to handle a wide variety of solid fuels and coals.[78]

Many fossil and non-fossil solid fuels are burned in stokers. Fossil fuels include bituminous coal, sub-bituminous coal, lignite, and anthracite coal. Examples of non-fossil fuels include municipal refuse, wood, biomass, peat, bagasse, furfural residue and peanut shells, to name a few. Some fuels are restricted to certain stoker types while others can be burned on all stoker types. This discussion pertains to coal or coal and other fuels firing when coal is more than 51 percent of the total fuel input by weight.

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[78] *Op. cit.*

Combustion performance on stoker fired boilers is dependent upon the type of fuel, its size consistency as delivered to the specific stoker type and the undergrate and overfire air distribution for combustion. There is more fuel use flexibility than for pulverized coal fired systems. Fuel size consistency and air distribution can be varied within a fairly wide range to handle fuel variability up to plus or minus fifteen percent without noticeable performance variation or temperature profile shifts. Wider variation can be handled within limits, however, efficiency and performance may be affected. Each stoker type has different specific limitations.

Ash is collected from two locations in stoker fired systems: bottom ash coming from the grate, and fly ash removed from the flue gases. Many units are equipped with an electrostatic precipitator ("ESP") or fabric filter (bag house) for fly ash capture. These units also will be equipped with a mechanical cyclone particulate collector upstream of the ESP or fabric filter. The mechanical collector can collect at least 85 percent of the particulate matter, which serves two purposes. First, the load on the ESP or fabric filter will be reduced. Second, the mechanical collector will allow for the reinjection of fly ash back to the furnace to reduce the amount of unburned carbon contained in the fly ash, thus maximizing carbon utilization. Few units use a scrubber to remove fly ash for particulate control.

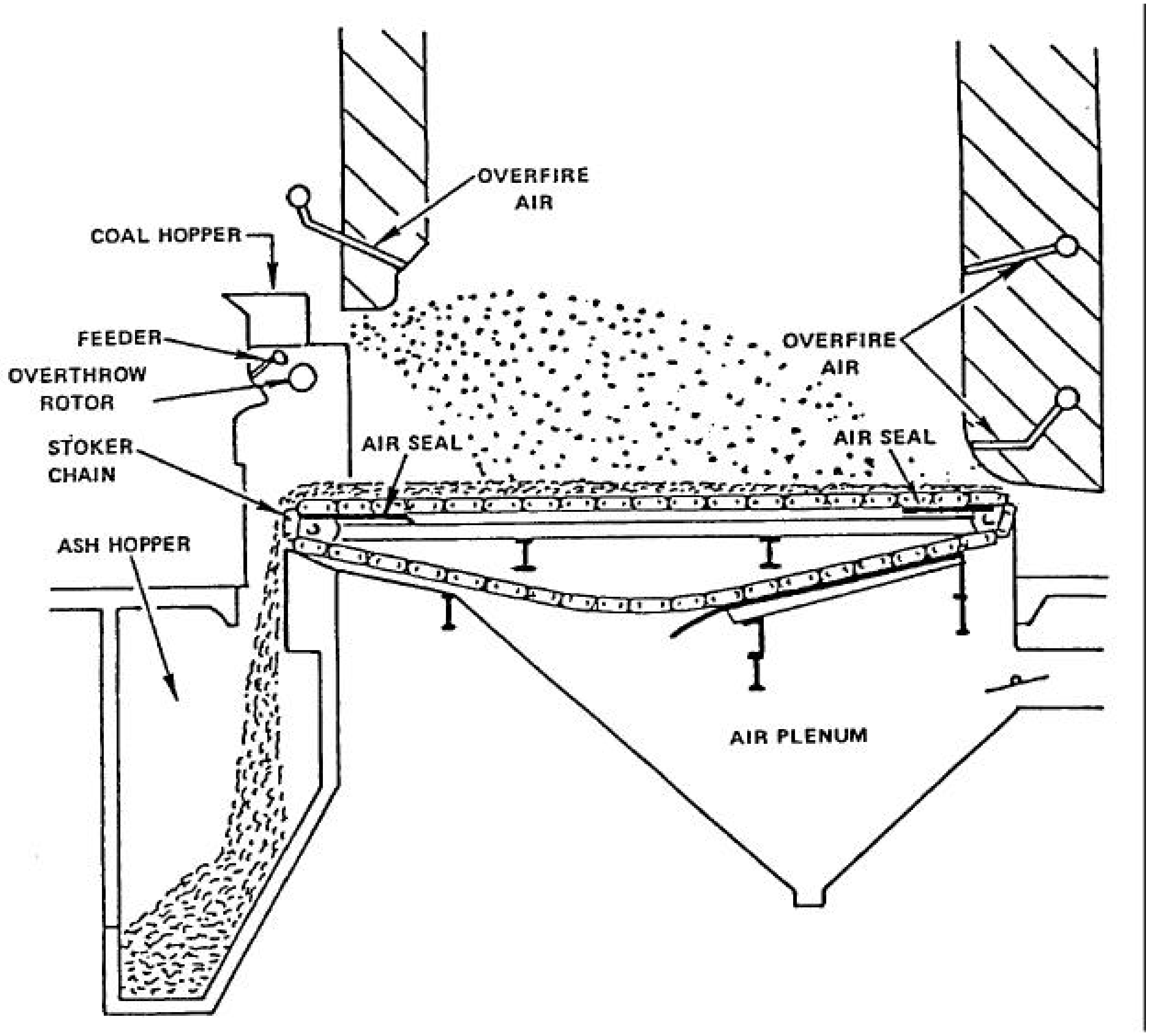
Each of the major stoker systems is described in turn in the following sections.

Spreader Stoker

Spreader stokers utilize the principle of propelling the fuel into the gas stream above a grate in a manner that evenly distributes the fuel over the entire grate surface, as depicted in Exhibit 3-2. The feeders or "stokers" used to introduce the fuel into the furnace, help to distribute it over the entire grate surface. Some of the fuel is burned in suspension above the grate and the remainder is burned on the grate. The proportions of suspension burning and grate burning depend on the stoker design and fuel sizing. The stoker grates act as both platforms on which the coarse fuel can burn and as ash discharge mechanisms. The grate is designed to provide an even flow of air upward through the grate to support complete combustion of the remaining fuel and an even heat release in the furnace.

When a fuel particle enters the furnace its temperature is raised by radiant, convective, and conductive heat transfer. This rise in temperature vaporizes moisture contained in the fuel and volatile matter is released. The volatile mater consists of hydrocarbons and other organic compounds which are ignited and burned. The remaining fuel particle, referred to as char, contains carbon and mineral matter (ash). Due to the high temperatures and turbulence in the furnace some of this char particle is consumed by oxidation prior to completion of the combustion process on the grate, leaving behind the mineral matter and some unburned carbon.

EXHIBIT 3-2
TRAVELING GRATE SPREADER STOKER



Source: Meyers, R.A. (Ed.), Coal Handbook. Marcel Decker, Inc. 1981.

The type of grate used to support the fuel and act as an ash discharge mechanism is referred to by the method used to move the fuel/ash along its length. The principal types include traveling grate, vibrating grate, reciprocating grate, and dumping grate. The first three types are considered continuous ash discharge mechanisms and the fourth an intermittent discharge mechanism. The continuous ash discharge mechanisms carry the ashes to the end of the grate where they are discharged into an ash pit and removed by a mechanical system. Ashes from a dumping grate cannot be discharged without disrupting the combustion process. Because of this, there are few dumping grate type spreader stokers in use today burning coal.

The combustion air systems for spreader stokers provide primary and secondary air. Primary air is delivered through the grates from a forced draft fan and a plenum chamber under the grates. On boilers so equipped, the air first passes through an air heater. The grate air admitting area and the plenum chamber are designed to provide an even distribution of the primary air through the grates. Modern spreader stokers are equipped with a secondary (over fire) air system for the complete combustion of the portion of the fuel that is burned in suspension, to reduce opacity by completing the burn-out of volatile material, and to reduce the emissions of NO_x. The secondary air may be either ambient or heated depending on the economics of air preheating. The combustion control system provides separate control of the primary and secondary air to operate the boiler at minimum excess air to maximize boiler efficiency.

A spreader stoker boiler can be started in a number of ways. Typically kindling wood, rags, or other material is distributed over the grate and ignited. Coal is then fed intermittently until a coal fire is established and the boiler is brought up required temperature and pressure. Boiler load is controlled by varying the fuel feed rate along with the primary and over fire air flows. At rated boiler capacity, the average temperature in the boiler furnace combustion zone is in the range of 2,400 to 3,200°F (1,316 to 1,649°C) depending on the amount of suspension and grate burning. The temperature in the fuel bed will vary from 2,000 to 2,500°F (1,093 to 1,371°C) depending on the type of coal and undergrate air flow and temperature. The actual ash fusion temperatures determine the design temperature and combustion limitations for a specific boiler and stoker.

Spreader stokers are utilized on boilers having steam generating capacities from about 25,000 lb/hr up to about 400,000 lb/hr with operating pressures up to 1,600 PSIG.

Spreader stokers are capable of burning a wide range of coals. Depending on design, bituminous coal use is limited by volatile matter content (usually greater than 20 percent), and an ash content of between four percent and 20 percent. Sub-bituminous coals are burned because of their low cost and low sulfur content, to meet emission requirements. Fuel sizing, high volatile matter content, and slagging and fouling characteristics are limits to their applicability. Like sub-bituminous coal, lignite is also burned in a few plants. It carries the same volatile, size, slagging, and fouling limitations. Anthracite coal cannot be burned successfully on spreader stokers due to its low volatile matter content. Because a coarser size distribution is required with a controlled level of fines (less than ¼"), fuel is normally purchased with a size distribution suitable for use, eliminating the need for on-site fuel processing facilities which generally increase the amount of fines.

The relative proportions of bottom ash, falling off the end of the grate, and fly ash, carried through the boiler to collection devices, is primarily influenced by coal sizing, friability, and primary and over fire air distribution. Increases in the amount of fines or the friability of the coal from the original design criterion will increase the amount of fly ash. High primary air flows increasing the velocity rising through the grates may re-entrain ash, increase the amount of suspension burning and thereby increase the amount of fly ash. At a constant excess air flow, a higher percentage of over fire air will reduce the amount of air through the grates and the amount of fly ash generated. An optimum balance of suspension burning versus grate burning must be established for each coal to achieve optimum performance and minimize fly ash. The percentage of bottom ash to total ash can range from 40 to 65 percent. Fly ash, conversely, can range from 35 to 60 percent of the total.

The bottom ash off the grate can have a consistency of "popcorn" (a separate fused ash), a lighter fluffy looking product, or a fused clinker.   A clinker forms when a fairly large amount of ash fuses together under high temperature. Formation of the popcorn, fluffy, or clinker form depends on the combustion and ash fusion characteristics of the coal and the manner in which the unit is being operated. The unburned carbon or combustible content of the bottom ash from tests reported in *Emission and Efficiency Performances of Industrial Coal Stoker Fired Boilers* published by the American Boiler Manufacturers Association in 1981, (the "ABMA tests") varied from 0 to 34 percent. The average fuel sulfur retained in the ash was 5 percent and the data indicated that sulfur conversion efficiencies (sulfur to SO_2) of 95 to 98 percent were obtained.

The size range of fly ash from spreader stokers can vary from above 30 mesh (>350 micron) to minus 10 micron. The factors that affect the distribution of the sizes are coal sizing, friability of the coal, furnace velocities, and the amount of fly ash reinjection. Higher rates of fly ash reinjection burn off carbon which results in smaller particle sizes and increased amounts of fly ash. Particle sizes 30 mesh and larger may have a combustible content of 90 percent while particle sizes less than 200 mesh may have a combustible content as low as 5 percent. The ABMA tests indicated a combustible content of fly ash from units with reinjection as little as 7.1 percent and combustible content of fly ash from units without reinjection of as much as 83.5 percent.

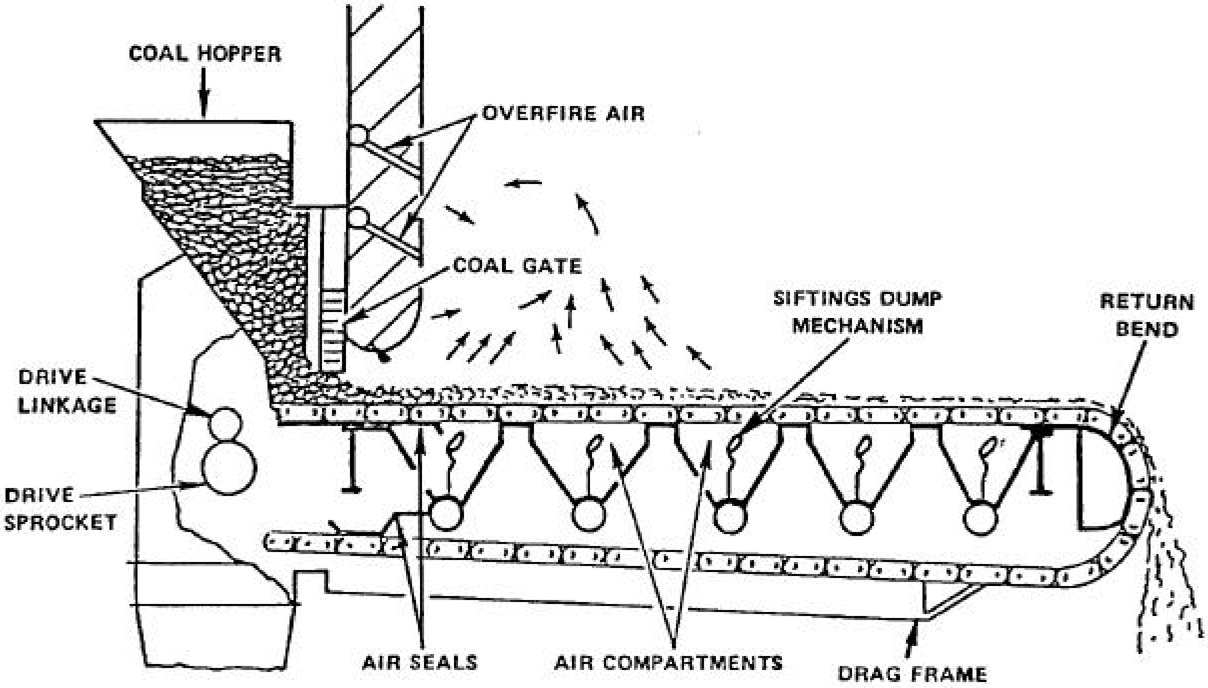
Spreader stoker fired boilers also may be equipped with air pollution control devices to reduce emissions of sulfur dioxide and NO_x. Flue gas desulfurization scrubbers can be used either upstream or downstream of the particulate (fly ash) removal system to reduce emissions of SO_2. If the scrubber is located upstream of the particulate control device, then the combustion byproducts collected will have the characteristics of the fuel ash, the scrubber reagent used, and the sulfur compounds formed in the scrubbing process. Selective catalytic and non-selective catalytic reduction of NO_x can be used in addition to staged combustion to reduce overall NO_x emissions.

Overfeed or Mass-fed Stokers

Overfeed (mass-fed) stokers utilize the principle of progressive burning. The fuel is fed out of a hopper by a traveling grate or vibrating grate and conveyed through the furnace from the front end to the rear where the ash is discharged Exhibit 3-3. The depth of the coal entering the furnace is controlled with a gate at the furnace entrance. Combustion consists of ignition, rapid combustion,

burnout, and then ash discharge as the grate moves the bed through the furnace. To support this principle, there are a series of transverse air zones from front to rear to provide the appropriate amount of air for combustion.   Over fire air is used to assist ignition, complete combustion of the volatile material, and reduce opacity. Over fire air is usually a small percentage of the total air and has no measurable affect on NO_x emission reductions. The over fire air systems typically are installed with a row of nozzles in the front wall of the furnace above the coal gate.

EXHIBIT 3-3
OVERFEED STOKER



Source: Meyers, R.A. 1981. op. cit.

Overfeed stokers are installed in boilers having steam generation capacities typically ranging from about 25,000 lb/hr to 150,000 lb/hr with operating pressures up to 600 PSI. These boilers are located primarily in institutional facilities and industrial plants where the steam is utilized for heating and limited process needs. Because the combustion process begins with the mass feeding of the coal, the overfeed stoker does not have the ability to follow wide load swings in an efficient manner. Therefore, they are not found in plants were process or power load swings are routine or substantial.

Bituminous coal is the most common fuel burned on overfeed stokers. There are a few units burning sub-bituminous and lignite in the upper midwest. The overfeed stoker also is more sensitive to ash fusion temperature than is the spreader stoker. It is, however, less sensitive to the fines concentration in the coal feed. Specially designed overfeed stokers are capable of burning anthracite coal. Because of the very low volatile content, large heat reflecting arches are installed above the grate assist in the ignition and complete combustion of the anthracite.

Combustion in a mass-feed or over-feed stoker is unlike that of a spreader stoker, in which ignition and devolatilization occur in suspension. In the mass-fed unit, ignition and devolatilization spread from the top of the coal flow down onto the grate from the feed gate as the stoker moves the coal across multiple air zones for combustion control and complete carbon burnout. Air zones can be adjusted to control air flow and burning temperature and rate depending on the free swelling index, ash fusion, and combustion characteristics of the coal. Coals with volatile contents of greater than 37 percent or free swelling indexes greater than 5 are not usually suitable coals for mass-feed units. Because of the top-down burning process associated with these stokers, the bed ash temperature will usually be in the range of 2,000 to 2,500°F (1,093 to 1,371°C).

Unit start-up for the mass feed stoker is much the same as for a spreader stoker. Kindling is ignited on the grate to heat up the arch and the coal is fed into the boiler. The air zones are adjusted as needed to avoid putting out the initial fire and bringing the unit up to load. Load is then adjusted by increasing or decreasing the height of the feed gate along with the grate speed to maintain proper ignition and char burnout.

Because there is no suspension burning of the coal and there are generally larger plan areas with lower grate air velocities in the furnace of an overfeed stoker than that of a spreader stoker, there is much less fly ash. Typically, less than 10 percent of the non-combustible material leaves the unit as fly ash.

The bottom ash from overfeed stokers can vary from free flowing ash, “popcorn,” to hard slag clinkers depending on the ash fusion and combustion characteristics of the coal and the manner in which the unit is operated. The combustible content of the bottom ash is higher than in that generated in spreader stokers. The ABMA tests indicate that the bottom ash combustible content from five overfeed stokers averaged from 16 to 26 percent with the average from six spreader stoker fired units being 9 to 14 percent. Because of the low heat release rates and velocities from an overfeed stoker, the size of the fly ash is smaller than that of a spreader stoker without fly ash reinjection. The smaller size fly ash contains less combustible material.

Underfeed Stokers

Underfeed stokers utilize a retort located below the level of air introduction to push the fuel into the furnace from the bottom up, and from front to the rear. One and two retort stokers discharge the ashes at the sides of the furnace from dumping grates. Underfeed stokers with more retorts are called multiple retort stokers and discharge their ash at the rear of the furnace. A small over fire air system is utilized with underfeed stokers to completely burn the volatile material and reduce opacity. The plan area of the furnace of underfeed stokers is larger than that of either overfeed stokers or spreader stokers. This results in lower heat release rates and upward gas velocities. As the coal rises from the retorts, it moves over air admitting devices called tuyeres. The combustion process is progressive from top to bottom, ignition through rapid combustion to burn out. The slow mass burning process is not suited to rapid load changes. Underfeed stokers are, therefore, used mainly to meet heating loads in institutional or industrial facilities. Underfeed stokers are used in boilers having steam generating capacities of generally less than 100,000 lb/hr and operating pressures up to 600 PSIG.

Underfeed stokers are able to burn "free burning" bituminous coals. Underfeed stokers are sensitive to the free swelling index of the coal and to the ash fusion temperatures. High free swelling indexes (+5) and low ash fusion temperatures (less than 2,400°F or 1,315°C) create slag-like clinkers that can block air distribution, thereby increasing fly ash and carbon carryover. Special underfeed stokers also burn Anthracite coal.

Combustion temperatures and start-up are much like those of the mass-feed stoker. Differences occur in the method for load control. Varying air flow through the tuyeres is the primary means of controlling the heat release for the boiler -- much like the old blacksmith's hearth. The ability to handle load variations is very limited. Although this is the oldest type of automatic coal firing system, it is very seldom used today, with very few remaining in existence.

Underfeed stokers produce mainly bottom ash. The percentage of fly ash is lower than that from overfeed stokers. The bottom ash, unless the coal is very free burning, with a low free swelling index and a high ash fusion temperature, tends to be in a clinker or slag form. The combustible content of the bottom ash is similar to that of overfeed stokers, with an average range of from 19 to 25 percent. The fly ash has a size consistency similar to that of overfeed stokers, and ABMA tests of two units indicated a combustible content of about 20 percent.

3.2.2 Pulverized Fuel Technology

Pulverized fuel firing differs from the other fuel combustion technologies used to process solid fuels primarily through the much smaller particle size used and the resulting high combustion rates. Due to this feature, pulverized fuel firing is the predominant technology employed in utility solid fuel fired boilers, and is used to a lesser extent in industrial boilers. Coal is the principal fuel fired by pulverized solid fuel technology, so the following discussions refers to coal and the technology as *pulverized coal* ("PC"). The combustion rate of coal as a solid fuel is, to a large extend, controlled by the total particle surface area. By pulverizing coal to a nominal 50 micron (0.002 inches) diameter or smaller, the coal can be completely burned in approximately one to two seconds. This approaches the rate for combusting oil and gas. In contrast, the other technologies discussed in other sections of this report use crushed coal of various sizes (from top size of less than 1/4-inch to about 1-1/2 inch in size) and provide substantially longer combustion zone residence times (up to 60 seconds or longer).[79]

Coal for use in a PC unit is prepared by pulverizing, i.e., mechanically crushing or grinding the coal in a pulverizer to a very fine power. Many different pulverizer designs are used, with the goal being to reduce the particles to a nearly uniform size of about 50 microns (0.002 inches) with about 70 to 80 percent of the pulverized coal passing a U. S. Sieve size of 200 mesh (74 microns, 0.003 inches). Heated primary air is introduced to the pulverizer to assist in fuel drying and to convey the pulverized coal to the burner assembly located in the furnace. At the burner, the pulverized coal is mixed with additional heated air (secondary air) and burned. The burner incorporates an ignitor using gas or oil to initiate ignition of the pulverized coal and to provide stability to the combustion of the pulverized coal under some operating conditions.

As a coal particle enters the furnace its surface temperature increases due to radiant and convective heat transfer from furnace gases and other burning particles. As particle temperature

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[79] The foregoing was adapted from *Steam: its generation and use, 40th edition*, p. 13-1.

increases, contained moisture is vaporized and volatile matter is released. This volatile matter, which ignites and burns almost immediately, further raises the temperature of the remaining coal particle, which is now referred to as a char particle. The char particle is then consumed by oxidation at high temperatures, leaving behind the fuel ash and some unburned carbon. The air volume around the burner is the hottest zone in the furnace, with the temperature reaching 3,000 to 3,500°F (1,649 to 1,927°C). The average temperature in the furnace is in the range of 2,200 to 2,800°F (1,204 to 1,538°C). The combustion of the coal particle occurs in suspension in the furnace with primary and secondary air and combustion gases being the suspending medium. The devolatilization is mostly completed within 0.01 seconds of entering the furnace, but char-based reactions continue for one to two seconds.[80]

Depending upon the location of the burners and the direction of coal injection into the furnace, PC-fired boilers can be classified as:

Single- and opposed-wall, also known as face firing;
Tangential, also known as corner firing; or
Vertical or roof firing.

Wall-fired boilers can be either single wall-fired, with burners on only one wall of the furnace firing horizontally, or opposed wall-fired, with burners mounted on two opposing walls. However, opposed wall boilers are usually much larger than 250 million Btu/hr heat input capacity and are much more common in utility rather than industrial applications.[81]

In a tangential firing configuration, the burners are mounted in the corners of the furnace. The fuel and air are injected tangential to a circle in the furnace to create a vortex that enhances air/fuel mixing. Larger flame volumes and flame interaction contribute to characteristically lower NO_x levels from tangential firing. Tangential boilers, like opposed-wall boilers, are commonly used in utility applications.[82]

The start-up of a PC unit is accomplished through the use of oil or gas fired start-up burners. The boiler furnace temperature is raised by firing the start-up burners to the minimum permissible solid fuel firing temperature. At this point the coal pulverizers are brought on line and the PC is introduced to the boiler through the PC burner which immediately ignites the fuel. The start-up burners are then shut off and the boiler load is increased by adding additional fuel to the PC burner or bringing on additional PC burners. The boiler load is controlled by limiting coal feed to the pulverizers and the number of burners in operation. The boiler control system maintains primary and secondary air flows automatically in response to changes in coal feed rates.

During the combustion process NO_x is formed. More than 75 percent of the NO_x formed during conventional PC firing is fuel NO_x; the remainder is primarily thermal NO_x. Fuel NO_x is formed

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[80] The foregoing was adapted from *Steam: its generation and use, 40th edition*, p. 13-2.

[81] The foregoing was adapted from the Gas Research Institute.

[82] *Ibid*.

due to oxidation of fuel bound nitrogen during devolatilization and char burnout. High oxygen availability and high flame temperatures during devolatilization encourage the conversion of volatile-released nitrogen to NO_x. Nitrogen retained in the char has a lower conversion efficiency to NO_x, primarily due to lower oxygen availability during char burnout. The thermal NO_x is formed due to oxidation of nitrogen in the combustion air at the high temperatures in the PC furnace. An effective way of controlling the fuel NO_x is to reduce the amount of oxygen (combustion air) available during the critical step of devolatilization. Two approaches are used to reduce oxygen availability during devolatilization. One method is to remove a portion of the combustion air from the burners and introduce it elsewhere in the furnace. This method is referred to as air staging. A second method of reducing oxygen availability during devolatilization is the design of the burner; the burner can be designed to pass all of the combustion air but limit its rate of introduction to the flame.[83] For conventional PC wall-fired units, NO_x emissions from conventional combustion systems typically range from 0.8 to 1.6 lb/million-Btu (984 to 1,968 mg/Nm^3). Low NO_x PC combustion systems are capable of reducing NO_x to 0.2 to 0.7 lb/million-Btu (246 to 861 mg/Nm^3).[84] If further reduction of NO_x is required, selective and non-selective catalytic reduction techniques can be employed.

The sulfur contained in the fuel will be converted to sulfur dioxide during the combustion process. As in the case of spreader stoker units, about 95 to 98 percent of the sulfur contained in the fuel will be converted to sulfur dioxide (SO_2) with the remaining sulfur being contained in the ash. The emissions of SO_2 must be controlled to meet air pollution control permit requirements. One option that is employed is the use of a low sulfur fuel. This compliance strategy, however, is not always possible. All other sulfur reduction methods effectively require "end-of-pipe" scrubbing, which is described in Section 3.5 of this report.

Because PC-fired boilers use a very small particle size, the majority of the ash leaving the furnace is in the form of fly ash. Typically, about 80 percent of the ash contained in the fuel leaves the boiler as fly ash. Electrostatic precipitators, fabric filters (baghouse), or scrubbers are used to control the particulate matter emissions. In the case of ESPs or fabric filters, the fly ash is conveyed from the particulate matter control device to ash storage or disposal by pneumatic conveying systems, mechanical conveyors, or water sluicing.

Ash not leaving the boiler as fly ash is referred to as bottom ash and the method or removal of the bottom ash from the boiler is classified as either dry bottom or wet bottom, depending on whether the ash is removed in solid or molten state. This is an important distinction with respect to NO_x emissions, as wet-bottom boilers operate at higher furnace temperatures and consequently emit greater amounts of NO_x. Boiler designs in wet- and dry-bottom furnaces hinge on coal quality and ash fusion properties. Wet-bottom furnaces are also referred to as slag tap furnaces.
Dry-bottom PC-fired boilers are much more widely used than wet-bottom boilers. In a dry-bottom PC-fired boiler, a water filled ash quench tank may be used to cool the bottom ash prior to

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[83] The foregoing was adapted from *Steam: its generation and use, 40th edition*, p. 13-7.

[84] *Ibid*.

removal from the boiler. Bottom ash can be conveyed to storage or disposal by sluicing, mechanical conveyors, or pneumatic conveying.

Industrial pulverized coal fired boilers are like their utility counterparts in all ways except for their size and use. They have the same concerns and limitations with regard to slagging and fouling. As such, industrial boiler operators must address the same considerations for design, operation, and fuel selection. The ash from an industrial pulverized coal fired boiler burning a given fuel would be indistinguishable from the ash generated by a similar utility boiler burning the same type of fuel. Because of the similarities between the combustion technologies used in industrial and utility pulverized coal fired boilers, utility and industrial companies usually purchase fuel from the same sources, though in different quantities.

3.2.3 Cyclones

Cyclone furnaces were developed for utility service to eliminate the need for pulverizers and to remove ash as a molten slag. Cyclone furnaces burn low ash-fusion-temperature coal crushed to a maximum particle size of about 95 percent through a one-quarter inch mesh screen. The coal is fed tangentially, with primary air, into a horizontal cylindrical combustor. Smaller coal particles are burned in suspension, while larger particles adhere to a molten layer of slag on the combustion chamber wall. The larger particles remain in the slag until they are burned.[85] The slag flows from the combustor to a water filled slag tank for cooling prior to removal from the boiler. Approximately 70 percent of the fuel ash is removed as boiler slag with the remainder removed as fly ash. The same fly ash collection systems and conveying systems used for PC systems are used in cyclone systems.[86] The slag from cyclone furnaces is more like glass or lava rock than any conventional coal ash and is highly valued as a sand blasting medium and for use in making shingles and other roofing materials.

Because of the design and operation of these boilers, industrial and utility boilers use the same fuels and produce ash that is indistinguishable one from another when burning similar coals.

Historically, cyclone equipped boilers have produced relatively high levels of NO_x emissions, typically ranging from 0.8 to 1.9 lb of NO_x as NO_2 per million Btu input. Selective catalytic reduction equipment can be applied to cyclone equipped boilers to control NO_x. Special combustion modifications, such as reburning technology, also can be employed.[87]

Sulfur dioxide emissions can be controlled from cyclone equipped boilers in the same manner as PC equipped boilers with increased attention paid to the fuel characteristics.

Cyclone furnaces are not as widely used in the industrial and utility sectors as wall, tangential, or stoker systems.

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[85] The foregoing was adapted from Gas Research Institute.

[86] The foregoing was adapted from *Steam: its generation and use, 40th edition*, Chapter 14.

[87] *Ibid*.

3.3 Fluidized Bed Combustion Technology

Beginning in the 1970s there was a growing interest in finding ways to a) combust a wider range of fossil fuels, b) improve the efficiency of the combustion process, and c) combust the fossil fuels in a "cleaner" manner, i.e., with lower pollutant emissions. One outcome of research and development work was fluidized bed combustion technology, which met these objectives.

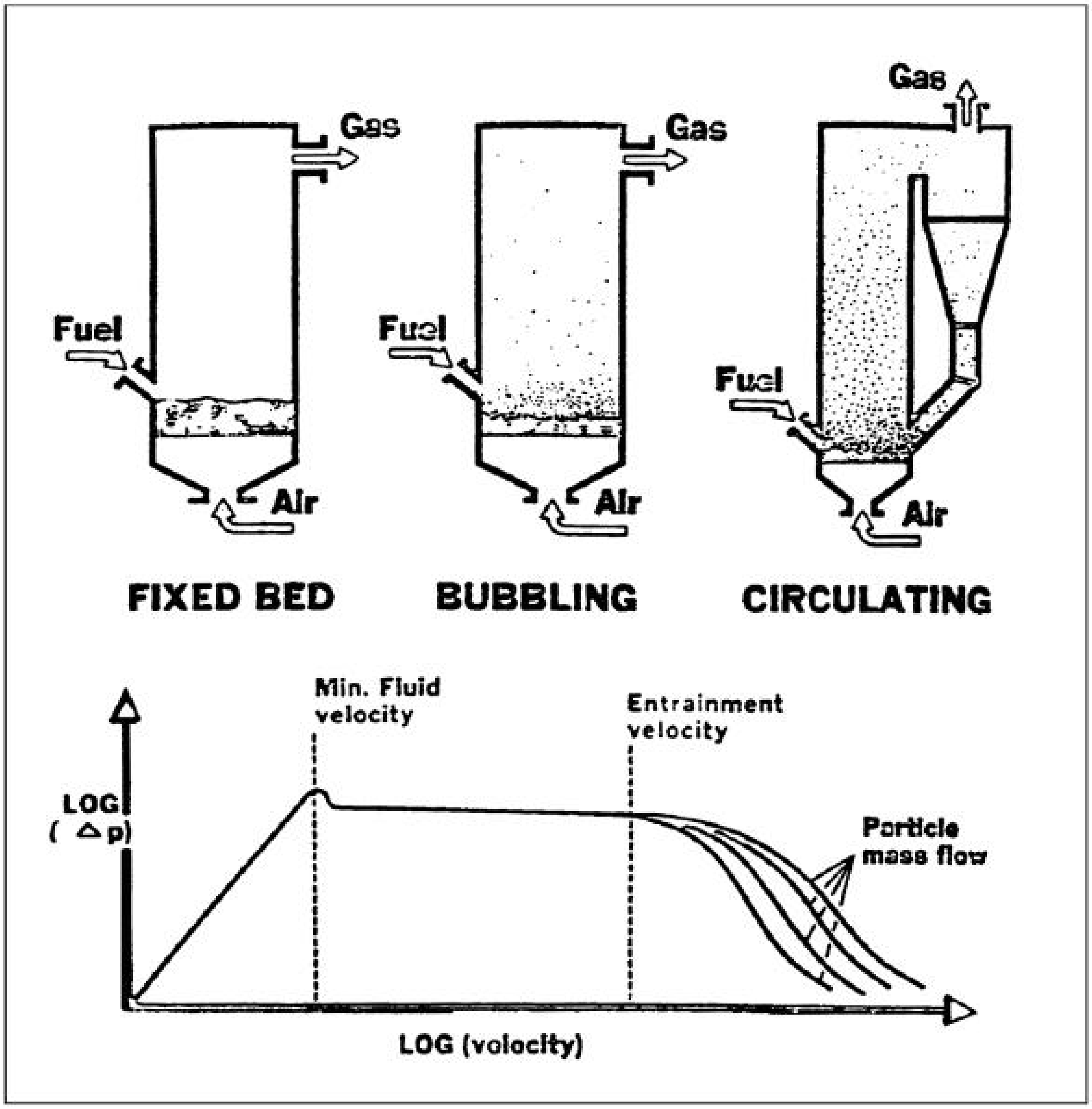
General Description of Fluidized-bed Combustion

"Fluidization" refers to the condition in which solid materials are given free-flowing, fluid-like behavior. As a gas is passed upward through a layer, or bed, of solid particles, the flow of gas produces forces that tend to separate the particles from one another. At low gas flows, the particles remain in contact with other solids and tend to resist movement. This condition is referred to as a fixed bed. As the gas flow is increased, a point is reached at which the forces on the particles are just sufficient to cause separation. The bed then becomes fluidized. The gas cushion between the particles allows them to move freely, giving the bed a liquid-like characteristic.

The transition from fixed bed to fluid bed is illustrated in Exhibit 3-4, which plots gas pressure drop through the bed versus gas velocity. For a fixed bed, pressure drop is proportional to the square of the velocity. As velocity is increased, the bed becomes fluidized; the velocity at which this transition occurs is called the minimum fluidization velocity, V_{mf}. The V_{mf} depends on many factors including particle diameter, gas and particle density, particle shape, gas viscosity, and bed void fraction. At velocities above V_{mf}, the pressure drop through the bed remains nearly constant and is equal to the weight of solids per unit area, as the drag forces on the particles just overcome the gravitational forces. Further increases in velocity bring about changes in the state of fluidization, to be discussed later.

In fluidized-bed combustion, fuel is burned in a bed of hot incombustible particles suspended by an upward flow of fluidizing gas. Typically, the fuel is a solid such as coal or biomass, though liquid and gaseous fuels can be readily used. The fluidizing gas is generally the combustion air and the gaseous products of combustion. Where sulfur capture is not required, the fuel ash may be supplemented by inert materials such as sand to maintain the bed. In applications where sulfur capture is required, limestone is used as the sorbent and forms a portion of the bed. Bed temperature

EXHIBIT 3-4
RELATIONSHIP BETWEEN GAS VELOCITY AND BED CHARACTERISTICS



Source: Foster Wheeler Energy Corporation.

is usually maintained between 1,550ºF - 1,700ºF (800ºC - 900ºC) by the use of heat-absorbing surface within or enclosing the bed. This temperature is optimal for the chemical processes needed to capture sulfur and control NO_x emissions. It also avoids ash softening in nearly all fuels. At this temperature, efficient combustion can be achieved because of the relatively long residence time of fuel in the bed and the good gas/solids contact there.

The above characteristics lead to the following major advantages of FBC:

Fuel Flexibility

Because temperature levels are held below the ash-softening level, the FBC boiler is not sensitive to fuel ash characteristics. A wide range of fuels with varying ash contents and properties can be burned in a single boiler.

The high thermal inertia of the bed mass provides for stable ignition and combustion of very low grade fuels such as fuels high in ash and/or moisture. Fuels containing up to 70 percent ash and 50 percent moisture have been successfully burned in a fluid bed. The high thermal inertia of the bed also provides for good performance when firing low-volatile fuels such as anthracite, anthracite waste, and petroleum coke.

Low Emissions

Sulfur oxide emissions are controlled within the combustor by addition of a sorbent material, typically limestone, so a stack-gas SO_2 scrubber is not required. The sulfur sorbent also can react with and remove other fuel constituents such as vanadium, reducing down-stream corrosion potential.

Nitrogen oxide emissions are considered to come from two sources: oxidation of nitrogen in the air (thermal NO_x) and oxidation of nitrogen and/or nitrogen components in the fuel (fuel NO_x). At the low temperatures in FBC, thermal NO_x production is essentially zero. Moreover, design features such as staged combustion can significantly reduce fuel NO_x, leading to low total NO_x emissions.

Types of FBC Systems

The state of fluidization in an FBC boiler depends mainly on the bed-particle diameter and fluidizing velocity. As shown in Exhibit 3-4, there are two basic fluid-bed combustion systems, each operating in a different state of fluidization. At relatively low velocities and with coarse bed-particle size, the fluid bed is dense, with a uniform solids concentration, and has a well-defined surface. This system is called a *bubbling fluid bed* ("BFB"), because the air in excess of that required to fluidize the bed passes through the bed in the form of bubbles. The BFB is further characterized by modest bed solids mixing rate, and relatively low solids entrainment in the flue gas.

At higher velocities and with finer bed-particle size, the fluid bed surface becomes diffuse as solids entrainment increases, such that there is no longer a defined bed top surface; recycle of entrained material to the bed at high rates is required to maintain bed inventory. Also, the bulk density of the bed decreases with increasing height in the furnace. A fluidized-bed with these characteristics is called a *circulating fluid bed* ("CFB") because of the high rate of material circulating from the furnace to the particle recycle system and back to the furnace. The CFB is further characterized by very high solids mixing rates.

Chemical Processes in FBC

Within the fluidized bed, several interrelated chemical processes occur, including combustion, sulfur capture, and NO_x reduction.

Fuel Combustion

Even at the relatively low temperature associated with fluidized bed combustion, the combustion of fuel in a fluid bed is a rapid process. The combustion rate is mainly a function of the reactivity of the fuel and the fuel surface area available. Solid fuel can be considered to consist of volatile matter and fixed carbon (char) which remains after the volatiles are driven off. Volatile combustible matter generally burns more rapidly than the residual char and volatile combustion can be viewed as a separate process in parallel with char combustion. The concentration of char within the fluidized bed at any given time is typically about one percent. The char concentration will increase with less reactive fuels to the point at which the surface area available compensates for the lower reactivity. Because sulfur dioxide is released during the combustion process, fuel-burning characteristics can significantly influence sulfur capture.

The loss of combustible fuel from an FBC boiler is predominantly a function of the amount of char that escapes the system without burning. Generally, the loss from unburned volatiles is insignificant. The char particles escape from the bed in the flue gas or are drained from the bed in the bottom ash. With proper design, unburned carbon can be limited to 1 percent or less of fuel heat input for nearly all fuels.

Sulfur Capture

The use of limestone as a sulfur capture sorbent allows sulfur emissions to be controlled within the fluidized bed during the combustion process. Limestone consists of calcium carbonate ($CaCO_3$) and various impurities. Lime (CaO) is formed by calcining the limestone to drive off carbon dioxide (CO_2).

$$CaCO_3 \rightarrow CaO + CO_2 \tag{1}$$

Sulfur in the fuel is converted to sulfur dioxide (SO_2) during the combustion process. Although nearly all of the sulfur is oxidized, some of the inorganically bound sulfur may be retained in the ash. The sulfur dioxide combines with the calcined lime.

$$SO_2 + CaO + \frac{1}{2} O_2 \rightarrow CaSO_4 \qquad (2)$$

Equations 1 and 2 indicate that a mole of calcium is required to capture one mole of sulfur. Therefore, defining the Ca/S molar ratio as moles of calcium in the limestone feed to moles of sulfur in the fuel feed, the theoretical minimum Ca/S required for a given level of sulfur removal is 1/1, which assumes 100-percent utilization of the sorbent.

In practical systems, 100 percent utilization is impossible to attain. Because the sulfurization process takes place on the surface of the lime particles in the bed, the lime contained in the particle core is generally not utilized. Also, some SO_2 will escape capture if the total sorbent surface area within the bed is insufficient. Consequently, Ca/S mole ratios greater than 1/1 are necessary.

The porosity of the particle surface formed during calcination is a strong factor in sulfur capture. Slow calcination results in a highly porous particle with an exposed surface larger in area than that of a smooth particle of similar diameter. As it forms, calcium sulfate tends to block these pores. Deep pores provide large surface area but may plug with sulfate before being filled. The optimum provides the maximum surface that can be fully sulfated. The presence of magnesium carbonate ($MgCO_3$) tends to enhance limestone utilization, even though it does not participate in the sulfur-capture process. This is because in calcining to magnesium oxide (MgO), the $MgCO_3$ increases the porosity of the stone.

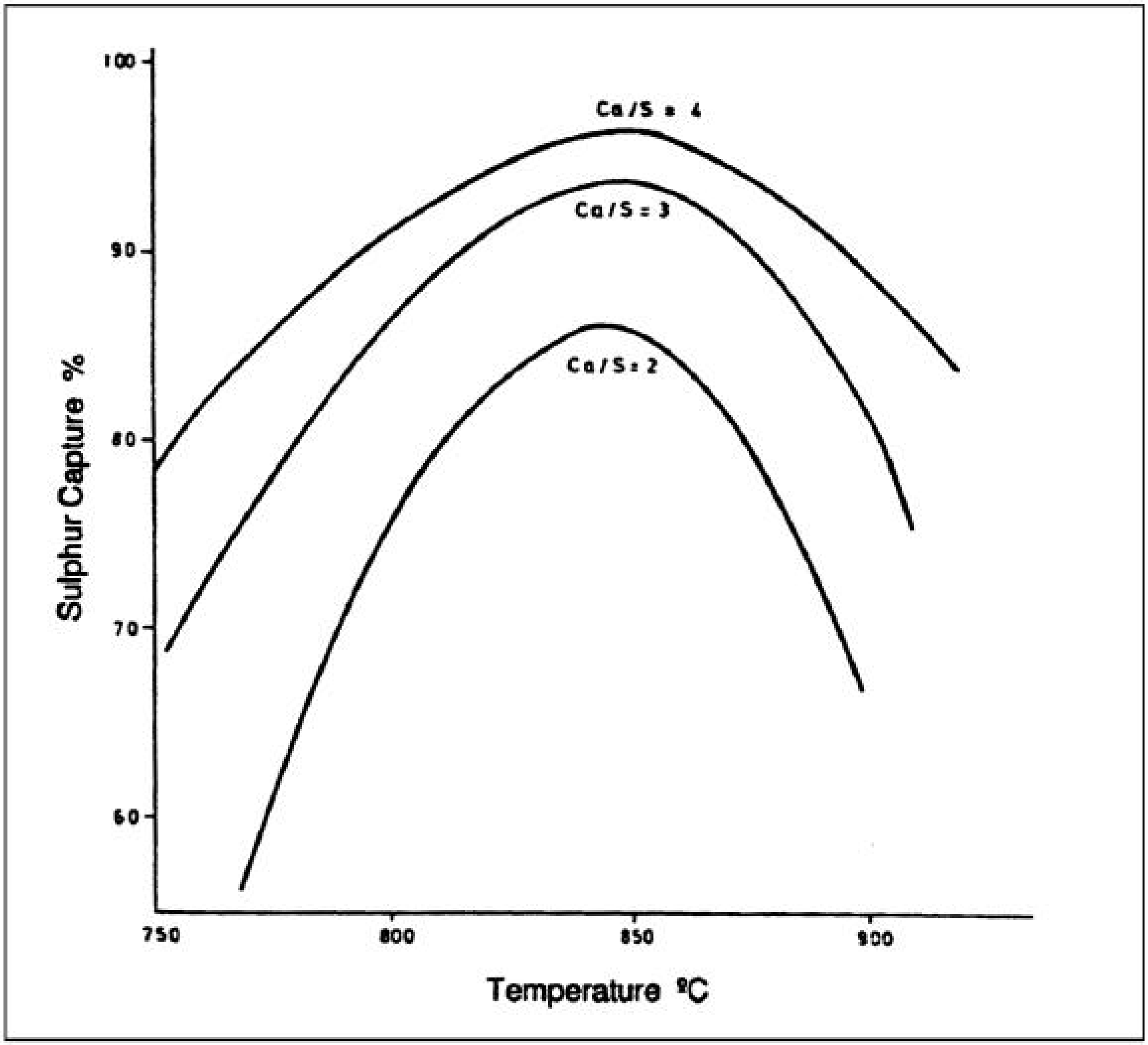
The calcination process begins at around 1,300°F (700°C) and, as with the sulfurization process, improves as temperature increases. The most favorable combination of calcination and sulfurization occurs, however, at about 1,550°F (840°C). Above this temperature, less-than-optimum porosity forms, limiting the sulfurization capacity of the lime particles. Exhibit 3-5 indicates the dependence of sulfur capture on temperature.

NO_x Reduction

NO_x emissions from an FBC boiler are generally less than 0.3 lb/million BTU (440 mg/Nm^3). Although at the low temperatures typical of FBC no atmospheric nitrogen is converted to NO_x, laboratory data have shown that nearly all of the fuel nitrogen is converted to NO_x during the burning process. For a typical coal containing 1 percent nitrogen, the potential NO_x release is roughly 3 lbs/million BTU (4,400 mg/Nm^3). Thus, secondary processes are responsible for the low NO_x emissions.

Carbon monoxide (CO) and char present in the bed are strong reducing agents and appear to be the principal factors in lowering NO_x. These agents strip oxygen from the NO_x in a reduction reaction that produces elemental nitrogen (N_2).

EXHIBIT 3-5
TEMPERATURE DEPENDENCE OF SULFUR CAPTURE



Source: Foster Wheeler Energy Corporation.

Additional NO_x reduction can be achieved by injection of ammonia (NH_3) into the gas stream leaving the furnace, as indicated below.

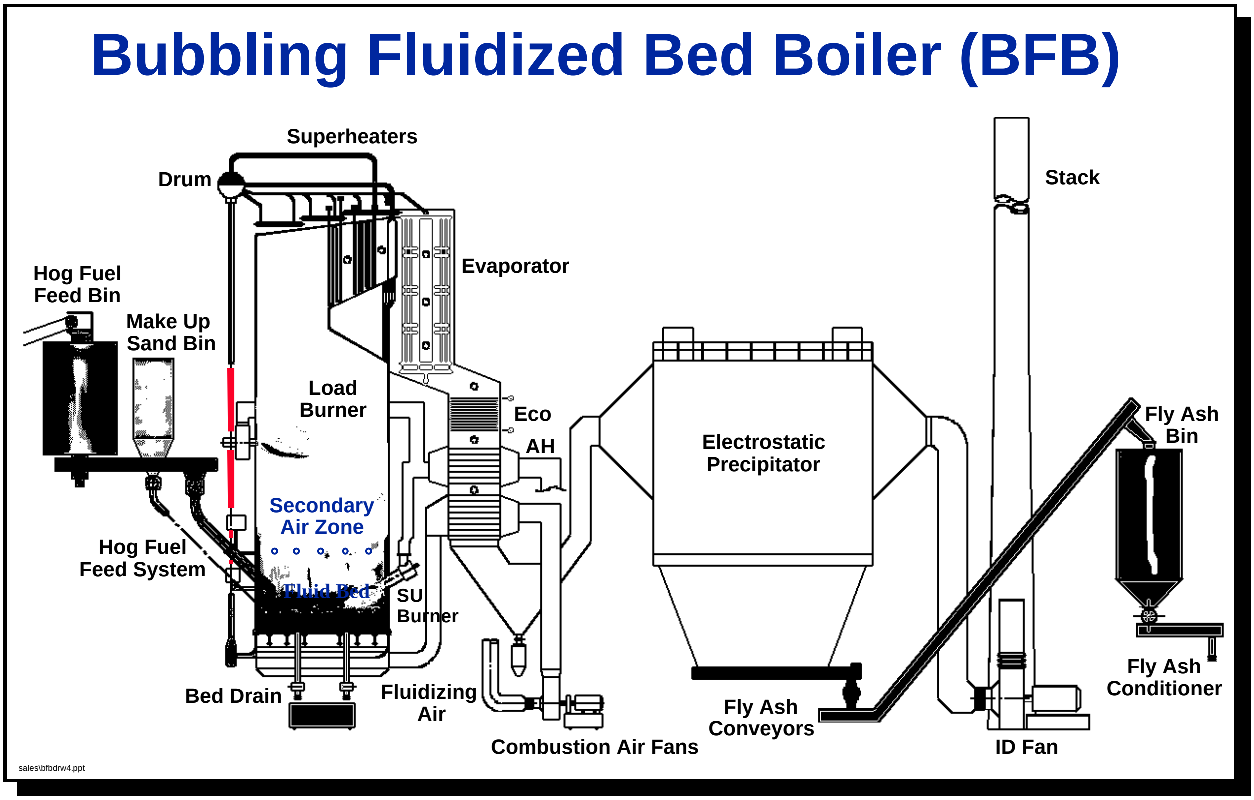
$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O \tag{3}$$

NO_x emissions can then be lowered to 0.1 lb/million BTU (150 Mg/Nm^3) and lower.

Bubbling Fluidized-Bed (BFB) Steam Generators

Exhibit 3-6 shows a typical BFB steam generator. Fuel is fed mechanically to the lower portion of the furnace above the surface of the bed. Primary air is supplied to the bottom of the furnace through an air distributor, with secondary air fed through one or more elevations of air ports above the bed.

EXHIBIT 3-6



Source: Foster Wheeler Energy Corporation.

Devolatilization, or gasification of the fuel, takes place in the bed. Combustion of the gases takes place above the bed. Flue gas leaves the furnace and passes over the various heat transfer surfaces such as a superheater, generating bank, economizer, and/or air heater.

Solids inventory in the furnace is controlled by draining hot solids through drains. Tramp material such as rocks can be removed from the bed by controlling the draining rate or frequency.

Early on, the BFB technology was used for firing 100 percent coal. Because the coal burns mainly within the bed, a heat transfer surface in the form of in-bed tubing cooled with water and/or steam, was needed to control bed temperature to the desired level. The experience with in-bed tubing has been mixed, with some units needing frequent maintenance. Today, BFB technology is mainly used for biomass and coal firing is limited to 30-40 percent heat input. Because biomass burns both within and above the bed, no in-bed tubing is needed.

Process Design

Design combustor velocity above the bed is established at 10 - 15 ft/sec (3 - 4.5 m/sec). This velocity level provides a reasonable amount of furnace heat-transfer surface for a given height, low erosion rates, and an acceptable turndown range with adequate bed stability. SO_2 emissions can be reduced by up to 50 percent at Ca/S molar ratio of 2-4 (depending on fuel sulfur levels, limestone reactivity, etc.).

Part-Load Operation

Turndown is accomplished by reducing both fuel and air to the unit. In the process, grid and furnace velocity are kept above a minimum level in order to produce adequate mixing and fluidization for reasonable fuel combustion and to avoid severe temperature maldistribution and back sifting of bed material into the air plenum.

Start-up

Start-up is accomplished by means of start-up burners located in the lower furnace walls and/or in the primary air duct. The start-up burners fire oil or gas. Minimum primary air flow is established and the start-up burners are used to heat the bed material. When solid-fuel permissive temperature is reached (typically 1,000°F to 1,100°F (540°C to 600°C)), solid fuel is added. Temperature is further increased by adding solid fuel and backing out start-up fuel. At about 25 percent load, the boiler can run on solid fuel alone.

BFB System and Components

The following subsections describe the major subsystems within the BFB boiler and discuss typical equipment and major performance criteria.

Fuel Preparation

Fuel preparation usually consists of one or more stages of crushing, with the system design and layout dependent on such fuel characteristics such as moisture and ash content, and required fuel sizing. Disc scalpers or other such screening devices are used to screen the oversize and tramp material with the oversize fuel being recycled through the fuel preparation system.

Sorbent Preparation

Sorbent can be purchased to the correct size specification, or can be crushed on site. Sizing equipment usually consists of a crusher, dryer (to limit moisture in the crushed product), and a storage bin.

Fuel Feed

The solid fuel feed system usually consists of a gravimetric or volumetric feeder and a fuel chute or pipe leading to the side of the lower furnace. Fuel from a rotary valve is fed by gravity and air assist into the furnace. The rotary valve forms the pressure seal between furnace and feeder.

Oil and gaseous fuels for load carrying are fired in burners located in the upper furnace. Full load can thus be obtained on liquid or gaseous fuels with adequate burner capacity. Oil or gas fuel feed can be initiated very quickly on a switch from solid fuel to liquid/gas, or to regain load in the event of a temporary loss of a portion of the solid fuel supply.

Sorbent Feed

The sorbent feed system usually consists of a day bin for storing sized limestone, followed by a rotary airlock feeder which drops the sorbent into a pneumatic conveying line for transport to the lower furnace. Gravimetric feeders can be used for a more accurate measurement of limestone flow. To provide the desired number of feed points, multiple bin outlets and feed systems can be used or the conveying line from a given feed system can be split. The sorbent also can be mixed with the fuel just before entering the furnace.

Sand Feed

In a solid fossil fuel based system without sorbent injection, sand is used to maintain the bed inventory if sufficient ash is not contained in the fuel to maintain mass flow through the unit and the design level of heat transfer. In the case of biomass fuels, sand forms the bulk of the bed material, because the biomass itself contains little ash. The sand feed system consists of a day bed storing sized sand feeds, a rotary feeder and a feed chute dropping the sand onto the bed by gravity. The feed rate is determined by the attrition rate, with the goal of maintaining the desired bed inventory.

Air Supply

Primary and secondary air are supplied to the furnace by separate centrifugal fans, generally arranged in parallel. Either or both of these streams may be preheated in an air heater, depending on the design feedwater and stack temperatures, and the economics of air-heater heat recovery versus heat recovery by water or steam heating surface.

Fluidizing-air nozzles are provided in the bottom of the furnace for proper distribution of fluidizing air. These nozzles are designed to minimize pressure drop, erosion and backsifting of solids into the air supply system.

Furnace

The BFB furnace consists of two zones: lower and upper. The lower furnace is that portion containing the bed, primary-air distributor, secondary-air ports, fuel feed ports, and bed drains. Physically, this section is usually rectangular, formed from finned waterwall tubing, and lined with refractory to protect the tubing from erosion by the bed. The optimum refractory lining is hard (to minimize erosion) and thin (to minimize weight).

The upper furnace, the section above the highest level of air distribution parts, provides retention time for complete combustion and cools the flue gas to the design furnace outlet temperature. The load carrying burners also are located in the upper furnace. Because all air has been fed in the lower furnace, the upper furnace operates under excess-air (oxidizing) conditions. Physically, this section is usually rectangular, straight-walled, formed from finned or fusion-welded waterwall tubing, and unlined to maximize heat absorption.

The air distributor (grid) containing the air nozzles is water-cooled. Water-cooling the grid provides a seal-welded, gas-tight furnace, and minimizes the size (and thus the maintenance concerns) of expansion joints connecting the primary-air ducts to the furnace.

The walls of the furnace (as well as the grid and plenum, when water-cooled) are cooled by thermo-siphonic (natural) circulation.

Convective Pass

The convective pass is of similar design as used in a pulverized-fuel or stoker-fired boiler. The enclosure walls are usually formed from finned or fusion-welded tubing, and are steam or water-cooled. Where gas temperatures are sufficiently low, duct plate can be used to form the enclosure.

The convection pass can contain the superheater, boiler bank, and economizer surface. Gas velocities are kept low to avoid erosion from the relatively high dust loading. Retractable or rotary sootblowers can be used to keep heat-transfer surfaces clean.

Air Heater

The size or presence of an air heater is based strictly on economics, because preheated air is not needed by the process, except with extremely wet and low heating value fuels. Generally, two separate air heaters are provided, one for primary air and one for secondary air. These can be arranged in series or in parallel with the gas stream.

Tubular air heaters are the most common design for BFB applications using a gas-over-tube/air-through-tube design. The flue gas passes over the tubes and, because the tubes are arranged in-line, they can be easily cleaned with sootblowers.

To protect the air heater from corrosion caused by condensation of flue gases during some operating conditions, such as start-up or low ambient air temperatures, steam preheating, hot-water preheating, or an air bypass is usually provided.

Bed Draining/Cooling

The main function of the bed draining system is to remove tramp material such as rocks and other oversize material. In a BFB, accumulation of such material can produce poor performance. The oversize material poses the greatest problem for the fuel handling and feeding equipment, and the highest plant availability will result from removal of the oversize material (rocks, iron, tramp, etc.) from the fuel stream. Six to twelve bed drains, depending on unit size, is usually sufficient.

Bed classifiers also may be used to remove oversize material, with the undersize material being reinjected back to the bed in order to reduce the consumption of make up sand. Reinjection of classified bed material may be limited, however, due to fuel characteristics such as high alkali levels.

The drained bed material can be cooled from furnace temperature (1,500°F to 1,700°F) to between 250°F and 450°F (120°C to 230°C), using a water-cooled screw before entering the bed drain conveying system. Cooled bed material from the screw cooler passes to the bed material handling system for transport to storage using mechanical or pneumatic conveying systems.

Fly Ash Removal System

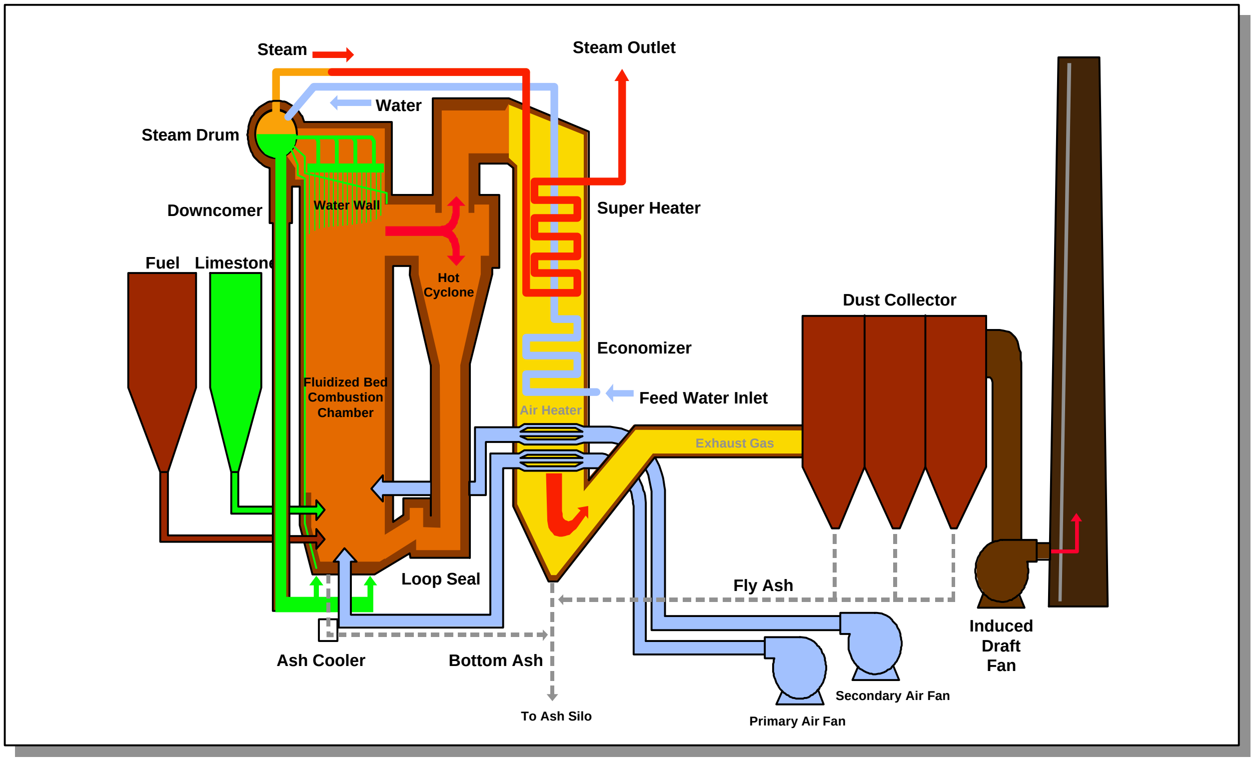
Electrostatic precipitators (ESP) and fabric filters (baghouse) are used for final particulate clean up. Fly ash from the economizer and air-heater hoppers is normally collected and handled with the bed material. The fly ash from the ESP or fabric filter is typically handled with a vacuum pneumatic system, although mechanical conveyors are also used to transport ash to storage. No ash cooling is necessary.

Circulating Fluidized-Bed (CFB) Steam Generators

Exhibit 3-7 shows a typical CFB steam generator. Crushed fuel and sorbent are fed mechanically or pneumatically to the lower portion of the furnace. Primary air is supplied to the bottom of the

EXHIBIT 3-7

CFB System Flow Chart



Source: Foster Wheeler Energy Corporation.

furnace through an air distributor, with secondary air fed through one or more elevations of air ports in the lower furnace. Combustion takes place throughout the furnace, which is filled with bed material. Flue gas and entrained solids leave the furnace and enter one or more particle separators where the solids are collected and fall to a loopseal. From the loopseal, the solids are recycled to the furnace.

Bed temperature in the furnace is essentially uniform and is maintained at an optimum level for sulfur capture and combustion efficiency by heat absorption by the walls of the furnace. Flue gas leaving the separators passes to a convection pass, air heater, baghouse, and induced draft (ID) fan. Solids inventory in the furnace is controlled by draining hot solids through an ash cooler.

Process Considerations

CFB conditions (also called *fast fluidization* or *lean phase fluidization*) are achieved as fluidization velocity is increased past the bubbling regime (see Exhibit 3-4). CFB conditions are generally attained at velocities greater than 10 ft/sec (3 m/s) with a mean bed particle size smaller than 500 microns (0.020 inches). A large fraction of the bed mass is small enough to be entrained in the gas stream. This material must be collected and recycled to maintain bed inventory. In a CFB environment, the distinction between bed and freeboard found in a BFB has faded, and bubbles are no longer apparent. The pressure drop from the bottom to the top of the combustor follows a smoothly declining gradient, rather than the steep decline found in a BFB.

Even though the gas velocity is above the entrainment velocity of most particles in the bed, the entire bed is not entrained out of the furnace. This is because the particles tend to form "clusters" which break-up, reform, and move up and down within the furnace. (Clusters in a CFB are somewhat analogous to bubbles in a BFB.) The gas velocity is below the entrainment velocity of the cluster. The clusters thus allow maintenance of considerable bed inventory at normal CFB velocities, and also account for considerable internal bed recirculation. The entrained material is of a large enough size to be captured by a separator for transport back to the furnace. This process results in substantial external recycle and leads to excellent mixing and gas-solids contact with high performance in terms of combustion efficiency and sorbent utilization. Recycle ratios of 10 to 100 and greater are typical and are required to maintain the desired high solids concentration in the furnace. When firing a typical bituminous coal with flue-gas flow ten times the fuel flow, a recycle ratio of 10 provides a solids loading of 1 lb solids/lb gas at the furnace outlet, while a recycle ratio of 100 provides a solids loading of 10 lb solids/lb gas at the furnace outlet. At these solids loadings, the temperature is essentially uniform throughout the furnace and separator, and the mixing rates are extremely high. Because of the high mixing rates, only a simple fuel/sorbent feed system with a few feed points is required.

Process Design

Proper fuel feed size is extremely important to both operation and performance. If the feed is too coarse, there will be insufficient material in circulation, and reduced carbon burnout, sorbent utilization, and furnace heat transfer will result. Further, coarse material that resides in the lower furnace can induce undesirable pressure drops. If the feed is too fine, excessive material will be entrained in the gas flow from the furnace, thereby producing insufficient material in circulation in the bed and a resultant negative impact on performance.

In general, high-ash fuels must be crushed finer than low ash-fuels, for two reasons. First, high-ash fuels tend to decrepitate less and so smaller feed size is required to produce the optimum bed particle size. Second, if high-ash fuels are not adequately crushed, carbon will be encapsulated by ash and the carbon loss will be unnecessarily high. Very high ash fuels such as anthracite culm (which may contain up to 70-percent ash), are typically crushed to 1/4-inch (6mm) top size, while lower-ash fuels such as bituminous coals are typically crushed to ½-inch (12mm) top size. More reactive fuels such as lignites are typically crushed to 3/4-inch (18mm) top size.

Proper sorbent size also is important for good performance. Limestone is generally crushed to 1mm top size, though the optimum sizing depends on the actual decrepitation and sulfur capture characteristics of a given limestone.

Managing the particle size of both fuel and sorbent to achieve adequate solids circulation rates is critical to CFB performance, and must take into account feed particle size, ash content, decrepitation rates, and separator efficiency. The optimal bed particle size is that which can be circulated through the system at the design velocity. Larger particles must be drained from the furnace, while finer particles are carried through the separator. Fuel and sorbent feed size must be set to provide an adequate inventory of particles in this size range for acceptable furnace performance.

Within the furnace, gas/solids temperatures are typically maintained in the range of 1,550°F to 1,650°F (840°C to 900°C).

Design combustor velocity is generally established at 15-17 ft/sec (4.5 to 5 m/sec). This velocity level provides reasonable furnace heat-transfer surface for a given height, low erosion rates, and an acceptable turndown range with adequate bed stability.

Performance in terms of carbon burnout and emissions is excellent. For high-ash, low-reactivity fuels such as anthracite culm, carbon loss can be as low as 1 to 2 percent, while for high reactivity fuels such as lignite, carbon loss is typically below 0.5 percent. SO_2 emissions can be reduced below 100 ppm, with 90-percent SO_2 capture at Ca/S of 1.5 to 2.5 (depending on fuel sulfur levels, limestone reactivity, etc.). Sulfur capture above 95 percent has been required and achieved in several commercial plants. CO levels are generally in the range of 50 to 200 ppm. NO_x levels below 100 ppm are typical.

Part-Load Operation

Turndown, i.e., load reduction, is accomplished by reducing both fuel and air to the unit. In the process, grid and furnace velocity should be kept above a minimum level in order to produce adequate mixing and solids recirculation for reasonable fuel combustion and to avoid severe temperature maldistribution and backsifting of bed material into the air plenum.

Start-up

Start-up is accomplished by means of dedicated burners located in the lower furnace walls and/or in the primary air duct. The start-up burners fire oil or gas. Minimum primary air flow is established and the start-up burners are used to heat the bed material. When the required solid fuel temperature is reached (typically 1,000°F to 1,300°F (540°C to 700°C), for coal), solid fuel is added. Temperature is further increased by adding solid fuel and backing out start-up fuel. At about 30 percent load, the boiler can operate on solid fuel alone.

CFB System and Components

The following subsections describe the major components of the CFB boiler and discuss typical equipment and major performance criteria.

Fuel Preparation

Fuel preparation usually consists of one or more stages of crushing, with the system design and layout dependent on such fuel characteristics such as moisture and ash content, and required fuel sizing.

Many types of crushers, including impact, hammer, and cage mills, have been applied. Cage mills can limit the introduction of oversize material to the boiler, as the mills physically wear down fuel particles; feed size is varied by changing mill speed. Hammer mills have grate bars that can be moved for adjusting fuel sizing. Alternatively, air-swept crushers have been successfully applied, and they allow for direct pneumatic feed to the furnace. While air-swept crushers also strictly limit oversize material and allow adjustment of fuel sizing, they are usually more expensive than the other types.

Sorbent Preparation

Sorbent of the correct size specification can be purchased, or can be produced (crushed) on site. Sizing equipment usually consists of a crusher, a dryer to limit moisture in the crushed product, and a storage bin.

Fuel Feed

The solid-fuel feed system usually consists of a gravimetric or volumetric feeder and a fuel chute or pipe leading to the side of the lower furnace or to the solids return line from the loopseal to the furnace. Fuel from the feeder falls by gravity into the furnace. The feeder is pressurized with cold primary air, and the head of fuel in the standpipe of the feeder inlet forms the pressure seal between bin and feeder. At least one completely redundant feed system is recommended.

Alternatively, the fuel can be dropped into an air stream and injected pneumatically into the furnace. This approach promotes fuel dispersion in the furnace and offers the possibility of using secondary-air ports for fuel feed, thereby reducing the total number of openings required in the walls of the furnace.

Liquid and gaseous fuels needed for load carrying are fired in lances, which fuel feed pipes that carry only fuel plus an atomizing medium (but not combustion air), these are located in the lower furnace. The lance is intended to disperse the fuel within the bed, where it is combusted in the fluidizing air stream. Full load can thus be obtained on liquid or gaseous fuels with adequate lance capacity. Because these fuels have much shorter bed residence time than solid fuel, they require more feed points for proper fuel distribution and performance. The lances can be either retractable or stationary. In either case, lance fuel feed can be initiated very quickly on a switch from solid fuel to liquid/gas, or to regain load in the event of a temporary loss of a portion of the solid fuel feed system.

Sorbent Feed

The sorbent feed system usually consists of a day bin for storing sized limestone, followed by a rotary airlock feeder that drops the sorbent into a pneumatic conveying line for transport to the lower furnace. Gravimetric feeders can be used for a more accurate measurement of limestone flow. To provide the desired number of feed points, multiple bin outlets and feed systems can be used or the conveying line from a given feed system can be split. The sorbent also can be mixed with the fuel just before entering the furnace.

Air Supply

Primary and secondary air are supplied to the furnace by separate centrifugal fans, generally arranged in parallel. Either or both of these streams may be preheated in an air heater, depending on the design feedwater and stack temperatures, the economics of air heater heat recovery versus heat recovery by water or steam heating surface, and whether an air-swept mill is used. An alternative to this fan arrangement is two fans in series with the second fan supplying the higher-pressure primary air.

With an air-swept crusher, secondary air is generally used to operate the fuel mill. To overcome the pressure losses through the mill and conveying lines that result when using this arrangement, the air pressure may need to be slightly higher than it would otherwise.

Fluidizing air for the loopseal is supplied by either positive-displacement or centrifugal blowers. Depending on the flow rates, it may be economical to preheat these air streams in an air heater.

Fluidizing air nozzles are provided in the bottom of the furnace, loopseal and ash coolers (if needed) for the proper distribution of fluidizing air. These nozzles are designed to minimize pressure drop, erosion, and back sifting of solids into the air supply system.

Furnace

The CFB furnace corresponds to the furnace in a pulverized-fuel or stoker-fired boiler, and consists of two zones, lower and upper.

The lower furnace is that portion containing the fuel, primary-air distributor, secondary-air ports, fuel feed ports, and solids-recycle ports. The density of the bed in this region is relatively high, on average, being highest at the elevation of the air distributor and dropping off rather rapidly with increasing furnace height. Due to the staged air feed, this region is also substoichiometric. Physically, this section is usually rectangular, tapered, formed from finned or fusion-welded waterwall tubing, and lined with refractory to protect the tubing from erosion by the dense bed and corrosion in the substoichiometric atmosphere. The optimum refractory lining is hard (to minimize erosion), thin (to minimize weight), and reasonably conductive (to maximize furnace heat absorption).

The upper furnace, the section above the refractory-lined lower furnace, contains the gas outlet or outlets to the separators. The density of the bed in this region is relatively low, and drops off very slowly with increasing height. Because all air has been fed in the lower furnace, the upper furnace operates under excess-air (oxidizing) conditions. Physically, this section is usually rectangular, straight-walled, formed from finned or fusion-welded waterwall tubing, and unlined to maximize heat absorption.

The air distributor (grid) containing the air nozzles can be uncooled or water-cooled, as can the air plenum below the grid. Water-cooling the grid and plenum provides a seal-welded, gas-tight furnace, and minimizes the size (and thus the maintenance concerns) of expansion joints connecting the primary-air ducts to the furnace.

Solids Separator

One or more separators are used to collect the solids entrained in the gas leaving the furnace. Separators are designed to collect essentially all particles with a diameter greater than about 100 microns (0.004 inches). Given the relatively large particle sizing entering the separator, the separation efficiency is typically over 99 percent. A *vortex finder* (also called a *re-entrant throat*) is usually added to the separator gas outlet to improve the collection efficiency.

The separator can take many forms. Typically a cyclone is used, constructed of steel plate with a multiple-layer refractory lining. Alternate construction uses water or steam-cooled tubing to form the cyclone case. Other separator configurations are used, including impact separators.

Loopseal

The loopseal is a non-mechanical valve that moves the solids collected by the separator back into the furnace against the furnace back pressure. Solids flow down on the inlet side, up the outlet side, then back to the furnace. The bottom portion of the seal is fluidized so that material in the seal can seek different levels on each side of the seal, with the difference in level corresponding to the pressure difference across the seal. Then, solids entering the seal inlet displace previously collected solids out of the seal on the outlet side.

The loopseal is usually constructed of steel plate or pipe with a multiple-layer refractory lining. Fluidizing nozzles along the bottom of the seal provide the fluidizing air.

Convective Pass

The convective pass is of the same basic design as used in a pulverized-fuel or stoker-fired boiler. The enclosure walls are usually formed from finned or fusion-welded tubing, and are steam- or water-cooled. In configurations in which gas temperatures are sufficiently low, carbon steel duct plate can be used to form the enclosure.

The convection pass can contain superheater, reheater, boiler bank, and/or economizer surfaces. Gas velocities are kept low to avoid erosion from the relatively high dust loading. Retractable or rotary sootblowers can be used to keep heat-transfer surfaces clean.

Air Heater

The size of the air heater is based strictly on economics, because preheated air is not needed by this process. The exception to this general statement is when an air-swept mill is used and preheated air is needed for fuel drying. Generally, two separate air heaters are provided, one for primary air and one for secondary air. These can be arranged either in series or in parallel with the gas stream.

Tubular air heaters are the most common design for CFB applications, and generally involve a gas-over-tube/air-through-tube design. The dust-laden flue gas passes over the tubes and, because the tubes are arranged in-line, they can be easily cleaned with sootblowers. Gas-through/air-over design tubular air heaters, though somewhat more difficult to clean, also have been used successfully.

To protect the air heater from corrosion caused by condensation of flue gases during some operating conditions, such as start-up or low ambient air temperatures, steam preheating, hot-water preheating, or an air bypass is usually provided.

Ash Removal/Cooling

The ash streams consist of the fuel ash, products of the limestone sulfur capture (CaO, $CaSO_4$), and a small amount of carbon, with the relative amounts depending on the fuel sulfur content, sulfur capture required, limestone reactivity, process conditions, etc. The ash-removal system includes both the bottom ash and fly ash systems.

Bottom Ash Removal System

The main function of the bottom ash system is to control bed inventory. Bed pressure drop is monitored as a measure of inventory, and bottom ash flow is adjusted to maintain the desired bed pressure drop. The bottom ash system also can help control accumulation of oversize material. In a CFB, such accumulation can produce an unfavorable pressure profile, with most of the material in lower furnace and little in the upper furnace, resulting in poor performance. One or two ash drains per furnace is usually sufficient.

Ash classifiers also may be used, to remove oversize material and to adjust the pressure profile, without requiring excessive bottom-ash flow rates. Such classifiers can operate continuously or in batch mode, and can also cool the ash.

The bottom ash must be cooled from furnace temperature (1,550°F to 1,700°F, 816°C to 900°C) to between 250°F and 450°F (120°C to 230°C), before entering the bottom ash conveying system. On high-ash fuels, the heat in the bottom ash stream may represent a significant percentage of boiler heat input. Consequently, it can be desirable to recover this heat. Fluidized bed ash coolers (FBAC's) are generally used for this purpose. The FBAC is essentially a BFB heat exchanger. Cooling coils immersed in the bed cool the ash and transfer heat to condensate or boiler feedwater. Water cooled screw coolers also are employed for bed ash cooling.

Cooled ash from the ash cooler passes to the bottom ash handling system for transport to storage using pressure pneumatic, vacuum pneumatic, or mechanical conveying systems.

Fly Ash Removal System

Fabric filters (baghouse) and electrostatic precipitators (ESPs) are used for final particulate matter clean up.

Fly ash from the economizer and air-heater hoppers and the fabric filter or ESP is typically handled with a vacuum pneumatic system, although mechanical conveyors also are used. No ash cooling is necessary. The bottom ash and fly ash streams can be stored for subsequent management together in the same silo or in separate silos.

3.4 Comparison of Combustion Systems

The following comparison of combustion systems is based on the discussion contained in Chapter 16 of *Steam: its generation and use, 40th Edition,* published by Babcock and Wilcox, Barberton, Ohio.

The FBC process, as with other firing methods, provides a means for mixing fuel with air to convert the chemical energy contained in the fuel into recoverable, sensible heat. Although FBCs are normally used to burn solid fuels, they also can be used to burn gas and liquid fuels.

In a PC fired furnace, the combustion process consists of oxidizing fine (70 percent less than 200 mesh), widely dispersed fuel particles suspended in air and combustion gases. The volume around the burners is the hottest zone in the furnace with temperatures reaching 3,000 to 3,500°F (1,649 to 1,927°C) which is significantly above the ash melting temperature. The average furnace temperature is in the range of 2,200 to 2,800°F (1,204 to 1,538°C). The residence time of the fuel particles in the furnace is close to the flue gas residence time (1 to 2 seconds).

Stoker firing uses considerably larger fuel particles than PC firing. Fuel sizing is typically 1 to 1.25 inches (25.4 to 31.8 mm) top size for bituminous coal. Most of the fuel is burned as an immobile mass on some type of moving grate, with the air and combustion gases passing through the fixed bed of fuel. Temperatures in the fuel bed may exceed 3,000°F (1,649°C), but are designed based on the fuel ash fusion temperatures and combustion characteristics. Temperatures are again above the ash softening and melting temperatures needed to fuse the ash. The average furnace temperature is in the range of 2,000 to 2,500°F (1,093 to 1,371°C).

The FBC process falls in between pulverized and stoker firing with respect to the size of the fuel feed. Coal is typically crushed to less than 0.25 inches (6.4 mm). Depending on the fuel properties, a larger (1.25 inch (31.8 mm)) or smaller (0.125 inch (3.18 mm)) fuel size may be used. Fuel is fed into the lower portion of a FBC furnace. The bed has a density of approximately 45 lb/ft^3 (721 kg/m^3) for a BFB and 35 lb/ft^3 (561 kg/m^3) for a CFB. The solids are maintained at a temperature of 1,500 to 1,700°F (816 to 900°C) in an upwardly moving stream of air and combustion gas.

When fuel is introduced into the bed it is quickly heated above its ignition temperature, ignites and becomes part of the burning mass. The flow of air and fuel to the dense bed is controlled so that the desired amount of heat is released to the furnace on a continuous basis. Typically, the fuel is burned with 20 percent excess air. Due to the long fuel residence time and high intensity of the mass transfer process, the fuel can be efficiently burned in the FBC at temperatures considerably lower than in conventional combustion processes. The temperatures in the FBC process are generally below the ash melting temperature for most fuels.

The fuel particles remain in the dense bed until they are entrained by combustion gas or removed with the bed drain solids (bottom ash). As the fuel particles burn, their size falls below a given value where the terminal and gas velocities are equal, which allows them to be entrained. Therefore, the residence time is determined by the initial fuel particle size and by the reduction of the initial size resulting from combustion and attrition.

In BFB, combustion occurs mostly in the bed due to lower gas velocity and coarser fuel feed size. The residence time of the fine fuel particles carried out of the bed with the combustion gas is, in many cases, increased by collecting and recycling the particles to the furnace.

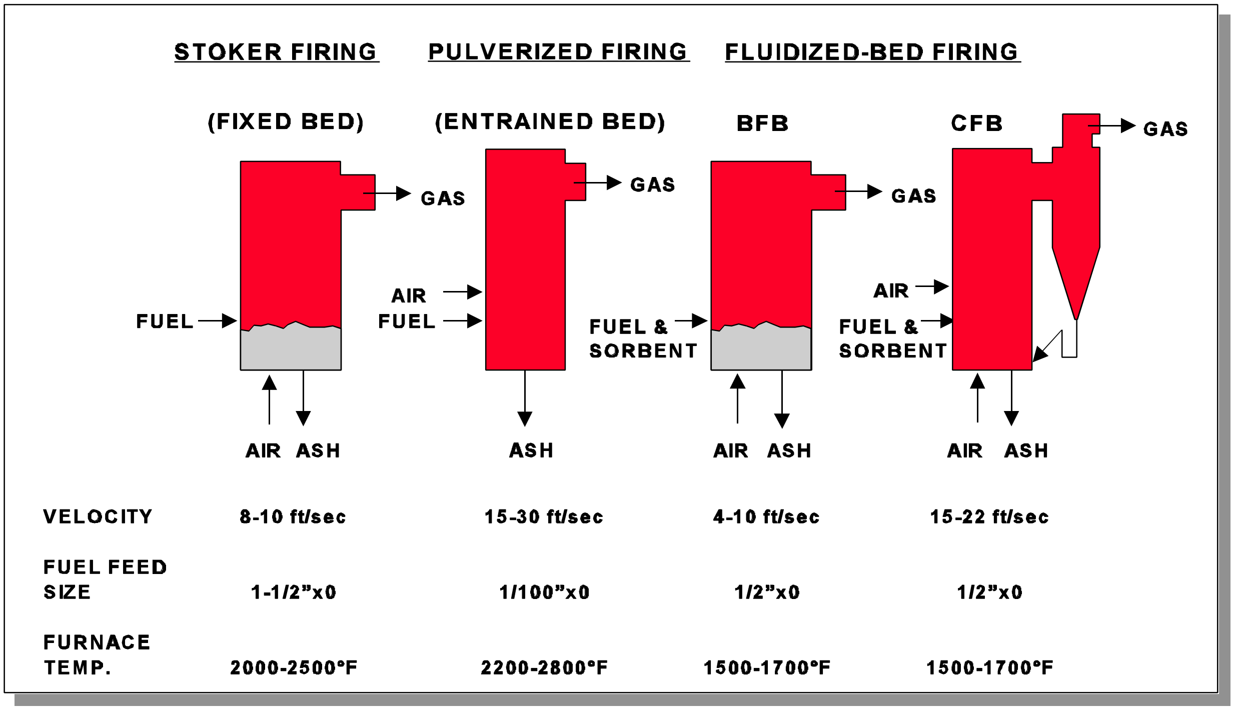
In CFB, more particles are blown from the bed (elutriated) than in a BFB. The particles are then collected by a particle separator and recirculated to the furnace. The residence time of the particles is determined by the collection efficiency of the particle separator and the solids circulation rate. As a result of the recirculation process, the effective fuel particle residence time greatly exceeds the gas residence time.

The concentration of fuel in the dense bed is normally quite low. For a reactive fuel such as wood, it is difficult to find a measurable amount of carbon in the bed. Normally, the carbon content in a bed burning bituminous coal is less than 1 percent. The remaining portion of the bed is made up of fuel ash, lime and calcium sulfate when a sorbent is used for sulfur capture, and sand or other inert material when a sorbent is not used.

Exhibit 3-8 summarizes these major differences between the various combustion technologies. Appendix C provides general comparisons of several significant applications of these technologies in various commercial and industrial settings. Some of these have previously been studied in depth by the EPA.

EXHIBIT 3-8

General Comparison of Combustion Technologies



	STOKER FIRING (FIXED BED)	PULVERIZED FIRING (ENTRAINED BED)	FLUIDIZED-BED FIRING BFB	FLUIDIZED-BED FIRING CFB
VELOCITY	8-10 ft/sec	15-30 ft/sec	4-10 ft/sec	15-22 ft/sec
FUEL FEED SIZE	1-1/2"x0	1/100"x0	1/2"x0	1/2"x0
FURNACE TEMP.	2000-2500°F	2200-2800°F	1500-1700°F	1500-1700°F

Source: Foster Wheeler Energy Corporation.

3.5 Air Pollution Control Technologies

This section provides an overview of air pollution control technologies that can be applied to utility and non-utility operated combustion systems. The purpose of this section is to provide the reader with a basic background in air pollution control technologies and an appreciation of how the various technologies will affect the combustion byproducts that are of interest in this pending Bevill determination.

The following synopsis of air pollution control technologies is based on the discussion contained in Chapter 32 of *Steam: its generation and use, 40th Edition*, published by Babcock and Wilcox, Barberton, Ohio.

SO_2 Control Strategies and Technologies

Sulfur dioxide emissions from coal-fired boilers can be reduced using pre-combustion techniques, combustion modifications, and post-combustion methods.

Pre-combustion techniques include the use of cleaned (beneficiated) coal or fuel switching in existing units. Beneficiated coal has a lower sulfur content due to removal of pyrites in the coal. Fuel switching can include the use of a lower sulfur coal, such as changing from a high-sulfur Illinois Basin coal to, for example, say a low-sulfur Powder River Basin coal.

Combustion modifications are principally used to control NO_x emissions. In the case of FBC systems, however, limestone [calcium carbonate ($CaCO_3$)] may be used as a bed material to control SO_2 emissions. The limestone can absorb more than 90 percent of the sulfur released during the combustion process. The solid combustion byproducts (fly ash and bottom ash) contain the fuel ash, lime (CaO) and calcium sulfate ($CaSO_4$) from the desulfurization process occurring in the FBC unit. For additional details on this process refer to the discussion in Section 3.3 entitled Chemical Reactions.

Sorbent injection is not a combustion modification, though it is applied in temperature regions ranging from those just outside the combustion zone in the upper furnace to those at the economizer and duct work following the air heater. Sorbent injection involves adding alkali compounds to the coal combustion gases for eventual reaction with SO_2. Typical calcium sorbents include limestone ($CaCO_3$), lime (CaO), hydrated lime ($Ca(OH)_2$), and of these compounds augmented with special additives. Sodium based compounds also are used. The manner in which injected sorbents react with sulfur oxides and the efficiency of the process depend on the temperature at the point of injection, sorbent type, sorbent surface area, and molar ratio of the sorbent to sulfur. As in the case of limestone injection in a CFB, the fly ash from a conventional combustion system using sorbent injection will contain the fuel ash, unreacted sorbent and the desulfurization product (a calcium or sodium and sulfur compound, depending on the sorbent used).

Wet and dry scrubbing technologies use slurries of water and sorbent to react with SO_2 in the flue gas, producing wet and dry waste products, respectively.

In the wet scrubbing process, a sorbent slurry consisting of water mixed with lime, limestone, magnesium promoted lime, or sodium carbonate (Na_2CO_3) is contacted with flue gas in a reactor vessel. Wet scrubbing is a highly efficient (greater than 90 percent sulfur capture at calcium/sulfur molar rations close to 1.0), well established technology that can produce usable byproducts.

Dry scrubbing involves spraying an aqueous sorbent slurry into a reactor vessel so that the slurry droplets dry as they contact the hot flue gas [~300°F (~149°C)]. The SO_2 reaction occurs during the drying process and results in a dry material containing reaction products and unreacted sorbent entrained in the flue gas, along with the fuel fly ash. These materials are captured downstream in the particulate control equipment.

NO_x Control Technologies

Nitrogen oxide emissions from fossil fuel-fired industrial and utility boilers arise from the nitrogen compounds in the fuel and molecular nitrogen in the air supplied for combustion. Conversion of molecular and fuel nitrogen into NO_x is promoted by the high temperatures and high volumetric heat release rates found in boilers. The main strategies for reducing NO_x emissions take two forms: 1) modification of the combustion process to control fuel and air mixing and reduce flame temperatures, and 2) post combustion treatment of the flue gas to remove NO_x.

Combustion modifications to reduce NO_x emissions can include the use of low NO_x burners, combustion staging, gas recirculation, or reburning technology. Post-combustion treatment include selective non-catalytic reduction and selective catalytic reduction. Both of these latter processes use ammonia or an ammonia compound to react with the NO_x.

Particulate Control Technologies

Particulate emissions from boilers arise from the noncombustible ash-forming mineral matter in the fuel that is released during the combustion process and is carried by the flue gas to the stack. Another source of particulate emissions is the incomplete combustion of the fuel, which results in unburned carbon particles.

The principal mechanical collectors used are cyclones which have been widely used on small boilers when less stringent particulate emission limits are applied. Cyclones are low cost, simple, compact, and rugged devices. Conventional cyclones are, however, limited to collection efficiencies of about 90 percent and are poor at collecting the smallest particles.

Fabric filters, also commonly referred to as baghouses, are available in a number of designs (reverse air, shake/deflate and pulse jet, referring to the cleaning method used to clean the filter), each of which has advantages and disadvantages in various applications. Applications include industrial and utility power plants firing coal or solid wastes, plants using sorbent injection and dry scrubbing FGD, and FBC units. Collection efficiency can be expected to be at least 99.8 percent or greater. Fabric filters have the potential for enhancing SO_2 capture in installations downstream of sorbent injection and dry scrubbing systems.

Electrostatic precipitators are available in a broad range of sizes for utility and industrial applications. Collection efficiency can be expected to be 99.8 percent or greater of the inlet dust loading. ESPs also have very low pressure drops. Power consumption of ESPs and fabric filters tend to be similar because the high fan power needed to overcome the higher fabric filter pressure drop is approximately equal to the power consumed by the ESP transformer rectifier sets. ESP performance is sensitive to fly ash loading, ash resistivity, and coal sulfur content.

CHAPTER FOUR

FOSSIL FUEL COMBUSTION BYPRODUCT GENERATION AND CHARACTERISTICS

4.0 Introduction

As discussed in Chapter 3, the fluidized bed combustion (FBC) process results in the generation of two combustion by-products: bottom (or bed) ash and fly ash. These ash streams consist of the fuel ash, products of the limestone sulfur capture (CaO, $CaSO_4$), carbon, various oxides, and trace metals; the exact composition of these streams is dependent on fuel type. This chapter presents information on ash generation rates and characteristics and describes the physical and chemical characteristics of FBC combustion byproducts. This chapter also presents information on the generation of ancillary wastes.

4.1 Fossil Fuel Characteristics

Based on the results of the Special Project Survey, 60 percent (26/43) of the respondents use coal as their primary fuel: bituminous coal (20/43), sub-bituminous coal (4/23), or lignite coal (2/43). The remaining respondents use anthracite culm (6/43), bituminous gob (5/23), petroleum coke (5/43), or natural gas (1/43) as their primary fuels. Exhibit 4-1 summarizes primary fuel usage by respondent facilities. Exhibit 4-1 also summarizes respondent fuel type usage for secondary, flame stabilization, and start-up purposes.

Exhibit 4-2 summarizes the total quantity of each type of fuel used - by purpose, as reported by the survey respondents. As shown below, usage of bituminous coal (bituminous coal, sub-bituminous coal, and bituminous gob) account for 67 percent (11,780,802/17,559,150 tons) of the primary fuel used by the respondents. Exhibit 4-3 provides a summary description of the various types of fossil fuels used by the survey respondents.

The major elemental components of coal are carbon, hydrogen, oxygen, nitrogen, and sulfur. Empirical formulas have been found to range from $C_{75}H_{140}O_{56}N_2S$ for a low grade peat to $C_{240}H_{90}O_4NS$ for a high grade anthracite coal. These formulas exclude the ash content of the coals, which ranges from 3 percent to 30 percent. The variations in the coal formulas and in the ash content can be attributed to the physical, chemical, and geological conditions under which coal formation occurred. In addition to the major organic ingredients (carbon, hydrogen and oxygen) coal also contains impurities. The impurities occurring in coal may be classified broadly into those that form ash and those that contribute sulfur. Other impurities occur but are of little importance in U.S. coals. However, the impurities that are of major concern are ash and sulfur, and they may exist as

EXHIBIT 4-1

NUMBER OF FACILITIES AND BOILERS USING SPECIFIC FUELS — 1995

FUEL	PRIMARY		SECONDARY		STABILIZATION		START-UP		TOTAL FACS	TOTAL UNITS
	Facs	Units	Facs	Units	Facs	Units	Facs	Units		
Anthracite Coal			1	3	1	1			2	4
Bituminous Coal	20	42	3	7					23	49
Culm	6	9							6	9
Gob	5	11							5	11
Lignite Coal	2	3							2	3
Natural Gas	1	1	2	2	1	1	18	26	22	30
Oil			4	7	2	2	12	18	18	27
Petroleum Coke	5	8	3	3					8	11
Propane					1	1	3	3	4	4
Sub-Bituminous Coal	4	7							4	7
Tires			3	8					3	8
Wood [1]			3	10					3	10
TOTAL	43	81	19	40	5	5	33	47		

[1] One facility reported using rail road ties as its primary fuel; this facility was removed because wood is not defined as a fossil fuel.

EXHIBIT 4-2

MASS (TONS) OF SPECIFIC FUELS USED IN BOILERS — 1995

FUEL	PRIMARY	SECONDARY	STABILIZATION	START-UP	TOTAL
Anthracite Coal		0	536		536
Bituminous Coal	7,384,624	65,386			7,450,009
Culm	2,604,863				2,604,863
Gob	2,089,268				2,089,268
Lignite Coal	2,086,227				2,086,227
Natural Gas	191,601	147,823	418	2,158,016	2,497,858
Oil		167	1,335	71,108	72,610
Petroleum Coke	895,658	125,400			1,021,058
Propane			73	1,949,569	1,949,642
Sub-Bituminous Coal	2,306,910				2,306,910
Tires		55,048			55,048
Wood		6,056			6,056
TOTAL	17,559,150	399,879	2,362	4,178,694	22,140,085

EXHIBIT 4-3

SUMMARY DESCRIPTIONS OF FOSSIL FUELS USED BY THE RESPONDENTS

- *Anthracite*. Anthracite, the highest rank of coal, is shiny black, hard and brittle, with little appearance of layers. It has the highest content of fixed carbon, 86 to 98%. However, its low volatile content makes it a slow burning fuel. Most anthracites have a very low moisture content of about 3% and heating values of 15,000 Btu/lb (34,890 kJ/kg). Anthracite is low in sulfur and volatiles and burns with a hot, clean flame. These qualities make it a premium fuel used mostly for domestic heating."

- *Bituminous*. Bituminous coal is the rank most commonly burned in electric utility and non-utility boilers. In general, it appears black with banded layers of glossy and dull black. Typical bituminous coals have heating values of 10,500 to 14,000 Btu/lb (24,423 to 36,053 kJ/kg) and a fixed carbon content of 69 to 86%. The heating value is higher but moisture and volatile content are lower than the sub-bituminous and lignite coals. Bituminous coals rarely experience spontaneous combustion in storage. Furthermore, the high heating value and fairly high volatile content enable bituminous coals to burn easily when pulverized to a fine powder. Some types of bituminous coal, when heated in the absence of air, soften and release volatiles to form the porous, hard, black product known as *coke*. Coke is used as fuel in blast furnaces to make iron.

- *Culm*. Culm or anthracite coal refuse is the byproduct of the coal cleaning processes that are used to separate anthracite coal from impurities in the coal seam or that are added during the mining process. Culm is a heterogeneous material containing small amounts of: misplaced anthracite coal; bone coal which is anthracite coal with a relatively high percentage of ash; carbonaceous shale, shale, clay and small amounts of pyrite.

- *Gob*. Gob, or bituminous coal refuse, is also a heterogeneous material which contains small amounts of bituminous coal created by the coal cleaning process. Gob contains; misplaced bituminous coal; bone coal which is bituminous coal with a relatively high percentage of ash; carbonaceous shale, shale, clay and pyrites. Gob also tends to contain more sulfur than culm since bituminous coal is inherently higher in sulfur than anthracite coal.

- *Peat*. Peat, the first product in the formation of coal, is a heterogeneous material consisting of partially decomposed plant and mineral matter. Its color ranges from yellow to brownish black, depending on its geologic age. Peat has a moisture content up to 70% and a heating value as low as 3,000 Btu/lb (6,978 kJ/kg).

- *Petroleum coke.* Petroleum coke consists of the heavy residuals resulting from petroleum cracking processes. Characteristics of these residues vary widely and depend on the process used. Solid fuels from oil include delayed coke, fluid coke, and petroleum pitch.

- *Lignite*. Lignite is the lowest rank coal. Lignites are relatively soft and brown to black in color with heating values of less than 8,300 Btu/lb (19,306 kJ/kg). The deposits are geologically young and can contain recognizable remains of plant debris. The moisture content of lignites is as high as 30% but the volatile content is also high; consequently, they ignite easily. Lignite coal dries when exposed to air and spontaneous combustion during storage is a concern. Long distance shipment of these coals is usually not economical because of their high moisture and low Btu contents. The largest lignite deposit in the world spreads over the regions of North and South Dakota, Wyoming, and Montana in the U.S. and parts of Saskatchewan and Manitoba in Canada.

EXHIBIT 4-3 (Continued)

SUMMARY DESCRIPTIONS OF FOSSIL FUELS USED BY THE RESPONDENTS

- *Silt.* Anthracite or Bituminous Silt, or Slurry as it is sometimes referred to, is a high ash waste product, usually less than 1/8" in size, generated during the wet gravity concentration techniques used to separate the clean coal product from the high ash reject stream emanating from the coal preparation facility. The silt or slurry because of its high moisture content is usually contained in settling ponds or impoundments.

- *Sub-bituminous*. Sub-bituminous coals are black, having little of the plant like texture and none of the brown color associated with the lower rank lignite coal. Sub-bituminous coals are noncoking (i.e. undergo little swelling upon heating) and have a relatively high moisture content which averages from 15 to 30%. They also display a tendency toward spontaneous combustion when drying. Although they are high in volatile matter content and ignite easily, sub-bituminous coals generally have less ash and are cleaner burning than lignite coals.

  Sub-bituminous coals in the U.S. in general have a very low sulfur content, often less than 1 percent. Because they have reasonably high heating values [8,300 to 11,500 Btu/lb (19,306 to 26,749 kJ/kg)] and low sulfur content, switching to sub-bituminous coal has become an attractive option for many power plants to limit SO_2 emissions.

either an inherent part of the coal (i.e., inseparable) or as extraneous (i.e., removable by washing, etc.).[88] Appendix D contains a synopsis of boiler input formation and preparation.

Ash

Ash is the non-combustible mineral residue that results from the combustion of coal. Ash sources include inorganic substances, such as silica, which are part of the chemical structure of the plants, and dissolved inorganic ions and mineral grains captured by the organic matter during early coalification. Mud, scale and pyrite are deposited in pores and cracks of the coal seams and contribute to the ash content.[89]

Sulfur

Sulfur occurs in coal in three forms:

(1) organic sulfur, which is part of the coal's molecular structure

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[88] *Steam its generation and use 40th edition*, Babcock & Wilcox, a McDermott company, Edited by S.C. Stultz and J.B. Kitto, Barberton, OH, 1992, Chapter 8, Pg. 8-3.

[89] *Combustion Fossil Power Systems, A Reference Book on Fuel Burning and Steam Generation*, Third Edition, Combustion Engineering, Inc., Joseph G. Singer, Editor, Windsor, CT, 1981, Chapter 2, Pg. 2-11.

(2) pyritic sulfur, which occurs as the mineral pyrite
(3) sulfate sulfur, primarily from iron sulfate.

The principal sulfur source is the sulfate ion, which is found in water. Fresh water has a low sulfate concentration while salt water has a high sulfate content. Therefore, bituminous coal, deposited in the interior of the U.S. when seas covered this region, are high in sulfur. Some Iowa coals contain as much as 8 percent sulfur."[90] Many of the coal deposits in the western states such as Wyoming and Montana contain less than 1 percent sulfur which is indicative of coal formation in a freshwater environment.

A proximate analysis is conducted to determine the fuel's moisture content, volatile matter, fixed carbon, sulfur, and ash content expressed on a percent by weight basis and the energy content in Btu/lb. Whereas, an ultimate analysis is conducted to determine the percent by weight basis of carbon, hydrogen, sulfur, nitrogen, chlorine, oxygen, and ash in the fuel. The results of these two tests are used to determine the principal characteristics of fossil fuel. Exhibits 4-4 and 4-5 summarize the results of the proximate and ultimate analyses of the major fuel types used by survey respondents, respectively.

Why is coal cleaning necessary?

The demand for coal cleaning has increased in response to environmental regulations restricting sulfur dioxide (SO_2) emissions from coal-fired boilers. The demand is also due to a gradual reduction in run-of-mine coal quality as higher quality seams are depleted and continuous mining machines are used to increase production. Approximately 70% of coal mined for electric utility use is cleaned in some way. A significant portion of the coal used by industrial plants, coke and gas plants and exporters is also cleaned.

Coal cleaning and preparation cover a broad range of intensity, from a combination of initial size reduction, screening to remove foreign material, and sizing, to more extensive processing to remove additional ash, sulfur and moisture more intimately associated with coal.

The potential benefits of coal cleaning must be balanced against the associated costs. The major costs to consider, in addition to the cleaning plant capital and operating costs, include the value of the coal lost to the refuse product through process related inefficiencies and the cost of disposing the refuse product.

Comparison of Coal and Waste Coal

Exhibit 4-6 provides summary level information on the proximate analysis of the different types of coal and waste coal being utilized at a number of circulating fluidized bed boilers throughout the country. As expected, the calorific content, measured in Btu/lb, is significantly lower in waste coal as compared to clean coal due to a higher ash content and a reduced carbon content in waste coal.

On a weight percent basis the sulfur content of coal and waste coal is approximately equal however the amount of sulfur on an energy basis is much higher for waste coal as compared to coal. Exhibit 4-7 presents summary level information on the ultimate analysis of coal and waste coal utilized by the Special Project Survey respondents.

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[90] Stultz, S.C. and J.B. Kitto, 1992, Op. cit. Chapter 8, Pg. 8-3.

EXHIBIT 4-4

RESPONDENTS FUEL COMPOSITION - PROXIMATE ANALYSIS

Parameter	Coal		Waste Coal		Petroleum Coke		Other Fossil		Other Non-Fossil	
	RANGE	**N**	**RANGE**	**N**	**RANGE**	**N**	**RANGE**	**N**	**RANGE**	**N**
HHV (Btu/lb)	6,812 - 13,352	27	3,372 - 7,730	20	13,365 - 15,891	8	1,000 - 14,000	14	10,000 - 16,250	4
Sulfur (%)	0.2 - 5.9	53	0.18 - 4.43	37	0.99 - 5.92	14	.22 - 8.5	6	0.03 - 1.23	6
Ash (%)	4.35 - 46.1	55	30.7 - 62.9	28	0.12 - 41.0	14	3.92 - 8.24	4	0.22 - 11.7	7
Vol. Matter (%)	4.6 - 59.8	32	5.7 - 42.7	20	3.9 - 18.9	12	30.7 - 99.2	4	50.6 - 66.6	6
Moisture (%)	2.14 - 35.6	56	4.37 - 19.1	31	1.6 - 8.1	7	11.6 - 17.4	4	0.6 - 40.8	8
Fixed Carbon (%)	5.99 - 78.5	34	22.0 - 50.0	17	80.8 - 92.6	9	39.7 - 75.2	4	7.6 - 28	6

COAL: Anthracite Coal, Sub-Bituminous Coal, Bituminous Coal, Lignite Coal
WASTE COAL: Anthracite Culm, Anthracite Silt, Bituminous Gob, Culm
PETROLEUM COKE: Petroleum Coke
OTHER FOSSIL: Natural Gas, Propane, No. 2 Oil, Diesel
OTHER NON-FOSSIL: RDF, Tires, Wood Chips

EXHIBIT 4-5

FUEL COMPOSITION - ULTIMATE ANALYSIS

Parameter	Coal		Waste Coal		Petroleum Coke		Other Fossil		Other Non-Fossil	
	RANGE	**N**	**RANGE**	**N**	**RANGE**	**N**	**RANGE**	**N**	**RANGE**	**N**
HHV (Btu/lb)	10930 - 13,600	11	3,801 - 8,589	14	14,360	1	16,666	1	5,147 - 6,146	2
Carbon	34.8 - 7,802	32	22.2 - 50	21	82.7 - 83.6	2	73.3 - 78.4	3	30.5 - 83.9	5
Hydrogen	2.26 - 6	30	0.75 - 3.4	22	2.07 - 3.5	2	4.7 - 23.5	4	6.62 - 8.58	5
Nitrogen	0.75 - 2	29	0.12 - 1	22	1.47 - 3.22	4	0.03 - 1.64	5	0.06 - 0.25	5
Chlorine	0.01 - 0.1	15	0.06	1	0.01	1	0.01	2	0.14 - 0.15	3
Sulfur - Total	0.25 - 4.28	15	0.31 - 4.5	18	5.68 - 5.71	2	0.34 - 1.68	4	0.03 - 1.3	3
Sulfur - Pyritic	0.01 - 2.58	8		0		0	0.18 - 0.78	3		0
Oxygen	1.07 - 17.4	30	1.93 - 11.7	21	0.09 - 0.25	2	5.47 - 8.34	3	1.22 - 60.5	4
Moisture	7.72 - 32.7	8	1.15 - 15.8	18		0		0	4.7 - 40.8	3
Ash	4.76 - 19.1	15	31.1 - 62.7	15	0.15 - 0.44	2	4.65 - 9.68	3	0.22 - 0.73	2
Ash minerals										
SiO2	19.3 - 63.3	20	31 - 60.3	6	8.85 - 11.8	2	31.8 - 59.1	3	3 - 5.16	2
Al2O3	7 - 35	20	12 - 26.8	6	2.05 - 3.35	2	20.2 - 33.8	3	0.4 - 1.93	2
TiO2	0.31 - 1.69	18	0.48 - 1.72	3	1 - 1.22	2	0.68 - 1.72	3	0.14	1
Fe2O3	2.46 - 32.4	19	2.95 - 8	6	4.76 - 7.04	2	3.73 - 20.0	3	0.32 - 90.4	3
CaO	0.32 - 41.8	19	0.51 - 21	9	7.67 - 11	2	0.48 - 1.16	3	0.38 - 0.56	2
MgO	0.53 - 8	17	0.03 - 2.5	8	2.76 - 3.96	2	0.32 - 0.64	3	0.1	1
Na2O	0.3 - 3.5	21	0.16 - 0.34	4	1.7 - 1.74	2	0.18 -0.56	3	0.13 - 0.2	2
K2O	0.3 - 3.01	19	1.83 - 3.05	5	0.31 - 0.48	2	0.9 - 1.78	3		0

COAL: Anthracite Coal, Sub-Bituminous Coal, Bituminous Coal, Lignite Coal
WASTE COAL: Anthracite Culm, Anthracite Silt, Bituminous Gob, Culm
PETROLEUM COKE: Petroleum Coke
OTHER FOSSIL: Natural Gas, Propane, No. 2 Oil, Diesel
OTHER NON-FOSSIL: RDF, Tires, Wood Chips

EXHIBIT 4-6
COMPARISON OF COAL AND WASTE COAL: PROXIMATE ANALYSIS
(Weight percent, except where noted)

Parameter	Range	
	Coal	Waste Coal
HHV (Btu/lb)	10,673 - 12,478	5,367 - 6,237
Sulfur	1.3 - 2.4	0.77 - 1.7
Ash	8.05 - 13.8	41.7 - 50.6
Vol. Matter	27.2 - 34.3	7.35 - 14.1
Moisture	6.1 - 13.8	6.7 - 11.1
Fixed Carbon	46.1 - 54.2	32.2 - 38.9

EXHIBIT 4-7
COMPARISON OF COAL AND WASTE COAL: ULTIMATE ANALYSIS
(Weight Percent, Except Where Noted)

Parameter	Range	
	Coal	Waste Coal
HHV (Btu/lb)	10,063 - 13,600	6,255 - 7,252
Carbon	432 - 1,620	32.8 - 40.7
Hydrogen	3.82 - 4.85	1.18 - 2.03
Nitrogen	1.06 - 1.47	0.27 - 0.66
Chlorine	0.01 - 0.04	0.06
Sulfur - Total	1.2 - 1.46	0.77 - 1.71
Sulfur - Pyritic	0.93 - 2.58	
Oxygen	5.46 - 10.9	3.09 - 6.51
Moisture	9 - 17.8	7.42 - 12.31
Ash	9.65	40.7 - 49.2
Ash minerals		
SiO2	36.7 - 51.1	43.3 - 68.3
Al2O3	17.2 - 31	18.3 - 26.8
TiO2	0.7 - 1.05	1.07
Fe2O3	9.6 - 26.2	2.95 - 6.89
CaO	0.32 - 13.8	1.44 - 10.9
MgO	0.53 - 4.53	0.71 - 1.68
Na2O	0.63 - 2.23	0.14 - 0.32
K2O	1.42 - 2.12	2.23 - 3.05

COAL: Anthracite Coal, Sub-Bituminous Coal, Bituminous Coal, Lignite Coal
WASTE COAL: Anthracite Culm, Anthracite Silt, Bituminous Gob

Mineral Species and Trace Elements Present in Coals

Inorganic constituents of coal are derived from the earth's crustal formations and can be separated into three major categories with respect to their relative concentrations in the coal. The grouping includes major constituents (greater than 1 percent), minor constituents (generally, 0.1 percent to 1 percent), and trace constituents (less than 0.1 percent).

Although several dozen minerals are reported in coals, the mineral matter of a coal is usually composed of primarily six minerals. These minerals are commonly one or two clays, one or two carbonates, sulfides, and quartz. Exhibit 4-8 lists the minerals most commonly found in coals.

EXHIBIT 4-8

MOST COMMON MINERALS IDENTIFIED IN COAL

Mineral	Chemical Formulae
Clays	
kaolinite	$Al_4Si_4O_{10}(OH)_8$
illite	$KAl_2(AlSi_3O_{10})(OH)_2$
montmorillonite	$(Ca,Na)_{0.2}(Al,Mg,Fe)_2(AlSi_3O_{10})(OH)_2$
Sulfides	
pyrite	FeS_2
marcasite	$FeS_{1.5}$
sphalerite	ZnS
galena	PbS
Carbonates	
calcite	$CaCO_3$
dolomite	$(Ca,Mg)CO_3$
siderite	$FeCO_3$
ankerite	$(Ca,Fe,Mg)CO_3$
Silicates	
quartz	SiO_2
biotite	$K(Mg,Fe)(AlSi_3O_{10})(OH)_2$
feldspar	$(K,Na)AlSi_3O_8$
Sulfates	
gypsum	$CaSO_4 \cdot 2H_2O$
coquimbite	$Fe_2(SO_4)_3\ 9H_2O$
Oxides	
hematite	Fe_2O_3
magnetite	Fe_3O_4
rutile	TiO_2
Chlorides	
halite	$NaCl$
sylvite	KCl
Phosphates	
apatite	$Ca_5(PO_4)_3(F,Cl,OH)$

Clays usually comprise 50 to 90 wt.% of the mineral matter, with kaolinite, illite, and mixed layer clay being the most abundant species. Quartz is the second most abundant species found in coals, in a wide range of concentrations. Sulfides are commonly present as pyrite and marcasite, while the carbonates consist mainly of calcite and dolomite. In addition to these common minerals, alkali minerals can be present in the form of sulfates and chlorides, with the amount highly dependent on coal rank and geological origin.

Inert mineral oxides are the predominant constituents commonly referred to as coal ash. Approximately 95% of the ash is made up of silicon, aluminum, iron, and calcium in their oxide forms. Magnesium, potassium, sodium, titanium, and sulfur are also present to a lesser degree. The range of these major chemical components, by percent, relative to coal rank, is illustrated in Exhibit 4-9. By convention, ash mineral analyses are reported as metal oxides (e.g., SiO_2, Al_2O_3).

EXHIBIT 4-9

MAJOR CHEMICAL COMPONENTS, VARIATIONS IN COAL ASH COMPOSITION WITH RANK[*]

	Anthracite	Bituminous	Sub-bituminous	Lignite
% SiO_2	48.0 - 68.0	7.0 - 68.0	17.0 - 58.0	6.0 - 40.0
% Al_2O_3	25.0 - 44.0	4.0 - 39.0	4.0 - 35.0	4.0 - 26.0
% Fe_2O_3	2.0 - 10.0	2.0 - 44.0	3.0 - 19.0	1.0 - 34.0
% TiO_2	1.0 - 2.0	0.5 - 4.0	0.6 - 2.0	0.0 - 0.8
% CaO	0.2 - 4.0	0.7 - 36.0	2.2 - 52.0	12.4 - 52.0
% MgO	0.2 - 1.0	0.1 - 4.0	0.5 - 8.0	2.8 - 14.0
% Na_2O	-	0.2 - 3.0	-	0.2 - 28.0
% K_2O	-	0.2 - 4.0	-	0.1 - 1.3
% SO_3	0.1 - 1.0	0.1 - 32.0	3.0 - 16.0	8.3 - 32.0
% Ash	4.0 - 19.0	3.0 - 32.0	3.0 - 16.0	4.0 - 19.0

[*] Ray, S.S., and Parker, F. G., *Characterization of Ash From Coal-Fired Power Plants.* Springfield, VA: National Technical Information Service, January 1977, EPA-600/7-77-010

Coals also contain many other elements in much smaller quantities; the type and proportions of these trace elements are highly variable. Typically, about 0.01 to 0.05% of coal by weight is composed of trace elements. The modes of occurrence of trace elements in coal is commonly held to be very important. Most of the trace element content in coal is associated with three major minerals: pyrite, kaolinite, and illite. The U.S. Clean Air Act Amendments (CAAA) of 1990 identified eleven trace elements commonly found in coal as potentially hazardous air pollutants (HAPs). These elements are listed in Exhibit 4-10 followed by typical concentrations and ranges in coal. Exhibit 4-11 lists
the content of some additional trace elements of laboratory-prepared ash from U.S. coals of various ranks. As shown in this table, the most abundant trace elements in U.S. coals are boron, barium, copper and strontium.

EXHIBIT 4-10

CONCENTRATION OF HAP CONSTITUENTS IN COALS (mg/kg)*

Element	Symbol	Concentration Typical	Range
beryllium	Be	2	0.1 - 15
chromium	Cr	20	0.5 - 60
manganese	Mn	70	5 - 300
cobalt	Co	5	0.5 - 30
nickel	Ni	20	0.5 - 50
arsenic	As	10	0.5 - 80
selenium	Se	1	0.2 - 10
cadmium	Cd	0.5	0.1 - 3
antimony	Sb	1	0.05 - 10
mercury	Hg	0.1	0.02 - 1
lead	Pb	40	2 - 80

* Davidson, R. And Clarke, L., *Trace Elements in Coal.* IEAPER/21, ISBN 92-9029-263-6, p.60, January 1996.

EXHIBIT 4-11

AVERAGE TRACE ELEMENT CONTENTS OF THE ASH FROM DIFFERENT RANK U.S. COALS (ppm)*

Element	**Anthracite**	**Low Volatile Bituminous**	**Medium Volatile Bituminous**	**High Volatile Bituminous**	**Lignite and Sub-bituminous**
Silver	<1	<1	<1	<1	<1
Boron	90	123	218	770	1010
Barium	866	740	896	1253	5027
Beryllium	9	16	13	17	6
Cobalt	81	172	105	64	45
Chromium	304	221	169	193	54
Copper	405	379	313	293	655
Gallium	42	41	-	40	23
Germanium	<20	<20	-	-	-
Lanthanum	142	110	83	111	62
Manganese	270	280	1432	120	688
Nickel	220	141	263	154	129
Lead	81	89	96	183	60
Scandium	61	50	56	32	18
Tin	962	92	75	171	156
Strontium	177	818	668	1987	4660
Vanadium	248	278	390	249	125
Yttrium	106	152	151	102	51
Ytterbium	8	10	9	10	4
Zinc	-	231	195	310	-
Zirconium	688	458	326	411	245

* Los Alamos Scientific Laboratory. *Environmental Contamination from Trace Elements in Coal Preparation Wastes.* Springfield, VA: National Technical Information Service, August 1976. PB267 339).

Optimization of fuel sources to enhance American energy independence is increased with FBC technology. An inherent capability of FBC is fuel flexibility. The material inventory comprising the "bed" provides a tremendously large, relatively hot, moving surface area that, via abrasion, exposes and allows even the smallest amounts of combustible materials to burn. In a very few cases of extremely high moisture and/or ash content fuels, auxiliary fuel use is required to sustain the combustion process (e.g., various process waste sludges used as a primary fuel). To optimize FBC system capabilities it is important for the systems to be designed for either a specific fuel(s) or for a variety of fuel sources, depending on the plant requirements.

The fuel flexibility of FBC technology provides energy consumers with the option of using fuel sources that are not available with conventional forms of combustion technology, such as stokers and pulverized fuel suspension firing systems. FBC also provides an environmentally benign alternative means of disposing of waste streams generated as byproducts of other industrial processes or fuel preparation operations (i.e., coal mining waste products such as anthracite culm and bituminous gob, pulp and paper industry waste sludges and waste water treatment/sewage sludges, and tires, to name just a few).

The combination of limestone use and lower combustion temperatures in FBC also appears to have the potential of reducing some air emissions, allowing the consideration of some otherwise unusable fuel sources.

The following is a partial listing of alternative fuels which are currently used in FBC systems or which have been or can be used:

- Biomass (agricultural wastes such as orchard pruning, rice hulls, cotton wastes, coffee grounds, tobacco stems, bagasse, chick litter and cow manure, wood wastes from construction, saw mills, pulping and de-barking operations)
- Coal and coal mining waste products (high sulfur, high ash, low heating value coals, coal mining silts, anthracite culm, bituminous gob)
- Industrial wastes (waste process materials such as paper and cardboard, waste plastics, coke breeze)
- Petroleum industry wastes (oil refining wastes such as delayed petroleum coke, fluid coke, sponge coke, heavy oil residuals, pitch and oil shales)
- Municipal solid waste

4.2 Limestone Characteristics

Sorbents, primarily carbonate rocks and sediments, are used in fluidized-bed combustors for the capture of SO_2 generated during the combustion of a sulfur-bearing fossil fuel. Limestone and dolostone are the principal carbonate rock types; however, limestone is the preferred carbonate rock type utilized in fluidized-bed combustors because of its higher calcium carbonate content. Unconsolidated carbonate sediment, such as aragonite sand, is used on a more limited basis due to its localized occurrence in the southern United States. Exhibit 4-12 presents the general characteristics of sorbents used by the Special Project Survey respondents.

EXHIBIT 4-12

CHARACTERISTICS OF SORBENTS USED IN FBC BOILERS (SUMMARY)

Primary Fuel	Range	N
CaCO3		
Coal	38.5 - 99.5	21
Petroleum Coke	89.5 - 93	2
Waste Coal	42 - 98.5	12
MgCO3		
Coal	0.2 - 16	17
Petroleum Coke	2.07 - 2.52	2
Waste Coal	0.5 - 58	11
Inert		
Coal	1 - 61.3	15
Petroleum Coke		
Waste Coal	0.31 - 23	9
Moisture		
Coal	0.01 - 5	18
Petroleum Coke	0.01 - .31	2
Waste Coal	0.1 - 5.04	9

COAL: Anthracite Coal, Sub-Bituminous Coal, Bituminous Coal, Lignite Coal
WASTE COAL: Anthracite Culm, Anthracite Silt, Bituminous Gob

The chemical composition of limestones is widely varied for reasons that are discussed in detail in Appendix D. When determining the chemical composition of limestones for fluidized-bed applications, most sorbent suppliers monitor and report the calcium, magnesium, and silica (or insoluble) content. Specifications for the calcium carbonate ($CaCO_3$) content of fluidized-bed sorbents have been relaxed in recent years as fluidized-bed operators attempt to optimize their sorbent consumption and cost. Most fluidized-bed facilities utilize a sorbent with a $CaCO_3$ content greater than 75% by weight (wt.%), while keeping the silica content low in an effort to minimize boiler tube erosion.[91]

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[91] Carr, D. D., Rooney, L. F. and Freas, R. C. 1994. *Limestone and Dolomite*, In: Carr, D. D., Industrial Minerals and Rocks, Society for Mining, Metallurgy, and Exploration, Inc.

Exhibit 4-13 presents the chemical composition of limestones and dolostones. Exhibit 4-13 was compiled from several sources.[92,93,94,95] The major/minor analyses of 20 Pennsylvania sorbents were determined as part of a sorbent evaluation study conducted by The Pennsylvania State University.[96] The Pennsylvania State study was conducted primarily to determine the effect of chemical composition on SO_2 capture; therefore, a broad compositional range of limestones and dolostones was evaluated.

EXHIBIT 4-13

GENERALIZED CHEMICAL COMPOSITION OF LIMESTONES AND DOLOSTONES

Major/Minor		**Trace**		**Radionuclides**	
	wt. %		**ppm**		**pCi/g**
CaO	55.7 - 27.8	Hg	0.04	U^{238}	0.099 - <8.25
MgO	0.4 - 21.7	Pb	9	Th^{232}	0.02 - < 2.75
SiO_2	0.7 - 18.9	As	1		
Al_2O_3	0.1 - 4.0	Cr	11		
TiO_2	< 0.03 - 0.2	Co	0.1		
Fe_2O_3	< 0.1 - 2.4	Ni	20		
Na_2O	< 0.02 - 0.4	F	330		
K_2O	0.05 - 2.6	Cl	150		
P_2O_5	< 0.1	Se	0.08 - 0.88		
SO_3	< 0.1 - 0.6	Cd	0.035		
		Sb	0.2 - 0.3		
		Mn	1100		
		Be	Not Measured		
		Ba	10		
		B	20		
		Mo	0.4		
		V	20		

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[92] Morrison, J.L., D.E. Romans, Y. Liu, N. Hu, S.V. Pisupati, B.G. Miller, S.F. Miller, and A.W. Scaroni. 1994. *Evaluation of Limestones and Dolostones For Use As Sorbents in Atmospheric Pressure Circulating Fluidized-Bed Combustors*, Pennsylvania Energy Development Authority, Final Report PEDAFR 893-4016.

[93] Veizer, J. 1983. *Trace Elements and Isotopes in Sedimentary Carbonates*, In: R.J. Reeder, Carbonates: Mineralogy and Chemistry, Mineralogical Society of America.

[94] Rose, A. W., H.E. Hawkes, and J.S. Webb. 1979. *Geochemistry in Mineral Exploration,* New York, Academic Press.

[95] U.S. Environmental Protection Agency. 1995. Technical Background Document Supporting Proposed Administrative Reporting Exemptions For Certain Release of Radionuclides.

[96] See as footnote 5.

		Cu	4		
		Zn	20		

Major/ Minor analyses reported as wt. % on an oxide basis. See footnote 5.

Exhibit 4-14 presents the quantity of limestone sorbent used by the Special Project Survey respondents by fuel type.

EXHIBIT 4-14

Summary of Limestone Sorbent Use By Fuel Type — 1995

Primary Fuel	No. of Plants	No. of Units	Gross Steam Capacity (lbs/hr)	Total Limestone Used (tons)
Coal	21	38	9,736,000	1,606,053
Petroleum Coke	4	7	1,401,800	275,761
Waste Coal	11	15	2,307,805	539,006
Total:	36	60	13,445,605	2,420,820

COAL: Anthracite Coal, Sub-Bituminous Coal, Bituminous Coal, Lignite Coal
WASTE COAL: Anthracite Culm, Anthracite Silt, Bituminous Gob, Culm

4.3 Other Inputs

Based on limited information provided by the Special Project Survey respondents, relatively minor quantities of non-combustible commodities are consumed. Specifically, as shown below in Exhibit 4-15, ammonia (as anhydrous ammonia or urea) is used for NO_X control; fired clay, gravel, and sand are used as FBC bed material or heat transfer material; and kaolin clay is used as an anti-agglomerate agent.

4.4 Fossil Fuel Combustion Byproducts (FFCBs)

The quantity and quality of FFCBs generated in FBC boilers varies widely mainly due to the wide variety of fuels used. The differences within the mineral matter in those fuels including, the percentage of ash and sulfur, the percentage of carbon, the higher heating value, as well as the different boiler manufacturers, the different production rates, the fuel moisture content, the sorbents used, and the plants operating efficiencies all have a direct impact of the level of byproduct generation.

4.4.1 FFCB Collection Systems

FFCB (ash) is typically removed from three locations in a FBC unit; the combustor bottom, the backpass air heater hoppers, and the fly ash bag house or other particulate removal equipment.

The main purpose of the combustor bottom ash removal is to control the inventory of material within the combustor by removing bed ash to reach a desired differential pressure within the combustor.

EXHIBIT 4-15

SUMMARY OF NON-COMBUSTIBLE COMMODITIES — 1995 (By Fuel Type)

Primary Fuel	Non-Combustible Commodities	Purpose	Total Annual Usage (tons)	Number of Respondents
Coal	Ammonia	To Control NO_X	398.4	1
	Fired Clay	Bed Material	600	1
	Gravel	Limestone Grinding	473	1
	Sand	Bed Material	15,984	17
	Urea	SNCR	91.9	1
Petroleum Coke	Kaolin Clay	Prevent Vanadium buildup	320	1
	Kaolin Clay	Anti-Agglomerate	775	1
	Sand	Bed Material	120	2
Waste Coal	Anhydrous Ammonia	To Control NO_X	344	1
	Sand	Bed Material	50	1

COAL: Anthracite Coal, Sub-Bituminous Coal, Bituminous Coal, Lignite Coal
WASTE COAL: Anthracite Culm, Anthracite Silt, Bituminous Gob, Culm

The main type of combustor bottom ash removal system is the ash screw cooler, which cools the hot ash leaving the unit before it enters the dry ash handling equipment. These units are typically large non-contact water cooled screw conveyors. Another type of combustor bottom ash removal system is the stripper cooler (or classifier). In these units, air nozzles located on the floor of the combustor direct solids material to the stripper inlet. Air is then used to fluidize the material. Fines are returned to the bed, while larger materials are removed from the strippers. Cooling coils are immersed in the bed to cool the ash.

Normally a fabric filter is used with atmospheric pressure fluidized bed boilers because it is less sensitive to the ash properties, such as size, concentration and resistivity, than electrostatic precipitators (ESPs). Survey respondents indicated that over 95% of the FBC units surveyed, representing 60% of the industry, use bag houses (fabric filters) for fly ash collection and pollution control. These units have an emissions preference over ESPs due to the consistent emissions, independent of the fuel characteristics or inlet particle load. Bag houses are seldom affected by the soot blowing or rapping which may cause emission spikes in an ESP. Bag house units operate by passing dust-laden air through a fabric at a low velocity. These bag houses are characterized by their various cleaning methods; reverse gas, pulse jet, and mechanical shaker. The material collected on the fabric is dropped into collection hoppers under each bag house filter compartment. Bag houses can remove sub micron size particles at efficiencies as high as 99.95%.

In ESPs, the particulate entering with the flue gas is given an electrical charge which causes the particle to attach to a collecting surface which has the opposite charge. The ash on the collection plates must be periodically removed. The collection plates are rapped and the dislodged material falls from the plate and into collection hoppers. The collection efficiencies of ESPs can be in excess of 99%.

The ashes collected at the backpass or bag house are generally collected in hoppers and transported by normal dry ash handling equipment. One or more cyclones (mechanical separator) may exist inside the FBC boiler in order to recycle the material within the unit. The systems that handle and transport the bed ash and fly ash in a FBC boiler are the same as those from any conventional boiler design and must be designed for the characteristics of each ash stream. These include particle size, density and temperature, as well as the chemical composition and characteristics of the ash particles.

Due to its density, bottom ash is typically transferred from the bottom ash removal system (screw coolers, etc.) into mechanical type conveying systems such as screw conveyors, drag chains, and bucket elevators. Pneumatic conveying is used in some applications.

Fly ash is more commonly moved in pneumatic systems since they are totally enclosed and virtually dust free. Pneumatic systems or conveyors are tubes or ducts through which material is moved by pressure or vacuum (suction) systems. Pressure systems can be either high or low pressure. Low-pressure systems operate at pressures obtainable from a fan while high pressure systems use a compressed air source. When material is fed into a pressure system, the airstream immediately suspends and conveys it to a cyclone vent or filter.

Cyclones are frequently used at ash transfer points in pneumatic transfer systems. In a typical cyclone the ash entrained gas stream enters at an angle and is spun rapidly. The centrifugal force created by the circular flows throws the ash particles toward the walls of the cyclone dropping them into a hopper located underneath. The ash may be transferred to on-site silos, stockpiles, or rail and/or truck load-outs in a combined or segregated state using the equipment described above.

4.4.2 FFCB Generation - Quantities

The total volume of FFCB (fly ash, bottom ash, boiler slag, and FGD) material generated, as well as the physical and chemical characteristics is influenced by a number of factors such as:

Combustion technology
- pulverized fuel
- cyclone
- stoker
- fluidized bed

Flue Gas Desulfurization technology

Unit operating schedule

Fuel characteristics
- Higher heating value
- Ash content

Sorbent characteristics

Unit size

In the case of pulverized coal firing without any FGD control the volume of fly ash and bottom ash generated is dependent only on the fuel characteristics, the unit size and unit operating schedule. In the case of a pulverized coal unit with FGD, in addition to the items mentioned above, the FGD technology used and sorbent characteristics will affect the total volume. Likewise for an FBC system the volume of byproducts will be a function of fuel and sorbent characteristics, unit size and unit operating schedule.

To illustrate how the technology employed will affect the total volume of combustion byproducts, we employed a proprietary project screening model developed by Foster Wheeler Power Systems, Inc. to develop operating parameters for a hypothetical 100 MWe (net) electric generating plant. This exercise assumed the use of a cleaned "compliance coal", (i.e., less than 1.20 lb SO_2 per million Btu heat input) from central Pennsylvania in a pulverized coal boiler, a pulverized coal boiler with a spray dry absorber ("SDA") for FGD control, and a CFB using limestone injection. The PC with SDA and the CFB assumed a sulfur removal of 70 percent. The results are summarized in Exhibit 4-16.

EXHIBIT 4-16

COMPARISON OF VOLUME OF COMBUSTION BYPRODUCT PRODUCED

Parameter	p.c.	p.c. w/ FGD[a]	FBC
Fuel requirement (lb/hr)	73,600	73,600	71,600
Sorbent requirement (lb/hr)	N/A	1,625	3,600
Total combustion byproduct generated (lb/hr)	5,814	7,012	7,974

a. Assumes the use of a spray dry absorber.

Exhibit 4-17 shows the combustion byproducts generation rates relative to power produced for the Special Project survey respondents. The respondents to the Special Project survey reported that a total of 5,949,062 short tons of combustion byproducts were generated in 1995. Exhibit 4-18 summarizes the FFCB generation rates by respondent facility for 1990 through 1995.

The volume of combustion byproducts produced at any facility will be a function of the fuel characteristics (heating value, ash content, sulfur content), unit size, unit operating schedule, and in the case of limestone injection for sulfur dioxide control the characteristics of the limestone used (purity, reactivity) and the calcium to sulfur ratio. The Special Projects group developed a methodology for extrapolating the respondent's site-specific data to arrive at an estimated generation rate for the universe of FBC combustion units. Using this methodology, which is described in detail in Appendix E, the most likely estimate of total FBC combustion byproducts generated in 1995 is 9,417,500 short tons.

EXHIBIT 4-17

RATIO OF POWER PRODUCED TO ASH PRODUCED BY FACILITY (1995)

Plant ID#	**Air Pollution Control Devices**				**Total Power (MW) Generated**	**Annual Ash Generation (1995 - tons)**	**Power to Ash Ratio (MW/tons)**
	Multicyclone	**Baghouse**	**Electrostatic Precipitator**	**Other-Description**			
Plant #01	Yes	Yes	No		21	120,986	1.74e-04
Plant #02	No	Yes	No	Single Cyclone	69	29,531	2.34e-03
Plant #03	No	Yes	No		65	29,000	2.24e-03
Plant #04	No	Yes	No	Single cyclone	69	28,243	2.44e-03
Plant #06	No	Yes	No		342	380,256	8.99e-04
Plant #07	Yes	No	Yes		486	6,800	7.15e-02
Plant #08	No	Yes	No		110	139,545	7.88e-04
Plant #09	Yes	Yes	No		36	166,504	2.16e-04
Plant #10	No	Yes	No		40	10,086	3.97e-03
Plant #11	Yes	Yes	No		115	298,255	3.84e-04
Plant #12	No	Yes	No		237	431,905	5.49e-04
Plant #13	No	Yes	No		8	8,019	9.73e-04
Plant #14	Yes	Yes	No		61	10,200	5.98e-03
Plant #15	Yes	Yes	No		60	287,395	2.09e-04
Plant #16	Yes	Yes	No		99	488,866	2.03e-04
Plant #17	Yes	Yes	No		56	38,810	1.43e-03
Plant #18	Yes	Yes	No		48	317,497	1.51e-04
Plant #19	No	Yes	No		90	274,150	3.28e-04
Plant #20	No	Yes	No		68	64,500	1.05e-03
Plant #22	No	Yes	No		21	NC	NC
Plant #23	No	Yes	No		535	220,185	2.43e-03
Plant #24	No	No	No		34	291,409	1.17e-04
Plant #25	No	Yes	No		377	41,317	9.12e-03
Plant #26	No	Yes	No		98	326,320	3.00e-04
Plant #28	No	Yes	No		8	200	3.90e-02
Plant #29	Yes	No	Yes		75	29,597	2.53e-03
Plant #30	No	Yes	No		6	4,225	1.48e-03
Plant #31	Yes	Yes	No		93	391,204	2.38e-04
Plant #32	No	Yes	No		122	147,000	8.30e-04
Plant #33	Yes	Yes	No		360	532,407	6.76e-04
Plant #35	No	Yes	No		50	95,000	5.26e-04
Plant #36	No	Yes	No		110	30,000	3.66e-03
Plant #37	No	Yes	No		50	23,000	2.17e-03
Plant #38	No	Yes	No		58	246,277	2.36e-04

Plant ID#	Air Pollution Control Devices				Total Power (MW) Generated	Annual Ash Generation (1995 - tons)	Power to Ash Ratio (MW/tons)
	Multicyclone	Baghouse	Electrostatic Precipitator	Other-Description			
Plant #39	No	Yes	No		115	48,698	2.36e-03
Plant #40	Yes	Yes	No		199	165,317	1.20e-03
Plant #41	No	Yes	No		41	24,120	1.70e-03
Plant #42	No	Yes	No		217	192,437	1.13e-03
Plant #43	No	Yes	No		72	9,800	7.35e-03

EXHIBIT 4-18

SUMMARY OF FFCB GENERATION RATES BY RESPONDENT FOR 1990 - 1995

Facility ID	Total FFCB Used (tons)					
	1990	1991	1992	1993	1994	1995
Plant #01	0	0	141,426	143,650	147,253	120,986
Plant #02	27,856	27,781	27,165	28,722	29,655	29,531
Plant #03	0	0	0	19,534	28,275	29,000
Plant #04	28,019	27,533	29,019	29,622	31,999	28,243
Plant #06	0	0	362,881	415,006	371,355	380,256
Plant #07	4,000	4,600	4,500	7,000	6,000	6,800
Plant #08	165,848	158,335	0	121,302	138,734	139,545
Plant #09	0	0	0	165,055	159,116	166,504
Plant #10	0	0	0	0	11,123	10,086
Plant #11	0	0	0	0	0	298,255
Plant #12	319,111	365,128	433,106	441,849	492,905	431,905
Plant #13	4,119	4,354	5,866	3,837	7,414	8,019
Plant #14	0	0	0	1,900	14,500	10,200
Plant #15	0	95,720	252,431	0	264,094	287,396
Plant #16	0	488,866	488,866	488,866	488,866	488,866
Plant #17	0	40,926	37,014	39,384	43,804	38,810
Plant #18	424,449	347,360	388,188	365,080	364,906	317,497
Plant #19	176,700	210,244	224,022	221,220	265,462	274,150
Plant #20	0	0	0	64,500	64,500	64,500
Plant #22	2,161	4,121	1,545	1,337	535	0
Plant #23	0	0	0	0	156,657	220,185
Plant #24	359,065	316,190	287,240	240,140	290,000	291,409
Plant #25	0	0	0	38,031	45,788	41,317
Plant #26	0	0	0	244,436	343,395	326,320
Plant #28	0	2,830	2,980	3,060	2,980	200
Plant #29	64,185	50,123	45,387	59,248	49,672	29,597
Plant #30	1,800	2,000	3,300	3,500	3,500	4,225
Plant #31	0	0	0	296,120	231,800	391,204
Plant #32	0	0	0	0	0	147,000
Plant #33	5,098	312,181	371,181	479,837	494,517	532,407
Plant #35	58,200	71,300	119,000	88,700	98,400	95,000
Plant #36	0	0	33,000	33,000	33,000	30,000
Plant #37	0	0	0	0	0	23,000

Plant #38	0	0	0	0	264,100	246,277
Plant #39	1,761	36,502	37,381	42,213	45,507	48,698
Plant #40	0	176,868	158,724	163,002	142,257	165,317
Plant #41	0	18,000	0	20,000	0	24,120
Plant #42	0	0	50,547	183,664	331,519	192,437
Plant #43	0	0	0	0	0	9,800
Total:	1,642,372	2,760,962	3,504,769	4,452,815	5,463,588	5,949,062

4.5 Fossil Fuel Combustion Byproduct (FFCB) Characterization

Combustion conditions have a significant effect on the physical and chemical properties of ash exiting a boiler. Exhibit 4-19 lists a comparison of some of the operating conditions of a CFB versus a p.c. boiler.

EXHIBIT 4-19

COMPARISON OF OPERATING PARAMETERS OF A CFB VERSUS P.C. BOILER

Parameter	CFB	P.C.
Fuel Feed Size	1/4" x 0	80% passing 74 μm
Furnace Temp, °F	1,600	2,000 - 3,000
Furnace Gas Residence Time, sec	4 - 5	1 - 2
Flue Gas O_2, %	3	4 - 5
Fly Ash Residence Time	1 - 5 hrs	< 3 sec
Bottom Ash Residence Time	10 - 20 hrs	< 2 sec

The time-temperature history of ash particles in a CFB is considerably different than that encountered in a p.c. boiler. A much lower temperature is utilized in a CFB (800 to 900°C) compared to a p.c. boiler in order to achieve a significant reduction in SO_2 emissions with limestone injection. As a result, some of the physical transformations of the mineral matter may be different in a CFB combustor. Due to the lower combustor temperature, less melting of the ash takes place resulting in ash particles which are irregular in shape and not well rounded.

In a CFB boiler, the coal is subjected to heating rates which are similar, but slightly lower than those encountered in a p.c. boiler (~10^4 to 10^5 °C per second). In the furnace, combustion takes place at a relatively uniform temperature of about 800 to 900°C, due to the circulation of solids in the system.

The residence time of the combustion gases in the furnace is on the order of 4 to 5 seconds. At the top of the furnace, most of solids in the flue gas are captured by a cyclone and returned to the furnace via a loopseal. The flue gas and elutriated solids exiting the cyclone are then rapidly cooled in a convective section as in a p.c. boiler with similar residence times, however, the exit temperature is generally lower. The fly ash in the flue gas is then removed prior to the stack by a particulate collection device such as a baghouse or ESP.

The residence time of the fly ash in the boiler varies as a function of the ash particle size and the capture efficiency of the cyclone. As a result, finer fly ash will have a shorter residence time than coarser material. Typically, fly ash material passing 200 mesh (74 microns) will have a residence time in the boiler of up to 1 hour. Coarser material between 100 and 200 mesh in size will have a longer residence time of up to several hours since it may become part of the bottom ash or elutriate and exit through the cyclone. Fine fly ash material (less than 50 microns) will have a residence time in the combustion chamber similar to the gas residence time in the order of 4 to 5 seconds.

The residence time of bottom ash in a CFB boiler depends upon such factors as coarseness of fuel and sorbent, system solids inventory, and the level of dense bed required in the combustor. Usually, the drain rate of solids from a CFB is the residence time of the bottom ash. Therefore the residence time is usually calculated by dividing the solids inventory by the drain rate of solids from the boiler. Typically, the residence time of the bottom ash is on the order of 10 to 20 hours, depending upon the specific boiler design and operation.

The thermal transformations of coal minerals in CFB boilers would be expected to be similar to those encountered in a p.c. boiler. A temperature of 900^{o}C is sufficient to cause the decomposition or oxidation of the five major minerals found in coals. Even though the furnace temperature is much lower in a CFB, the ash residence time is significantly longer than a p.c. boiler. As a result, the extent of these reactions is nearly as complete as in p.c. boilers.

Quartz moves through the CFB boiler relatively unchanged for most coals, and its composition does not change during combustion. Illite is unaffected by combustion and its partitioning between fly and bottom ash will depend upon the mineral size in the coal. Iron-rich species (from pyrite or siderite) are found mostly as isolated iron-rich particles an in association with silica and alumina in the bottom ash. The wide range of compositions of Fe-Si-Al particles with no specific range indicates the associations are a result of physical agglomeration, not chemical reaction.

CFB fly and bottom ash are composed not only of coal minerals, but also ash derived from the sorbent used for sulfur capture. As a result, CFB ashes generally contain a higher content of calcium and sulfate, but a lower content of silica and alumina than corresponding ashes generated from p.c. combustion. This is due to the dilution effect caused by the increased ash volume from sorbent addition. The sorbent material in the fly and bottom ash is present as lime particles surrounded by a sulfate shell. The extent of sulfation of the lime in the sorbent is usually related to the reactivity of the limestone, sulfur content of the fuel, and specific boiler operating conditions. The partitioning of the sorbent between fly and bottom ash is related primarily to sorbent friability and attrition characteristics.

In addition to reaction with SO_2, sorbent can also react with some of the mineral species present in the fuel. For example, calcium oxide can react with relatively fine minerals such as silica and clays, especially in the dense bed of the CFB. These reactions result in the formation of calcium silicates and aluminosilicates. Similar reactions are commonly observed in p.c. boilers while firing western U.S. subbituminous coals and lignites, which contain calcium in a fine organic form. In CFB boilers firing petroleum coke, calcium has been found to react with vanadium and nickel to form complex vanadium-nickel vanadates.

4.5.1 Physical Characteristics

The physical characteristics of the ash generated from the combustion of fossil fuels is a function of the type of combustion technology used, the size of the fuel feed, the sorbents used (if any), the collection equipment used, and many other factors. In a dry-ash p.c. boiler, which is particularly applicable to coals with high ash fusion temperatures, the furnace is provided with a hopper bottom and with sufficient cooling surface so that the ash impinging on furnace walls or hopper bottom is solid and dry and can be removed as dry particles. With may coals having low ash fusion temperatures, it is difficult to use a dry-bottom boiler because the slag is either molten or sticky and tends to cling and build up on the boiler walls or bottom. The slag-tap or cyclone boiler has been developed to handle coals of these types. The slag drops in liquid form onto a floor where a pool of liquid slag is maintained and tapped into a slag containing water. Here the ash material shatters into glassy, angular particles known as boiler slag.

Approximately 80% of the ash produced in p.c.-fired units with dry bottom removal systems exits from the furnace in the flue gas stream as fly ash, leaving only 20% of the ash to form bottom ash. Typically, 65% of this fly ash is finer than 0.010 mm (4×10^{-4} in). For units with a wet-bottom removal system, the percentage of fly ash produced drops to about 50% and the quantity of ash forming boiler slag increases accordingly.

P.C. boilers typically utilize fuel that is dried and pulverized such that 80% of the particles are smaller than 0.075 mm ($3 \text{ X } 10^{-3}$ in). On the other hand, cyclone furnaces use a crushed coal with a diameter of less than ½ inch as fuel which is burned by continuous swirling in a high heat intensity zone. Between 70 and 85% of the ash melts and is tapped from the furnace as boiler slag, leaving 15-30% of the ash to exit in the flue gas as fly ash.

The feedstocks to FBC boilers include crushed fuel and limestone-based sorbent for capturing sulfur released into the flue gas. In FBC boilers, the furnace temperature is considerably lower than those in p.c. and cyclone boilers, resulting in a dry bottom type of ash. Both fly ash and bottom ash are a mixture of fuel ash, unburned carbonaceous material and sorbent lime (CaO) particles coated with sulfate layers. Thus, FBC ashes generally contain a higher content of calcium (as an oxide and sulfate), but a lower content of oxidized coal minerals than ashes generated from p.c. and cyclone boilers. The split of fly/bottom ash in FBC boilers varies considerably and is dependent upon such factors as fuel mineral composition and size, limestone sorbent physical and chemical properties, and combustor fluid dynamics.

The major difference in the physical characteristics of FBC boilers versus p.c. boiler ash is the shape, particularly for fly ash. Since the combustion temperature is considerably higher in a p.c. boiler, fly ash particles appear more rounded due to a higher degree of melting. The fly ash from CFB boilers is very similar in fineness compared to that from p.c. boilers. Typically, between 60 and 90% of the fly ash from CFB boilers is finer than 100 microns. On the other hand, bottom ash from CFB boilers can be somewhat different in size compared to p.c. bottom ash. Depending upon the fuel and sorbent characteristics, the average particle size of bottom ash can vary from about 0.5 mm to 2 mm. The particle size of bottom ash from p.c. boilers is generally coarse and the size will depend upon the type of boiler (dry bottom versus wet bottom). In any event, bottom ash is coarse in nature since it forms from material which is too large to be entrained in the relatively high velocity of the combustion gases.

4.5.2 Bulk Chemical Characteristics

The major difference in the chemical composition FBC ash versus p.c. boiler ash is the higher calcium content originating from the sorbent. The chemical composition of FBC ash varies with the ash and sulfur content of the coal and the calcium to sulfur ratio (Ca/S) used to control SO_2 emissions. Exhibit 4-20, provides a comparison of how the ash characteristics can vary within the FBC units depending on the technology being examined. For example ashes derived from BFB combustion show considerable variation between the fines and the bed ash.

EXHIBIT 4-20

COMPARISON OF BFB AND CFB COMBUSTOR ASH PROPERTIES[*]

BFB residues	**Fines**	**Bed ash**
Organic carbon	20-40%	<5%
Sorbent -derived material		
Calcium sulfate anhydrite	up to 14%	up to 50%
Free lime	up to 12%	up to 42%
Uncalcined sorbent	up to 16%	up to 6%
TOTAL	11-35%	74-86%
CFB residues		
Organic carbon	1-10%	
Sorbent-derived material		
Calcium sulfate anhydrite	3-53%	
Free lime	2-25%	
Uncalcined sorbent	1-5%	
TOTAL	7-74%	

[*] "The Environmental Implications of Fluidized Bed Ash Disposal", British Coal Corporation, Project Summary 041, February 1995.

If a p.c. fired unit is fitted with a spray dry absorber, the fly ash will contain both the fuel ash constituents, the sulfur byproducts from scrubbing and unreacted sorbent. Exhibit 4-21 summarizes in a general way the similarities and differences between p.c., FBC, and p.c. with dry FGD fly ashes.

Exhibit 4-22 shows the range of concentrations of eight major elements in both fly and bottom ash/boiler slags from firing U.S. coals of various ranks. The bulk of the fly ash is made up of oxides of silicon, aluminum, iron, and calcium. Carbon can also be present in various amounts in the fly ash. The carbon content is dependent upon the efficiency of the particular boiler unit and the fineness to which the coal is pulverized. Older boilers tend to produce higher carbon fly ash than the new, more efficient units. Consequently, carbon is considered a contaminant in the ash, particularly if the ash is to be utilized.

EXHIBIT 4-21

COMPARISON OF P.C., FBC AND P.C. w/ FGD, FLY ASH CHARACTERISTICS

	P.C. Class F[a,b]	**P.C. Class C[a,b]**	**CFB[b]**	**P.C. w/ FGD[c]**
Chemical Analysis (percent)				
Silicon Dioxide, SiO_2	51.86	30.97	16.95	30.8
Aluminum Oxide, Al_2O_3	24.16	17.08	7.51	7.10
Titanium Dioxide, TiO_2	1.16	1.00	0.43	0.40
Iron Oxide, Fe_2O_3	13.85	5.27	10.21	5.20
Calcium Oxide, CaO	3.04	30.07	40.89	34.5
Magnesium Oxide, MgO	1.53	7.14	2.10	3.29
Potassium Oxide, K_2O	3.13	0.18	0.82	0.98
Sodium Oxide, Na_2O	0.62	2.68	0.52	1.85
Sulfur Trioxide, SO_3	0.06	3.37	19.01	17.4
Phosphorus Pentoxide, P_2O_5	0.24	1.06	0.26	0.64
Strontium Oxide, SrO	0.12	0.52	0.05	---
Barium Oxide, BaO	0.15	0.62	0.00	0.34
Manganese Dioxide, MnO_2	0.06	0.05	0.11	0.07
Physical Analysis				
Density	2.28	2.77	2.83	
Amt. Retained on # 325 Sieve	14.5	15.4	54.00	
Mineral Analysis (percent)				
Anhydrite, $CaSO_4$	----	2	30	
Lime, CaO	----	1	15	
Quartz, SiO_2	8	6	6	
Hematite, Fe_2O_3	2	----	12	
Calcite, $CaCO_3$	----	----	20	
Calcined clays	----	----	10	
Mullite, $Al_6Si_2O_{13}$	12	6	----	
Ferrite Spinel, $(Mg,Fe)(Fe,Al)_2O_4$	2	2	----	
Melilite $Ca_2(Mg,Al)(Al,Si)_2O_7$	----	2	----	
Tricalcium Aluminate $Ca_3Al_2O_6$	----	3	----	
Merwinite, $Ca_3Mg(SiO_4)_2$	----	7	----	
Pericles, MgO	----	3	----	

Notes:

a. The Class of fly ash refers to ash classifications contained in ASTM C-618 *Standard Specification for Fly Ash or Calcined Natural Pozzolan for use as a Mineral Admixture in Portland Cement Concrete*.

b. Sharp, Kevan D. Editor, *Fly Ash for Soil Improvement*, Geotechnical Special Publication No. 36, American Society of Civil Engineers, New York, NY, 1993, p.69.

c. U.S. EPA Docket No. F-93-FFCA-S0033B

EXHIBIT 4-22

RANGE OF CONCENTRATIONS OF MAJOR OXIDES FOUND IN FLY AND BOTTOM ASH/BOILER SLAG FROM COAL-FIRED BOILERS (ppm)[*]

	Fly Ash		Bottom Ash/Boiler Slag	
Element	**Low**	**High**	**Low**	**High**
Aluminum	11,500	144,000	88,000	135,000
Calcium	5,400	177,100	8,400	50,600
Iron	7,800	289,000	27,000	203,000
Magnesium	4,900	60,800	4,500	32,500
Potassium	1,534	34,700	7,300	15,800
Silicon	196,000	271,000	180,000	273,000
Sodium	1,180	20,300	1,180	13,100
Titanium	400	15,900	3,300	7,210

[*] *Report and Technical Studies on the Disposal and Utilization of Fossil-Fuel Combustion By-Products, Appendix A.* Submitted to the U.S EPA, October 26, 1982, p .31

Bottom ash consists of angular particles which have a porous texture and are normally gray to black in color. Boiler slag is composed of black angular particles having a somewhat glassy appearance. For any particular type of coal, the chemical composition of the bottom ash or boiler slag derived from this coal will be similar to, but may have a lower carbon content than, fly ash derived from the same combustion process.

It should be noted that many element concentrations in coal ash are similar to those found in naturally occurring soils, see Exhibit 4-23 below.

EXHIBIT 4-23

COMPARISON OF FLY ASH CONSTITUENTS TO NATURAL SOIL

Constituent	Formula	Typical Coal Ash Weight%	Typical Soil Weight%
Silicon Dioxide	SiO_2	45.7	45.1
Aluminum Oxide	Al_2O_3	26.0	28.4
Iron Oxide	Fe_2O_3	17.1	16.7
Calcium Oxide	CaO	3.8	2.8
Sulfate	SO_3	2.6	2.6
Potassium Oxide	K2O	1.5	1.8
Titanium Dioxide	TiO_2	1.2	1.4
Magnesium Oxide	MgO	1.2	0.9
Sodium Oxide	Na_2O	0.6	1.8
Phosphorus Pentoxide	P_2O_5	0.3	2.1

Source: Fitzgerald, H.B., Chumley, J.W. and Waldrop, B. “Where to Stash the Ash,” presented at the 1994 TAPPI Engineering Conference, San Francisco, CA, September 19-22.

Exhibit 4-24 shows the bulk constituents of combustion byproducts by fuel type as reported by the Special Project survey respondents. Exhibit 4-25 presents other parameters (e.g., pH, acid neutralizing potential, chlorides, sodium, and total organic carbon) of ash as reported by the survey respondents.

EXHIBIT 4-24

BULK CONSTITUENTS OF FLY, BED, AND COMBINED ASH (weight percent)

FUEL=Coal

Parameter	Fly Ash					Bed Ash					Combined Ash				
	MIN	MEAN	MAX	N	# Non-Detects	MIN	MEAN	MAX	N	# Non-Detects	MIN	MEAN	MAX	N	# Non-Detects
Aluminum Oxide	7	10.55	14.1	2	0				0	0	7.87	8.8925	10.17	4	0
Barium Oxide	0.04	0.04	0.04	1	0				0	0				0	0
Calcium Carbonate				0	0				0	0	37.39	41.24	43.4	3	0
Calcium Oxide	28.1	34.94	41.78	2	0				0	0	37.16	40.9925	43.59	4	0
Iron Oxide	7.18	7.29	7.4	2	0				0	0	9	9.8175	10.41	4	0
Magnesium Oxide	1.65	1.65	1.65	1	0				0	0	1.75	2.88	4.27	4	0
Manganese Oxide	0.07	0.07	0.07	1	0				0	0				0	0
Phosphorus Pentoxide	0.18	0.18	0.18	1	0				0	0				0	0
Potassium Oxide	0.6	0.6	0.6	1	0				0	0	0.78	0.845	0.91	2	0
Silica	19.27	24.585	29.9	2	0				0	0	15.08	16.37	17.8	4	0
Sodium Oxide	0.61	0.61	0.61	1	0				0	0	0.16	0.48	0.8	2	0
Strontium Oxide	0.04	0.04	0.04	1	0				0	0				0	0
Sulfur Trioxide	7.9	14.585	21.27	2	0				0	0	18.48	19.565	20.13	4	0
Titanium Oxide	0.31	0.31	0.31	1	0				0	0				0	0

FUEL=Petroleum Coke

Parameter	Fly Ash					Bed Ash					Combined Ash				
	MIN	MEAN	MAX	N	# Non Detects	MIN	MEAN	MAX	N	# Non-Detects	MIN	MEAN	MAX	N	# Non-Detects
Calcium Carbonate	19.24	20.025	20.81	2	0				0	0				0	0
Calcium Oxide	10.78	10.78	10.78	1	0				0	0				0	0
Magnesium Oxide	0.63	0.63	0.63	1	0				0	0				0	0
Magnesium carbonate	1.32	1.32	1.32	1	0				0	0				0	0

FUEL=Waste Coal

Parameter	Fly Ash					Bed Ash					Combined Ash				
	MIN	MEAN	MAX	N	# Non Detects	MIN	MEAN	MAX	N	# Non-Detects	MIN	MEAN	MAX	N	# Non-Detects
Aluminum Oxide	23.1	23.1	23.1	1	0	11.31	11.31	11.31	1	0				0	0
Calcium Oxide	15.27	15.27	15.27	1	0	42.64	42.64	42.64	1	0				0	0
Iron Oxide	5.53	5.53	5.53	1	0	2.64	2.64	2.64	1	0				0	0
Magnesium Oxide	0.73	0.73	0.73	1	0	1.04	1.04	1.04	1	0				0	0
Manganese Oxide	0.07	0.07	0.07	1	0	0.07	0.07	0.07	1	0				0	0
Potassium Oxide	0.95	0.95	0.95	1	0	0.63	0.63	0.63	1	0				0	0
Silica	42.58	42.58	42.58	1	0	19.64	19.64	19.64	1	0				0	0
Sodium Oxide	0.25	0.25	0.25	1	0	0.28	0.28	0.28	1	0				0	0
Strontium Oxide	0.1	0.1	0.1	1	0	0.07	0.07	0.07	1	0				0	0
Sulfur Trioxide	8.8	8.8	8.8	1	0	20.64	20.64	20.64	1	0				0	0

EXHIBIT 4-25

MISCELLANEOUS PARAMETERS BY FUEL TYPE

FUEL=Coal

Parameter	Fly Ash					Bed Ash					Combined Ash				
	MIN	MEAN	MAX	N	# Non-Detects	MIN	MEAN	MAX	N	# Non-Detects	MIN	MEAN	MAX	N	# Non-Detects
Acid Neutralizing Potential (per ton)	150.4	158.2	166	2	0	200.3	200.3	200.3	1	0	59	82.72	94.75	5	0
Ammonia-Nitrogen (ppm)	0.0001	2.50	5	2	1	0.00088	5.00	10	2	0	0.5	0.5	0.5	1	1
Chemical Oxygen Demand (ppm)	2167.87	2167.87	2167.87	1	0	2382.96	2382.96	2382.96	1	0				0	0
Chloride (ppm)	19.57	69.78	120	2	0	13.47	39.23	65	2	0	17.5	273.75	530	2	0
Cyanide (ppm)	0.01	0.34	1	3	0	0.01	0.48	1	3	1	0.01	0.01	0.01	1	1
PH (su)	8.8	10.87	12.1	3	0	11.68	11.84	12	2	0	6.2	11.91	12.6	16	0
Phenolics (ppm)	0.004	0.022	0.040	2	0	0.004	0.023	0.04275	2	0	0.003	0.015	0.025	3	1
Sodium (ppm)	4.65	7188.82	14373	2	0	0.7	0.7	0.7	1	0	1030	1030	1030	1	0
Total Organic Carbon (ppm)	0.00198	107.53	322.01	3	0	0.000677	176.51	353.02	2	0	0.00076	8000	16000	2	0
Total Organic Halides (ppm)	0.0053	0.0071	0.0089	2	0	0.0025	0.0082	0.0139	2	1	0.0025	0.0025	0.0025	1	1

FUEL=Petroleum Coke

Parameter	Fly Ash					Bed Ash					Combined Ash				
	MIN	MEAN	MAX	N	# Non Detects	MIN	MEAN	MAX	N	# Non-Detects	MIN	MEAN	MAX	N	# Non-Detects
Acid Neutralizing Potential (ton)				0	0	298.1	298.1	298.1	1	0				0	0
Cyanide (ppm)				0	0				0	0	0.0025	0.0025	0.0025	1	1
PH (su)				0	0	11.9	11.9	11.9	1	0				0	0
Sodium (ppm)				0	0				0	0	3095	3095	3095	1	0
Total Organic Carbon (ppm)				0	0				0	0	1	1	1	1	0
Total Organic Halides (ppm)				0	0				0	0	0.006	0.006	0.006	1	0

FUEL=Waste Coal

Parameter	Fly Ash					Bed Ash					Combined Ash				
	MIN	MEAN	MAX	N	# Non Detects	MIN	MEAN	MAX	N	# Non-Detects	MIN	MEAN	MAX	N	# Non-Detects
Acid Neutralizing Potential (ton)	127.5	191.56	270.8	4	0	402	492.74	665.1	5	0	36.35	65.82	91.31	3	0
Ammonia-Nitrogen (ppm)	0.5	0.81	1.12	2	1	1.12	1.12	1.12	1	0	23.8	23.8	23.8	1	0
Chemical Oxygen Demand (ppm)	4	12	20	2	0	52	52	52	1	0	81.6	81.6	81.6	1	0
Chloride (ppm)	7.5	924.38	2750	4	0	0.75	0.75	0.75	1	0	4.97	4.97	4.97	1	0
Cyanide (ppm)	0.0025	0.048	0.18	4	2	0.0025	0.0025	0.0025	1	1	5	5	5	1	1
PH (su)	11.5	11.85	12.3	5	0	11.46	11.88	12.3	2	0	10.05	10.93	12.2	8	0
Phenolics (ppm)	0.0025	0.0038	0.005	2	2	0.0025	0.0025	0.0025	1	1				0	0
Sodium (ppm)				0	0				0	0	10.7	10.7	10.7	1	0
Total Organic Carbon (ppm)	0.5	0.5	0.5	2	2	1	1	1	1	0	1	1	1	1	1
Total Organic Halides (ppm)	0.005	32.50	65	2	1	0.005	0.005	0.005	1	1	5	5	5	1	0

4.5.3 Trace Characteristics - Total Constituent Concentrations

Studies have shown that partitioning of the various trace elements occurs during the combustion process. In addition to the enrichment in trace element content in the ash relative to the coal, the ratio of trace element concentrations also varies within the different ash streams.

As a result of this partitioning, the trace elements can be divided into three categories:

- Elements concentrating approximately equally in the fly and bottom ash
- Elements preferentially concentrated in the fly ash
- Elements tending to be discharged to the atmosphere as vapors

Exhibit 4-26 presents a breakdown of trace elements into each of these categories as determined in a study.

EXHIBIT 4-26

PARTITION OF ELEMENTS BY THEIR TENDENCIES FOR DISTRIBUTION IN COAL COMBUSTION RESIDUES[*]

Group I
Elements Concentrated Approximately Equally in Fly and Bottom Ash

Al Ca Co Fe K Mg Rb Si Sr Th
Ba Ce Eu Hf La Mn Sc Sm Ta Ti

Group II
Elements Preferentially Concentrated in the Fly Ash

As Cd Cu Ga Mo Pb Sb S Zn

Group III
Elements Tending to Be Discharged to Atmosphere as Vapors

Hg Br Cl

[*] Ray, S. S., and Parker, F. G., *Characterization of Ash From Coal-Fired Power Plants.* Springfield, VA: NTIS, January 1977. EPA-600/7-77-010.

As with p.c. ashes, the most abundant trace elements found in FBC ashes are arsenic, barium, boron, chromium, copper, manganese, nickel, vanadium and zinc. In general the fines show a higher concentration of these elements than the bed ash. Overall, with the exception of arsenic, boron, molybdenum, nickel and selenium, the trace element content is the same order of magnitude as reported for soils.

As mentioned earlier, the ash analysis expressed as oxides does not represent the actual mineral forms of metallic elements present in ash residues. X-ray diffraction (XRD) can provide a better technique for comparing the composition of FBC versus p.c. boiler ashes. As shown in Exhibit 4-21, similar coal mineral species have been identified in the fly ash from both FBC and p.c. boilers. These include silica, dehydrated clays and hematite. A total of 31 Special Project survey respondents submitted total constituent data from the analysis of a total of 211 separate samples analyzed for one or more of the TC metals, aluminum, antimony, beryllium, boron, cobalt, copper, iron, manganese, molybdenum, nickel, potassium, thallium, vanadium, and zinc. Exhibit 4-27 presents a summary of constituents found in ash as reported by the Special Project survey respondents. Exhibits 4-28 through 4-31 present statistical summaries of the respondent's total constituent data aggregated by fuel types - all fuels, coal, waste coal, and petroleum coke, respectively.

4.5.4 Trace Characteristics - Leachable Concentrations

The occurrence of trace element constituents in leachates from field storage coal ash sites is difficult to predict, since the laboratory tests to determine toxicity do not represent normal field storage conditions. Generally, the leachate quality is governed by the physical-chemical characteristics of the ash and the soil-water matrix through which the leachate flows. Estimation of the leachate quality at any point will require a knowledge of the laboratory leachate quality and the specific attenuation-translation factors of the soil-ash system. The principal reactions controlling the leachate compositions have been identified as dissolution/precipitation, adsorption/desorption and redox transformation.

Not all elements in the ash will leach into the surrounding area, since coal ash particles from p.c. firing are typically glass spheres, with an exterior glass hull and an interior glass matrix. As a result, the location of elements in the sphere determines whether they will leach out or not. The elements located in the surface glass layer are more reactive with water than those in the interior glass matrix of the particle. Therefore, the distribution of the trace elements in the ash particle is important in estimating whether they will dissolve or be retained in the ash. Arsenic, boron, calcium, magnesium, selenium, and chromium are preferentially concentrated on and in the glass surface. Elements that are not predominant on the surface include aluminum, silicon, sodium, potassium, lead rubidium, cesium and many other trace elements.[97,98]

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[97] "Coal Ash and the Environment: Characteristics of Fly Ash." EPRI Environment Division, *Technical Brief*, RP2485-8, 1989.

[98] Horn, M. E., "Ashes and Scrubber Sludges." Utility Solid Waste Activities Group, Disposal Committee, May 1988, p 23.

EXHIBIT 4-27

SUMMARY OF TOTAL CONSTITUENT ANALYSIS RESULTS -- ALL FUELS (mg/kg)

Material Type	Aluminum				Antimony				Arsenic			
	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX
Bed Ash	34	9	20189.71	104300	58	0.1	48.47745	1775	62	0.25	24.19802	119.7
Fly Ash	42	20	42999.05	176300	66	0.1	48.87567	1370	73	0.1	31.74832	176
Combined Ash	48	1.09	24972.95	75850	45	0.0025	18.12843	142	60	0.14	25.27943	115.5

Material Type	Barium				Beryllium				Boron			
	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX
Bed Ash	68	0.05	97.267	453	38	0.5	4.97711	31	52	0.05	23.166	304
Fly Ash	73	0.1	355.628	7700	39	0.5	3.45064	16	60	0.05	94.888	2473
Combined Ash	57	0.1	214.512	690	12	0.295	2.49458	9.5	45	0.904	59.867	1670

Material Type	Cadmium				Chromium				Cobalt			
	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX
Bed Ash	61	0.0025	1.59778	14	68	3.7	26.93999	259.8	47	0.125	12.25447	128.4
Fly Ash	72	0.0025	1.65387	13	76	0.5	38.40946	211.1	47	0.125	15.56043	178.5
Combined Ash	50	0.00025	1.23929	7	58	8	65.94483	1906	30	1.2	5.65667	18.7

Material Type	Copper				Iron				Lead			
	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX
Bed Ash	65	0.5	12.1576	50	33	6.2	11838.5	31500	67	0.05	16.6172	89.9
Fly Ash	71	0.5	30.57766	99	46	22.17	27390.8	81318	75	0.5	26.236	129.5
Combined Ash	56	1.9	45.7525	408.1	48	850	13869.77	51600	57	0.714	25.9922	89

Material Type	Manganese				Mercury				Molybdenum			
	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX
Bed Ash	33	34.5	245.5739	892.9	54	0.0001	4.06986	208.9	52	0.05	17.31763	190
Fly Ash	42	0.1	2802.492	57700	73	0.0001	6.65997	384.2	67	0.05	15.00967	143.6
Combined Ash	47	20	98.86085	905	57	0.0001	0.96601	29	50	0.05	10.9745	41

Material Type	Nickel				Potassium				Selenium			
	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX
Bed Ash	63	2	381.592	1440	41	1.3	931.63	11950	56	0.001	3.17729	45
Fly Ash	75	12.5	277.072	1270	44	1.13	2227.19	14680	69	0.001	9.36696	166
Combined Ash	59	0.5	60.689	985	26	2.82	4032.88	9163	59	0.0025	6.35638	27

Material Type	Silver				Thallium				Vanadium			
	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX
Bed Ash	55	0.005	7.57442	338	29	0.25	6.681	50	37	12	3682.514	10000
Fly Ash	64	0.005	1.93527	38.5	34	0.5	6.47	39.011	39	36.333	2507.789	10000
Combined Ash	48	0.005	1.57383	21.8	8	0.18	9.549	25	11	19.57	707.0736	5000

Material Type	Zinc			
	N	MIN	MEAN	MAX
Bed Ash	65	1	39.69514	399
Fly Ash	73	1	46.91701	167.9
Combined Ash	57	6.1	1640.991	90619

EXHIBIT 4-28

Statistical Summary of all Total Constituent Results by All Fuels (mg/kg)

Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value
Bed Ash	Aluminum	34	9.000	3825.00	10682.00	30446.00	56700.00	68800.00	104300.00
	Antimony	58	0.100	2.50	3.50	28.00	62.00	111.40	1775.00
	Arsenic	62	0.250	3.50	9.93	34.70	58.00	82.00	119.70
	Barium	68	0.050	7.00	62.15	172.00	274.00	316.10	453.00
	Beryllium	38	0.500	0.50	1.10	8.00	15.00	17.00	31.00
	Boron	52	0.050	1.50	3.15	22.74	41.38	118.00	304.00
	Cadmium	61	0.003	0.50	0.50	1.50	3.60	6.75	14.00
	Chromium	68	3.700	5.00	16.18	41.85	56.10	74.10	259.80
	Cobalt	47	0.125	1.40	3.90	14.00	37.90	51.40	128.40
	Copper	65	0.500	1.70	8.90	18.50	26.00	42.70	50.00
	Iron	33	6.200	9570.00	13010.00	15640.00	18534.00	21111.10	31500.00
	Lead	67	0.050	1.50	2.50	26.00	56.00	66.00	89.90
	Manganese	33	34.500	62.00	110.00	379.00	610.00	719.40	892.90
	Mercury	54	0.000	0.01	0.10	0.10	0.43	1.10	208.90
	Molybdenum	52	0.050	3.90	13.00	19.60	27.00	48.00	190.00
	Nickel	63	2.000	22.50	66.70	735.00	1000.00	1270.00	1440.00
	Potassium	41	1.300	100.00	150.00	240.00	1340.00	4700.00	11950.00
	Selenium	56	0.001	0.52	2.00	3.50	3.50	13.40	45.00
	Silver	55	0.005	0.50	0.50	1.00	5.00	7.00	338.00
	Thallium	29	0.250	2.50	3.50	5.00	20.00	25.00	50.00
	Vanadium	37	12.000	1150.00	3820.00	5700.00	7550.00	8700.00	10000.00
	Zinc	65	1.000	20.00	26.00	33.10	52.70	147.50	399.00
Fly Ash	Aluminum	42	20.000	23495.60	32835.65	53415.00	88900.00	105920.00	176300.00
	Antimony	66	0.100	2.86	3.50	36.00	63.55	151.70	1370.00
	Arsenic	73	0.100	3.50	17.00	39.22	93.70	115.00	176.00
	Barium	73	0.100	17.00	177.00	320.33	540.00	940.00	7700.00
	Beryllium	39	0.500	0.50	1.20	6.00	11.00	15.00	16.00
	Boron	60	0.050	1.50	6.98	50.00	101.95	606.00	2473.00
	Cadmium	72	0.003	0.50	0.60	2.10	4.00	7.00	13.00
	Chromium	76	0.500	6.05	29.50	56.45	77.60	104.00	211.10
	Cobalt	47	0.125	2.00	5.00	19.00	33.90	75.30	178.50
	Copper	71	0.500	2.00	28.10	47.00	73.35	73.35	99.00
	Iron	46	22.170	18620.00	26530.00	32722.00	50900.00	55962.00	81318.00
	Lead	75	0.500	1.50	17.50	44.80	65.00	73.00	129.50
	Manganese	42	0.100	86.00	126.40	196.70	470.00	661.60	57700.00
	Mercury	73	0.000	0.10	0.31	0.95	1.68	7.35	384.20
	Molybdenum	67	0.050	3.10	9.00	21.10	28.50	48.64	143.60
	Nickel	75	12.500	32.80	51.20	529.00	825.00	900.00	1270.00
	Potassium	44	1.125	150.00	214.50	3132.00	8332.49	11478.80	14680.00
	Selenium	69	0.001	2.05	3.50	5.40	23.00	39.00	166.00
	Silver	64	0.005	0.50	0.50	2.00	3.40	5.00	38.50
	Thallium	34	0.500	2.50	3.50	5.00	20.00	25.00	39.01
	Vanadium	39	36.333	160.00	2880.00	3840.00	4830.00	5430.00	10000.00
	Zinc	73	1.000	28.00	36.00	54.50	79.77	114.40	167.90
Combined Ash	Aluminum	48	1.090	14617.50	24585.00	32950.00	44300.00	64000.00	75850.00
	Antimony	45	0.003	0.50	10.00	26.00	43.87	51.70	142.00
	Arsenic	60	0.140	7.08	13.05	32.49	68.90	106.15	115.50
	Barium	57	0.100	120.00	180.00	253.00	457.70	650.00	690.00
	Beryllium	12	0.295	0.99	1.91	2.51	5.00	9.50	9.50
	Boron	45	0.904	14.40	21.10	31.95	45.00	49.00	1670.00
	Cadmium	50	0.000	0.25	0.69	1.34	3.49	5.00	7.00
	Chromium	58	8.000	19.30	34.50	47.30	53.70	56.00	1906.00
	Cobalt	30	1.200	2.84	4.60	8.00	9.80	12.54	18.70
	Copper	56	1.900	19.10	26.10	37.45	71.00	249.00	408.10
	Iron	48	850.000	8042.50	12765.00	18175.00	26600.00	28074.70	51600.00
	Lead	57	0.714	13.00	23.00	33.80	52.30	67.00	89.00
	Manganese	47	20.000	49.00	61.80	91.00	133.00	170.40	905.00
	Mercury	57	0.000	0.06	0.26	0.61	0.80	2.78	29.00
	Molybdenum	50	0.050	2.50	9.96	16.00	24.00	27.00	41.00
	Nickel	59	0.500	11.35	15.40	23.00	70.60	530.00	985.00
	Potassium	26	2.820	2950.00	4140.00	5400.00	6362.00	6600.00	9163.00
	Selenium	59	0.003	1.25	4.00	9.80	16.00	22.97	27.00
	Silver	48	0.005	0.35	0.75	1.70	2.45	5.00	21.80
	Thallium	8	0.180	1.88	5.19	18.55	25.00	25.00	25.00
	Vanadium	11	19.570	21.50	38.00	838.00	1700.00	5000.00	5000.00
	Zinc	57	6.100	14.40	19.90	26.00	48.10	257.00	90619.00

EXHIBIT 4-29

Statistical Summary of all Total Constituent Results by Fuel = Coal (mg/kg)

Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value
Bed Ash	Aluminum	11	9.00	9.00	1390.00	41000.00	42850.00	68800.00	68800.00
	Antimony	12	2.00	3.75	7.50	44.00	158.00	1775.00	1775.00
	Arsenic	14	1.09	4.40	8.65	56.00	80.00	99.00	99.00
	Barium	19	66.00	88.00	175.00	274.00	431.00	453.00	453.00
	Beryllium	14	0.50	0.50	1.05	2.50	7.00	8.00	8.00
	Boron	10	0.06	0.06	45.18	118.00	247.00	304.00	304.00
	Cadmium	15	0.25	0.50	1.00	3.20	5.00	14.00	14.00
	Chromium	19	4.10	4.10	23.00	55.00	86.00	86.00	86.00
	Cobalt	17	1.40	1.40	12.50	25.00	61.20	128.40	128.40
	Copper	17	4.40	5.10	7.00	25.80	37.00	42.70	42.70
	Iron	10	6.20	6.20	466.10	13400.00	17470.00	19300.00	19300.00
	Lead	20	2.00	2.00	6.38	31.00	65.50	77.40	81.80
	Manganese	11	40.90	74.80	110.00	530.00	607.00	672.00	672.00
	Mercury	13	0.01	0.01	0.10	0.10	0.10	4.60	4.60
	Molybdenum	11	5.15	12.00	16.00	25.00	48.00	70.00	70.00
	Nickel	17	2.00	3.10	25.00	66.70	697.00	1440.00	1440.00
	Potassium	10	1.30	1.30	120.65	584.00	2010.00	3330.00	3330.00
	Selenium	13	0.25	1.00	1.00	2.00	5.00	45.00	45.00
	Silver	13	0.50	1.00	1.00	5.00	10.00	338.00	338.00
	Thallium	7	0.25	1.00	5.00	25.00	50.00	50.00	50.00
	Vanadium	12	12.00	12.00	54.00	1150.00	1150.00	1510.00	1510.00
	Zinc	17	20.00	29.00	29.00	40.00	71.10	399.00	399.00
Fly Ash	Aluminum	14	20.00	20.00	29895.00	88900.00	166000.00	176300.00	176300.00
	Antimony	17	2.00	2.86	5.00	22.00	70.00	1370.00	1370.00
	Arsenic	23	1.78	5.20	12.00	38.70	44.00	45.70	46.00
	Barium	20	150.00	296.00	320.33	672.00	1989.50	5194.50	7700.00
	Beryllium	13	0.50	1.08	2.20	2.50	11.00	12.00	12.00
	Boron	11	0.71	0.71	90.40	571.00	641.00	652.00	652.00
	Cadmium	23	0.42	0.46	0.60	2.50	3.00	4.00	13.00
	Chromium	23	12.00	21.33	29.00	49.40	72.00	140.00	141.60
	Cobalt	16	5.57	5.57	13.50	22.50	33.90	178.50	178.50
	Copper	20	9.80	25.08	42.50	73.35	82.38	95.20	99.00
	Iron	18	22.17	22.17	30729.05	47961.00	71721.00	81318.00	81318.00
	Lead	24	4.27	5.80	14.96	32.00	60.00	62.20	73.00
	Manganese	15	0.10	85.60	126.40	409.00	53000.00	57700.00	57700.00
	Mercury	22	0.10	0.16	0.31	0.47	0.64	0.79	7.35
	Molybdenum	21	2.10	3.10	5.80	10.00	23.00	25.00	61.00
	Nickel	22	12.50	16.27	34.50	51.20	825.00	1000.00	1020.00
	Potassium	13	1.13	1.13	1543.00	2364.00	4530.00	14680.00	14680.00
	Selenium	22	0.25	2.30	4.77	9.00	23.00	39.00	46.00
	Silver	19	0.29	0.29	1.00	2.80	5.00	38.50	38.50
	Thallium	12	0.50	2.40	2.79	5.00	25.00	25.00	25.00
	Vanadium	13	36.33	36.33	61.00	778.00	1000.00	1120.00	1120.00
	Zinc	22	24.00	28.00	36.00	72.00	81.71	90.00	105.00
Combined Ash	Aluminum	3	15800.00	15800.00	35875.00	39000.00	39000.00	39000.00	39000.00
	Antimony	6	0.13	2.50	14.50	25.00	40.86	40.86	40.86
	Arsenic	13	0.71	1.80	4.95	5.01	33.65	56.00	56.00
	Barium	11	29.40	180.50	457.70	650.00	690.00	690.00	690.00
	Beryllium	10	0.71	1.07	1.91	2.50	6.01	9.50	9.50
	Boron	5	2.50	4.80	27.00	49.00	1670.00	1670.00	1670.00
	Cadmium	12	0.27	1.30	2.40	3.64	5.90	7.00	7.00
	Chromium	11	11.00	16.50	25.00	45.00	55.50	113.00	113.00
	Cobalt	8	2.50	3.42	4.53	5.80	9.00	9.00	9.00
	Copper	12	8.86	16.50	43.25	175.80	357.00	408.10	408.10
	Iron	3	7430.00	7430.00	16000.00	16775.00	16775.00	16775.00	16775.00
	Lead	13	0.71	8.27	13.00	16.55	67.00	77.00	77.00
	Manganese	2	89.00	89.00	115.00	141.00	141.00	141.00	141.00
	Mercury	12	0.01	0.03	0.06	0.35	0.45	0.61	0.61
	Molybdenum	9	2.20	3.86	11.00	12.50	17.18	17.18	17.18
	Nickel	13	0.77	12.00	14.82	44.00	83.00	911.00	911.00
	Potassium	4	2.82	671.41	3170.00	7081.50	9163.00	9163.00	9163.00
	Selenium	12	0.43	1.61	4.10	6.72	8.00	18.00	18.00
	Silver	10	0.27	0.50	1.41	2.45	3.73	5.00	5.00
	Thallium	6	1.25	2.50	5.19	12.09	25.00	25.00	25.00
	Vanadium	9	19.57	21.50	31.27	41.00	838.00	838.00	838.00
	Zinc	12	11.00	20.66	27.85	52.05	127.00	257.00	257.00

EXHIBIT 4-30

Statistical Summary of all Total Constituent Results by Fuel = Waste Coal (mg/kg)

Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value
Bed Ash	Aluminum	23	538.20	7730.00	10980.00	30446.00	56700.00	56900.00	104300.00
	Antimony	23	0.10	0.59	26.96	42.00	71.00	75.00	111.40
	Arsenic	23	0.35	8.30	15.48	34.70	56.00	93.69	119.70
	Barium	23	0.05	35.90	79.40	199.80	216.50	316.00	316.10
	Beryllium	2	0.93	0.93	1.17	1.40	1.40	1.40	1.40
	Boron	19	0.05	1.20	19.79	29.00	35.40	41.38	41.38
	Cadmium	22	0.00	0.60	1.25	2.30	6.75	7.00	7.90
	Chromium	23	12.10	23.80	35.00	45.70	56.10	67.10	259.80
	Cobalt	6	0.13	14.70	17.40	40.00	51.40	51.40	51.40
	Copper	23	10.62	16.00	18.00	21.40	43.80	47.50	50.00
	Iron	23	6563.50	12060.00	13500.00	16100.00	18534.00	21111.10	31500.00
	Lead	22	0.05	20.00	27.00	38.80	56.50	66.00	89.90
	Manganese	22	34.50	52.70	174.15	379.00	610.00	719.40	892.90
	Mercury	17	0.00	0.00	0.01	0.11	0.45	208.90	208.90
	Molybdenum	17	0.05	0.15	14.00	22.00	43.78	190.00	190.00
	Nickel	21	9.00	15.00	30.10	37.50	54.80	67.50	99.90
	Potassium	6	721.10	1130.00	3020.00	10275.00	11950.00	11950.00	11950.00
	Selenium	19	0.00	0.00	0.35	0.75	13.40	25.30	25.30
	Silver	19	0.01	0.01	0.50	1.50	2.50	2.90	2.90
	Thallium	0							
	Vanadium	0							
	Zinc	23	9.50	21.50	25.57	48.83	147.50	156.30	214.80
Fly Ash	Aluminum	28	12142.80	30157.50	33102.50	47505.50	60984.00	62500.00	95200.00
	Antimony	27	0.10	0.55	37.00	55.00	151.70	221.30	561.20
	Arsenic	28	0.10	14.10	43.87	94.95	115.00	158.30	176.00
	Barium	28	0.10	130.00	206.50	297.00	452.90	670.00	692.00
	Beryllium	5	1.20	2.70	2.75	2.80	2.85	2.85	2.85
	Boron	27	0.05	18.00	37.77	53.00	75.00	108.00	2473.00
	Cadmium	27	0.00	0.70	1.59	2.80	7.00	7.00	7.15
	Chromium	28	24.80	51.85	56.45	73.20	94.10	104.00	211.10
	Cobalt	8	0.13	14.08	24.75	55.22	82.60	82.60	82.60
	Copper	27	24.30	31.29	40.70	52.00	65.80	72.00	73.50
	Iron	28	11298.00	19660.00	25577.81	30527.50	32980.00	47100.00	55962.00
	Lead	28	19.60	33.73	44.00	61.75	75.50	105.48	129.50
	Manganese	27	48.50	86.00	150.00	196.70	433.90	524.88	661.60
	Mercury	28	0.00	0.34	1.11	1.59	12.15	48.80	384.20
	Molybdenum	22	0.05	0.15	5.68	21.10	48.64	51.64	143.60
	Nickel	28	18.00	30.84	38.50	49.75	60.10	119.40	129.50
	Potassium	8	4390.00	4895.00	7085.55	10858.90	11571.00	11571.00	11571.00
	Selenium	24	0.00	1.39	2.81	9.15	32.70	77.90	166.00
	Silver	23	0.01	0.05	0.80	3.20	3.40	3.60	5.45
	Thallium	1	39.01	39.01	39.01	39.01	39.01	39.01	39.01
	Vanadium	1	36.43	36.43	36.43	36.43	36.43	36.43	36.43
	Zinc	27	16.88	33.10	51.48	59.30	150.90	163.00	167.90
Combined Ash	Aluminum	43	1.09	14800.00	24900.00	32600.00	44300.00	64000.00	75850.00
	Antimony	37	0.00	0.50	10.00	28.00	49.00	59.00	142.00
	Arsenic	45	0.14	11.00	18.10	35.00	82.30	110.70	115.50
	Barium	45	0.10	120.00	158.00	240.00	273.60	297.40	340.00
	Beryllium	0							
	Boron	39	0.90	15.98	21.10	31.95	40.00	46.50	50.00
	Cadmium	36	0.00	0.25	0.31	1.05	1.30	1.90	4.00
	Chromium	45	8.00	22.40	36.00	47.70	52.88	55.70	1906.00
	Cobalt	20	2.00	2.75	5.00	8.00	9.80	11.17	12.54
	Copper	42	8.52	19.40	24.05	34.20	42.00	46.56	71.00
	Iron	43	1905.00	8090.00	13200.00	19500.00	26600.00	28074.70	51600.00
	Lead	42	1.25	19.00	26.50	37.40	52.00	55.40	89.00
	Manganese	43	28.50	50.60	61.80	91.00	112.00	170.40	905.00
	Mercury	43	0.00	0.15	0.34	0.68	0.81	2.78	29.00
	Molybdenum	40	0.05	2.50	8.46	17.47	24.00	27.00	38.00
	Nickel	44	0.50	11.25	15.60	21.25	34.00	44.00	84.80
	Potassium	20	1860.00	3355.00	4180.00	5450.00	6281.00	6481.00	6600.00
	Selenium	45	0.00	1.20	3.45	10.00	16.00	22.97	27.00
	Silver	36	0.01	0.25	0.58	1.55	2.20	3.30	5.00
	Thallium	0							
	Vanadium	0							
	Zinc	43	6.10	13.40	15.90	24.00	30.00	43.27	90619.00

EXHIBIT 4-31

Statistical Summary of all Total Constituent Results by Fuel = Petroleum Coke (mg/kg)

Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value
Bed Ash	Aluminum	0							
	Antimony	23	0.31	2.50	3.50	3.50	3.50	3.50	3.50
	Arsenic	25	0.25	3.50	3.50	33.00	53.00	58.00	82.00
	Barium	26	0.25	5.10	6.55	8.00	13.00	14.40	18.00
	Beryllium	22	0.50	0.50	3.25	14.00	15.00	17.00	31.00
	Boron	23	1.00	1.50	2.00	3.35	4.00	5.00	17.00
	Cadmium	24	0.13	0.50	0.50	0.50	1.00	1.50	2.60
	Chromium	26	3.70	5.00	5.50	6.80	8.00	9.30	11.00
	Cobalt	24	0.50	1.05	3.00	3.95	5.00	5.00	8.00
	Copper	25	0.50	0.50	0.50	2.00	4.40	8.90	9.10
	Iron	0							
	Lead	25	0.49	1.00	1.50	1.50	1.50	2.30	3.90
	Manganese	0							
	Mercury	24	0.00	0.10	0.10	0.10	0.10	1.00	1.10
	Molybdenum	24	1.00	2.00	11.80	15.50	20.20	21.50	27.00
	Nickel	25	211.00	644.00	750.00	960.00	1270.00	1330.00	1430.00
	Potassium	25	3.35	100.00	150.00	150.00	150.00	150.00	165.00
	Selenium	24	0.05	2.50	3.25	3.50	3.50	3.50	3.50
	Silver	23	0.50	0.50	0.50	1.00	5.00	6.90	7.00
	Thallium	22	1.00	2.50	3.50	5.00	6.00	13.00	20.00
	Vanadium	25	2050.00	3820.00	4710.00	6400.00	8480.00	8700.00	10000.00
	Zinc	25	1.00	15.80	22.00	28.00	32.00	33.00	40.00
Fly Ash	Aluminum	0							
	Antimony	22	2.50	2.50	3.50	3.50	3.50	3.50	3.50
	Arsenic	22	0.25	2.50	3.50	20.00	33.00	33.00	38.00
	Barium	25	0.25	6.70	14.20	19.00	27.00	35.00	460.00
	Beryllium	21	0.50	0.50	0.50	7.00	8.00	15.00	16.00
	Boron	22	1.00	1.50	2.50	4.00	7.00	12.00	16.00
	Cadmium	22	0.50	0.50	0.50	0.50	1.00	1.00	3.70
	Chromium	25	0.50	4.00	5.00	6.00	6.60	7.00	14.00
	Cobalt	23	0.50	1.10	2.10	4.00	4.40	5.00	5.00
	Copper	24	0.50	0.50	1.00	2.45	6.90	8.80	9.10
	Iron	0							
	Lead	23	0.50	1.00	1.50	1.50	3.00	3.00	5.20
	Manganese	0							
	Mercury	23	0.00	0.10	0.10	0.10	0.60	1.00	1.00
	Molybdenum	24	1.00	9.00	14.95	23.50	28.00	28.50	36.00
	Nickel	25	277.00	430.00	562.00	740.00	865.00	900.00	1270.00
	Potassium	23	100.00	150.00	150.00	254.00	300.00	400.00	500.00
	Selenium	23	0.05	2.50	3.50	3.50	3.50	3.50	4.00
	Silver	22	0.50	0.50	0.50	0.50	1.00	2.00	9.70
	Thallium	21	1.00	2.50	3.50	3.50	10.00	13.00	20.00
	Vanadium	25	1589.00	2880.00	3450.00	4140.00	4860.00	5430.00	10000.00
	Zinc	24	1.00	19.10	31.20	40.00	46.50	48.00	56.40
Combined Ash	Aluminum	2	1700.00	1700.00	2805.00	3910.00	3910.00	3910.00	3910.00
	Antimony	2	1.20	1.20	6.85	12.50	12.50	12.50	12.50
	Arsenic	2	1.40	1.40	6.95	12.50	12.50	12.50	12.50
	Barium	1	39.20	39.20	39.20	39.20	39.20	39.20	39.20
	Beryllium	2	0.30	0.30	2.65	5.00	5.00	5.00	5.00
	Boron	1	12.00	12.00	12.00	12.00	12.00	12.00	12.00
	Cadmium	2	0.02	0.02	2.51	5.00	5.00	5.00	5.00
	Chromium	2	12.00	12.00	12.45	12.90	12.90	12.90	12.90
	Cobalt	2	1.20	1.20	9.95	18.70	18.70	18.70	18.70
	Copper	2	1.90	1.90	19.60	37.30	37.30	37.30	37.30
	Iron	2	850.00	850.00	3275.00	5700.00	5700.00	5700.00	5700.00
	Lead	2	0.90	0.90	4.20	7.50	7.50	7.50	7.50
	Manganese	2	20.00	20.00	32.90	45.80	45.80	45.80	45.80
	Mercury	2	0.06	0.06	0.16	0.25	0.25	0.25	0.25
	Molybdenum	1	41.00	41.00	41.00	41.00	41.00	41.00	41.00
	Nickel	2	530.00	530.00	757.50	985.00	985.00	985.00	985.00
	Potassium	2	637.00	637.00	668.50	700.00	700.00	700.00	700.00
	Selenium	2	7.00	7.00	9.75	12.50	12.50	12.50	12.50
	Silver	2	0.60	0.60	11.20	21.80	21.80	21.80	21.80
	Thallium	2	0.18	0.18	12.59	25.00	25.00	25.00	25.00
	Vanadium	2	1700.00	1700.00	3350.00	5000.00	5000.00	5000.00	5000.00
	Zinc	2	11.00	11.00	725.50	1440.00	1440.00	1440.00	1440.00

Experiments have been conducted to identify factors and quantify reaction rates controlling concentrations of inorganic elements in ash leachates. Overall, experimental results suggested that the two characteristics of fossil fuel combustion wastes that most affect their leaching behavior are the solid phases of the wastes and pH.[99] These results also indicate that the aqueous concentration of an individual element is dependent on its reaction chemistry and the hydrologic environment rather than its total amount in the waste.[100]

A total of 35 Special Project survey respondents submitted leachate data obtained from one or more leaching procedures (ASTM, EP, SPLP, STLC, TCLP) conducted on a total of 240 separate samples. These samples were analyzed for one or more of the TC metals, aluminum, antimony, beryllium, boron, cobalt, copper, iron, manganese, molybdenum, nickel, potassium, thallium, vanadium, and zinc. Exhibit 4-32 presents a summary of constituents found in ash as reported by the Special Project survey respondents. Exhibits 4-33 through 4-37 present statistical summaries of the respondent's leachate data aggregated by all tests and all fuel types, tests and all fuels, tests and coal, tests and waste coal, and tests and petroleum coke, respectively.

A comparison of the various leaching results by material type and fuel type with the TC levels found that none of the leachate results exceeded the TC levels - regardless of the fuel used - except for one bed ash sample that was analyzed for selenium and one fly ash sample analyzed for mercury. Both of these samples were determined to be statistical outliers using the Dixon Extreme Value test. In the case of selenium, 1 sample (2.5 mg/L) out of 64 samples exceeded the TC level of 1.0 mg/L. The next highest sample result for selenium was 0.1 mg/L. For mercury, 1 sample (0.29 mg/L) out of 76 samples exceeded the TC level of 0.2 mg/L. The next highest sample result for mercury was 0.01 mg/L.

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[99] "Characterization of Fossil-Fuel Combustion Wastes." EPRI Environment Division, *SWES News,* November 1987.

[100] "Geochemcial Reactions Control Leachate Composition of Fossil Fuel Wastes." EPRI Environment Division, *SWES News,* March 1988, pp. 1-5.

EXHIBIT 4-32

SUMMARY OF LEACHING TEST RESULTS -- ALL LEACHING TESTS -- ALL FUELS (mg/l)

Material Type	Aluminum				Antimony				Arsenic			
	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX
Bed Ash	26	0.05	2.226	20.6	26	0.0025	0.34788	1.25	69	0.001	0.05013	0.3
Fly Ash	35	0.04	10.702	120.8	37	0.0025	0.35402	1.52	81	0.0005	0.06189	0.6
Combined Ash	44	0.01	3.246	18.67	42	0.0001	0.18336	1.2	62	0.0023	0.08411	0.89

Material Type	Barium				Beryllium				Boron			
	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX
Bed Ash	67	0.025	0.485	8.4	11	0.00008	0.04911	0.28	23	0.003	0.594	3.95
Fly Ash	90	0.025	1.319	42	14	0.00008	0.02028	0.05	33	0.03	1.091	23.317
Combined Ash	60	0.005	1.218	37	6	0.002	1.31217	7.8	43	0.005	0.868	26.7

Material Type	Cadmium				Chromium				Cobalt			
	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX
Bed Ash	63	0.001	0.03537	0.5	68	0.005	0.05938	0.32	15	0.05	0.154	0.31
Fly Ash	76	0.001	0.03644	0.5	83	0.005	0.09124	0.91	18	0.005	0.10592	0.27
Combined Ash	51	0.0025	0.01526	0.13	60	0.0033	0.08599	0.6	24	0.0007	0.04012	0.4

Material Type	Copper				Iron				Lead			
	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX
Bed Ash	30	0.01	0.05377	0.184	29	0.04	1.78838	38.8	69	0.005	0.1438	0.71
Fly Ash	39	0.005	0.06289	0.183	38	0.01	0.47853	7.79	80	0.001	0.1579	0.7
Combined Ash	52	0.0025	0.28323	6.1	46	0.00005	0.14952	2.045	54	0.001	0.1211	1.54

Material Type	Manganese				Mercury				Molybdenum			
	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX
Bed Ash	28	0.004	0.78321	10.9	61	0.0001	0.00285	0.1	23	0.05	0.25543	1.2
Fly Ash	37	0.0025	0.22451	1.13	76	0.0001	0.00735	0.29	35	0.0232	0.24272	0.72
Combined Ash	47	0.0025	0.16556	0.66	51	0.0001	0.00652	0.1	46	0.025	0.16978	1.2

Material Type	Nickel				Potassium				Selenium			
	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX
Bed Ash	54	0.005	0.134	2.5	13	0.13	5.93	18.6	64	0.0005	0.08118	2.5
Fly Ash	65	0.005	0.111	1.2	20	1.21	24.14	66.8	81	0.0005	0.07391	0.42
Combined Ash	48	0.005	0.091	0.9	23	1.55	14.94	45.3	63	0.001	0.06072	0.35

Material Type	Silver				Thallium				Vanadium			
	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX	N	MIN	MEAN	MAX
Bed Ash	63	0.0015	0.04174	0.31	7	0.005	0.149	0.5	32	0.025	1.69875	40
Fly Ash	74	0.004	0.03216	0.24	9	0.005	0.103	0.5	35	0.0075	0.30333	3.2
Combined Ash	51	0.0025	0.02321	0.25	5	0.001	0.202	0.5	6	0.005	0.59967	2.2

Material Type	Zinc			
	N	MIN	MEAN	MAX
Bed Ash	34	0.0025	0.27581	4.46
Fly Ash	42	0.005	0.25083	4.46
Combined Ash	54	0.0025	0.14843	2.4

EXHIBIT 4-33
Statistical Summary of all Leachate Test Results by All Fuels (mg/l)

Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value
Bed Ash	Aluminum	26	0.05000	0.13000	0.3250	1.6000	10.5000	13.140	20.600
	Antimony	26	0.00250	0.05000	0.3350	0.5000	0.7100	0.920	1.250
	Arsenic	69	0.00100	0.01000	0.0500	0.0500	0.1250	0.180	0.300
	Barium	67	0.02500	0.05000	0.2000	0.4520	0.9000	1.000	8.400
	Beryllium	11	0.00008	0.00500	0.0250	0.0500	0.0500	0.280	0.280
	Boron	23	0.00300	0.10000	0.1200	0.5500	2.6000	2.800	3.950
	Cadmium	63	0.00100	0.01600	0.0250	0.0300	0.0500	0.090	0.500
	Chromium	68	0.00500	0.02500	0.0250	0.0550	0.1770	0.220	0.320
	Cobalt	15	0.05000	0.12500	0.1400	0.1750	0.2500	0.310	0.310
	Copper	30	0.01000	0.02000	0.0495	0.0600	0.1340	0.158	0.184
	Iron	29	0.04000	0.09900	0.1900	0.5100	2.7900	3.200	38.800
	Lead	69	0.00500	0.02500	0.0500	0.2500	0.3600	0.418	0.710
	Manganese	28	0.00400	0.03350	0.0545	0.1900	0.7800	7.600	10.900
	Mercury	61	0.00010	0.00030	0.0010	0.0010	0.0014	0.010	0.100
	Molybdenum	23	0.05000	0.12500	0.1600	0.2400	0.6100	0.940	1.200
	Nickel	54	0.00500	0.02500	0.0500	0.1600	0.2360	0.250	2.500
	Potassium	13	0.12500	2.00000	5.6000	8.4000	11.0000	18.600	18.600
	Selenium	64	0.00050	0.00250	0.0500	0.0500	0.1000	0.134	2.500
	Silver	63	0.00150	0.02400	0.0250	0.0430	0.1000	0.125	0.310
	Thallium	7	0.00500	0.04500	0.0500	0.3250	0.5000	0.500	0.500
	Vanadium	32	0.02500	0.10500	0.3300	0.4550	1.6400	3.400	40.000
	Zinc	34	0.00250	0.02000	0.0650	0.1110	0.5100	1.040	4.460
Fly Ash	Aluminum	35	0.04000	0.22000	0.5000	8.4500	23.9000	111.000	120.800
	Antimony	37	0.00250	0.03070	0.1000	0.5000	1.1700	1.290	1.520
	Arsenic	81	0.00050	0.01100	0.0500	0.0500	0.1190	0.250	0.600
	Barium	90	0.02500	0.08000	0.3000	0.6250	1.5500	6.500	42.000
	Beryllium	14	0.00008	0.00330	0.0105	0.0500	0.0500	0.050	0.050
	Boron	33	0.03000	0.10000	0.2800	0.6000	0.9800	1.400	23.317
	Cadmium	76	0.00100	0.02000	0.0250	0.0400	0.0600	0.100	0.500
	Chromium	83	0.00500	0.02500	0.0500	0.1200	0.2000	0.260	0.910
	Cobalt	18	0.00500	0.04500	0.0980	0.1370	0.2500	0.270	0.270
	Copper	39	0.00500	0.02000	0.0580	0.0850	0.1330	0.160	0.183
	Iron	38	0.01000	0.09000	0.1800	0.5000	0.7600	0.900	7.790
	Lead	80	0.00100	0.02500	0.0500	0.2685	0.4450	0.518	0.700
	Manganese	37	0.00250	0.03000	0.0500	0.3300	0.7300	1.100	1.130
	Mercury	76	0.00010	0.00025	0.0010	0.0010	0.0040	0.010	0.290
	Molybdenum	35	0.02320	0.07000	0.2000	0.3200	0.5900	0.610	0.720
	Nickel	65	0.00500	0.02500	0.0500	0.1600	0.2500	0.330	1.200
	Potassium	20	1.21000	4.63000	17.7000	39.3000	54.2500	63.400	66.800
	Selenium	81	0.00050	0.00700	0.0500	0.1000	0.2000	0.266	0.420
	Silver	74	0.00400	0.02000	0.0250	0.0400	0.0520	0.100	0.240
	Thallium	9	0.00500	0.04500	0.0500	0.0500	0.5000	0.500	0.500
	Vanadium	35	0.00750	0.09000	0.1300	0.2040	0.7000	1.640	3.200
	Zinc	42	0.00500	0.02000	0.0568	0.1400	0.3700	1.040	4.460
Combined Ash	Aluminum	44	0.01000	0.53500	1.8650	4.0550	8.8900	10.700	18.670
	Antimony	42	0.00010	0.00500	0.0950	0.2700	0.5000	0.590	1.200
	Arsenic	62	0.00230	0.01000	0.0250	0.0500	0.2500	0.350	0.890
	Barium	60	0.00500	0.05600	0.1700	0.5950	1.1585	3.925	37.000
	Beryllium	6	0.00200	0.00200	0.0095	0.0500	7.8000	7.800	7.800
	Boron	43	0.00500	0.09000	0.1600	0.4600	0.6000	0.650	26.700
	Cadmium	51	0.00250	0.00250	0.0050	0.0130	0.0500	0.050	0.130
	Chromium	60	0.00330	0.02500	0.0500	0.1150	0.2450	0.280	0.600
	Cobalt	24	0.00070	0.00500	0.0180	0.0250	0.0315	0.250	0.400
	Copper	52	0.00250	0.01000	0.0225	0.0855	0.4400	1.860	6.100
	Iron	46	0.00005	0.01500	0.0700	0.1780	0.3100	0.360	2.045
	Lead	54	0.00100	0.02500	0.0500	0.1290	0.2500	0.430	1.540
	Manganese	47	0.00250	0.00500	0.0500	0.3100	0.4700	0.619	0.660
	Mercury	51	0.00010	0.00010	0.0002	0.0010	0.0020	0.100	0.100
	Molybdenum	46	0.02500	0.05000	0.0865	0.2000	0.4100	0.540	1.200
	Nickel	48	0.00500	0.02000	0.0250	0.0920	0.2640	0.420	0.900
	Potassium	23	1.55400	7.50000	14.5000	20.0000	24.0000	27.200	45.300
	Selenium	63	0.00100	0.00800	0.0200	0.0500	0.2400	0.256	0.350
	Silver	51	0.00250	0.00500	0.0050	0.0150	0.0400	0.130	0.250
	Thallium	5	0.00100	0.00100	0.0500	0.4600	0.5000	0.500	0.500
	Vanadium	6	0.00500	0.08599	0.1535	1.0000	2.2000	2.200	2.200
	Zinc	54	0.00250	0.00500	0.0215	0.1340	0.3000	0.480	2.400

EXHIBIT 4-34
Statistical Summary of Leachate Test Results by Leachate Test and All Fuels (mg/l)

Leach Procedure	Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value
ASTM	Combined Ash	Aluminum	0							
		Antimony	1	0.003	0.003	0.003	0.003	0.003	0.003	0.003
		Arsenic	2	0.003	0.003	0.006	0.010	0.010	0.010	0.010
		Barium	2	0.270	0.270	18.635	37.000	37.000	37.000	37.000
		Beryllium	2	0.002	0.002	0.002	0.002	0.002	0.002	0.002
		Boron	2	0.005	0.005	0.048	0.090	0.090	0.090	0.090
		Cadmium	2	0.003	0.003	0.003	0.003	0.003	0.003	0.003
		Chromium	2	0.005	0.005	0.013	0.020	0.020	0.020	0.020
		Cobalt	2	0.005	0.005	0.005	0.005	0.005	0.005	0.005
		Copper	2	0.005	0.005	0.005	0.005	0.005	0.005	0.005
		Iron	2	0.005	0.005	0.005	0.005	0.005	0.005	0.005
		Lead	2	0.003	0.003	0.004	0.006	0.006	0.006	0.006
		Manganese	2	0.003	0.003	0.003	0.003	0.003	0.003	0.003
		Mercury	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Molybdenum	0							
		Nickel	2	0.005	0.005	0.005	0.005	0.005	0.005	0.005
		Potassium	0							
		Selenium	2	0.010	0.010	0.018	0.025	0.025	0.025	0.025
		Silver	2	0.005	0.005	0.005	0.005	0.005	0.005	0.005
		Thallium	2	0.001	0.001	0.001	0.001	0.001	0.001	0.001
		Vanadium	0							
		Zinc	2	0.005	0.005	0.033	0.060	0.060	0.060	0.060
OTHER	Bed Ash	Aluminum	0							
		Antimony	2	0.100	0.100	0.300	0.500	0.500	0.500	0.500
		Arsenic	2	0.050	0.050	0.065	0.080	0.080	0.080	0.080
		Barium	2	0.730	0.730	1.115	1.500	1.500	1.500	1.500
		Beryllium	2	0.030	0.030	0.040	0.050	0.050	0.050	0.050
		Boron	1	2.800	2.800	2.800	2.800	2.800	2.800	2.800
		Cadmium	2	0.050	0.050	0.103	0.155	0.155	0.155	0.155
		Chromium	2	0.050	0.050	0.114	0.177	0.177	0.177	0.177
		Cobalt	2	0.175	0.175	0.213	0.250	0.250	0.250	0.250
		Copper	2	0.050	0.050	0.117	0.184	0.184	0.184	0.184
		Iron	0							
		Lead	2	0.210	0.210	0.230	0.250	0.250	0.250	0.250
		Manganese	1	7.600	7.600	7.600	7.600	7.600	7.600	7.600
		Mercury	2	0.001	0.001	0.001	0.001	0.001	0.001	0.001
		Molybdenum	2	0.175	0.175	0.557	0.940	0.940	0.940	0.940
		Nickel	2	0.175	0.175	1.338	2.500	2.500	2.500	2.500
		Potassium	0							
		Selenium	2	0.010	0.010	0.045	0.080	0.080	0.080	0.080
		Silver	2	0.100	0.100	0.128	0.155	0.155	0.155	0.155
		Thallium	2	0.050	0.050	0.188	0.325	0.325	0.325	0.325
		Vanadium	2	0.290	0.290	1.845	3.400	3.400	3.400	3.400
		Zinc	2	0.250	0.250	0.310	0.370	0.370	0.370	0.370
OTHER	Fly Ash	Aluminum	1	111.000	111.000	111.000	111.000	111.000	111.000	111.000
		Antimony	4	0.003	0.066	0.315	0.500	0.500	0.500	0.500
		Arsenic	4	0.002	0.006	0.030	0.085	0.119	0.119	0.119
		Barium	6	0.363	0.580	4.100	8.000	11.900	11.900	11.900
		Beryllium	3	0.016	0.016	0.050	0.050	0.050	0.050	0.050
		Boron	1	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Cadmium	4	0.003	0.026	0.050	0.054	0.058	0.058	0.058
		Chromium	5	0.010	0.134	0.140	0.150	0.200	0.200	0.200
		Cobalt	3	0.086	0.086	0.250	0.250	0.250	0.250	0.250
		Copper	5	0.005	0.050	0.100	0.160	0.183	0.183	0.183
		Iron	1	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Lead	4	0.001	0.082	0.206	0.250	0.250	0.250	0.250
		Manganese	1	0.005	0.005	0.005	0.005	0.005	0.005	0.005
		Mercury	4	0.000	0.001	0.001	0.002	0.003	0.003	0.003
		Molybdenum	4	0.040	0.133	0.238	0.420	0.590	0.590	0.590
		Nickel	4	0.005	0.128	0.338	0.813	1.200	1.200	1.200
		Potassium	1	27.000	27.000	27.000	27.000	27.000	27.000	27.000
		Selenium	7	0.003	0.070	0.266	0.310	0.340	0.340	0.340
		Silver	4	0.005	0.029	0.076	0.100	0.100	0.100	0.100
		Thallium	3	0.050	0.050	0.144	0.500	0.500	0.500	0.500
		Vanadium	4	0.204	0.402	0.700	2.000	3.200	3.200	3.200
		Zinc	4	0.010	0.066	0.186	0.250	0.250	0.250	0.250
OTHER	Combined Ash	Aluminum	0							
		Antimony	3	0.017	0.017	0.050	0.500	0.500	0.500	0.500
		Arsenic	6	0.005	0.010	0.026	0.100	0.890	0.890	0.890
		Barium	5	0.280	0.820	1.820	2.550	5.300	5.300	5.300
		Beryllium	3	0.005	0.005	0.050	7.800	7.800	7.800	7.800
		Boron	2	0.037	0.037	0.069	0.100	0.100	0.100	0.100
		Cadmium	4	0.008	0.029	0.050	0.090	0.130	0.130	0.130
		Chromium	6	0.027	0.050	0.053	0.300	0.600	0.600	0.600
		Cobalt	2	0.025	0.025	0.138	0.250	0.250	0.250	0.250
		Copper	7	0.005	0.050	0.440	2.790	6.100	6.100	6.100
		Iron	1	0.025	0.025	0.025	0.025	0.025	0.025	0.025
		Lead	5	0.014	0.045	0.250	0.250	1.540	1.540	1.540

EXHIBIT 4-34 (Continued)
Statistical Summary of Leachate Test Results by Leachate Test and All Fuels (mg/l)

Leach Procedure	Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value
		Manganese	1	0.025	0.025	0.025	0.025	0.025	0.025	0.025
		Mercury	4	0.001	0.001	0.002	0.006	0.010	0.010	0.010
		Molybdenum	6	0.057	0.140	0.495	0.614	1.200	1.200	1.200
		Nickel	4	0.025	0.035	0.148	0.575	0.900	0.900	0.900
		Potassium	0							
		Selenium	6	0.009	0.010	0.027	0.104	0.300	0.300	0.300
		Silver	4	0.009	0.009	0.055	0.150	0.200	0.200	0.200
		Thallium	3	0.050	0.050	0.460	0.500	0.500	0.500	0.500
		Vanadium	6	0.005	0.086	0.154	1.000	2.200	2.200	2.200
		Zinc	6	0.025	0.100	0.225	0.250	2.400	2.400	2.400
SPLP	Bed Ash	Aluminum	12	0.050	0.170	0.415	1.050	1.600	2.130	2.130
		Antimony	8	0.003	0.018	0.250	0.475	0.505	0.505	0.505
		Arsenic	11	0.003	0.003	0.006	0.084	0.176	0.180	0.180
		Barium	10	0.100	0.240	0.330	0.360	0.478	0.512	0.512
		Beryllium	3	0.000	0.000	0.025	0.025	0.025	0.025	0.025
		Boron	9	0.050	0.100	0.100	0.200	0.244	0.244	0.244
		Cadmium	9	0.003	0.005	0.013	0.016	0.040	0.040	0.040
		Chromium	11	0.025	0.030	0.050	0.067	0.075	0.075	0.075
		Cobalt	9	0.080	0.125	0.125	0.140	0.155	0.155	0.155
		Copper	12	0.013	0.020	0.035	0.048	0.050	0.060	0.060
		Iron	12	0.050	0.075	0.165	0.443	0.570	2.790	2.790
		Lead	12	0.050	0.105	0.245	0.320	0.418	0.710	0.710
		Manganese	11	0.020	0.030	0.036	0.050	0.190	0.780	0.780
		Mercury	7	0.000	0.000	0.000	0.001	0.100	0.100	0.100
		Molybdenum	9	0.070	0.125	0.150	0.180	0.240	0.240	0.240
		Nickel	11	0.050	0.050	0.110	0.170	0.170	0.236	0.236
		Potassium	11	0.125	1.480	5.600	8.400	9.400	18.600	18.600
		Selenium	10	0.001	0.003	0.009	0.134	0.290	0.400	0.400
		Silver	8	0.005	0.027	0.040	0.067	0.310	0.310	0.310
		Thallium	1	0.005	0.005	0.005	0.005	0.005	0.005	0.005
		Vanadium	2	0.038	0.038	0.038	0.038	0.038	0.038	0.038
		Zinc	12	0.009	0.018	0.056	0.068	0.080	1.030	1.030
SPLP	Fly Ash	Aluminum	14	0.080	0.150	0.320	0.620	8.450	16.620	16.620
		Antimony	10	0.003	0.018	0.065	0.140	0.352	0.470	0.470
		Arsenic	14	0.002	0.003	0.015	0.042	0.100	0.400	0.400
		Barium	13	0.050	0.210	0.420	0.610	0.722	0.892	0.892
		Beryllium	3	0.000	0.000	0.000	0.005	0.005	0.005	0.005
		Boron	11	0.050	0.070	0.100	0.370	0.650	23.317	23.317
		Cadmium	11	0.003	0.015	0.020	0.050	0.053	0.100	0.100
		Chromium	14	0.010	0.050	0.070	0.090	0.170	0.190	0.190
		Cobalt	10	0.009	0.025	0.095	0.125	0.146	0.155	0.155
		Copper	14	0.010	0.020	0.044	0.058	0.070	0.085	0.085
		Iron	14	0.015	0.075	0.121	0.160	0.380	0.760	0.760
		Lead	14	0.002	0.050	0.220	0.310	0.516	0.600	0.600
		Manganese	13	0.005	0.020	0.030	0.040	0.250	0.570	0.570
		Mercury	13	0.000	0.000	0.000	0.001	0.080	0.100	0.100
		Molybdenum	12	0.023	0.104	0.190	0.335	0.400	0.500	0.500
		Nickel	13	0.014	0.050	0.050	0.140	0.180	0.196	0.196
		Potassium	13	1.210	4.700	19.300	38.000	60.000	66.800	66.800
		Selenium	13	0.001	0.003	0.028	0.072	0.180	0.420	0.420
		Silver	11	0.005	0.007	0.027	0.030	0.040	0.046	0.046
		Thallium	1	0.005	0.005	0.005	0.005	0.005	0.005	0.005
		Vanadium	1	0.008	0.008	0.008	0.008	0.008	0.008	0.008
		Zinc	14	0.010	0.015	0.039	0.070	0.250	1.200	1.200
SPLP	Combined Ash	Aluminum	19	0.010	0.790	1.590	2.870	8.280	8.850	8.850
		Antimony	15	0.000	0.005	0.030	0.130	0.320	0.490	0.490
		Arsenic	19	0.003	0.010	0.017	0.025	0.140	0.250	0.250
		Barium	18	0.050	0.050	0.120	0.150	0.330	0.550	0.550
		Beryllium	0							
		Boron	15	0.010	0.063	0.100	0.240	0.420	0.570	0.570
		Cadmium	13	0.003	0.003	0.005	0.010	0.010	0.026	0.026
		Chromium	18	0.025	0.025	0.100	0.150	0.280	0.280	0.280
		Cobalt	12	0.001	0.005	0.021	0.025	0.025	0.032	0.032
		Copper	15	0.005	0.010	0.010	0.040	0.079	0.250	0.250
		Iron	18	0.000	0.015	0.060	0.110	0.310	0.330	0.330
		Lead	15	0.005	0.025	0.025	0.120	0.160	0.160	0.160
		Manganese	17	0.003	0.005	0.005	0.050	0.370	0.380	0.380
		Mercury	14	0.000	0.000	0.000	0.001	0.100	0.100	0.100
		Molybdenum	18	0.038	0.058	0.091	0.190	0.230	0.240	0.240
		Nickel	16	0.005	0.020	0.025	0.055	0.090	0.120	0.120
		Potassium	16	5.200	7.835	12.800	21.450	27.200	45.300	45.300
		Selenium	20	0.001	0.005	0.010	0.030	0.050	0.130	0.210
		Silver	13	0.003	0.005	0.005	0.010	0.010	0.020	0.020
		Thallium	0							
		Vanadium	0							
		Zinc	21	0.003	0.005	0.017	0.040	0.080	0.220	0.441

EXHIBIT 4-34 (Continued)
Statistical Summary of Leachate Test Results by Leachate Test and All Fuels (mg/l)

Leach Procedure	Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value

STLC	Bed Ash	Aluminum	0							
		Antimony	1	0.500	0.500	0.500	0.500	0.500	0.500	0.500
		Arsenic	1	0.010	0.010	0.010	0.010	0.010	0.010	0.010
		Barium	1	0.820	0.820	0.820	0.820	0.820	0.820	0.820
		Beryllium	1	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Boron	0							
		Cadmium	1	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Chromium	1	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Cobalt	1	0.250	0.250	0.250	0.250	0.250	0.250	0.250
		Copper	1	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Iron	0							
		Lead	1	0.250	0.250	0.250	0.250	0.250	0.250	0.250
		Manganese	0							
		Mercury	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
		Molybdenum	1	1.200	1.200	1.200	1.200	1.200	1.200	1.200
		Nickel	1	0.250	0.250	0.250	0.250	0.250	0.250	0.250
		Potassium	0							
		Selenium	1	0.010	0.010	0.010	0.010	0.010	0.010	0.010
		Silver	1	0.100	0.100	0.100	0.100	0.100	0.100	0.100
		Thallium	1	0.500	0.500	0.500	0.500	0.500	0.500	0.500
		Vanadium	1	2.200	2.200	2.200	2.200	2.200	2.200	2.200
		Zinc	1	0.250	0.250	0.250	0.250	0.250	0.250	0.250
STLC	Fly Ash	Aluminum	0							
		Antimony	0							
		Arsenic	0							
		Barium	1	6.000	6.000	6.000	6.000	6.000	6.000	6.000
		Beryllium	0							
		Boron	0							
		Cadmium	0							
		Chromium	1	0.200	0.200	0.200	0.200	0.200	0.200	0.200
		Cobalt	0							
		Copper	1	0.100	0.100	0.100	0.100	0.100	0.100	0.100
		Iron	0							
		Lead	0							
		Manganese	0							
		Mercury	0							
		Molybdenum	0							
		Nickel	0							
		Potassium	0							
		Selenium	1	0.240	0.240	0.240	0.240	0.240	0.240	0.240
		Silver	0							
		Thallium	0							
		Vanadium	1	0.700	0.700	0.700	0.700	0.700	0.700	0.700
		Zinc	0							
STLC	Combined Ash	Aluminum	0							
		Antimony	0							
		Arsenic	1	0.570	0.570	0.570	0.570	0.570	0.570	0.570
		Barium	0							
		Beryllium	1	0.014	0.014	0.014	0.014	0.014	0.014	0.014
		Boron	0							
		Cadmium	0							
		Chromium	0							
		Cobalt	0							
		Copper	1	1.860	1.860	1.860	1.860	1.860	1.860	1.860
		Iron	0							
		Lead	1	0.430	0.430	0.430	0.430	0.430	0.430	0.430
		Manganese	0							
		Mercury	0							
		Molybdenum	0							
		Nickel	0							
		Potassium	0							
		Selenium	1	0.103	0.103	0.103	0.103	0.103	0.103	0.103
		Silver	0							
		Thallium	0							
		Vanadium	0							
		Zinc	0							
TCLP + EP	Bed Ash	Aluminum	14	0.050	0.113	0.315	2.000	13.140	20.600	20.600
		Antimony	15	0.010	0.050	0.330	0.590	0.920	1.250	1.250
		Arsenic	54	0.001	0.012	0.050	0.050	0.061	0.250	0.300
		Barium	53	0.025	0.025	0.130	0.400	0.900	1.000	8.400
		Beryllium	5	0.000	0.005	0.025	0.050	0.280	0.280	0.280
		Boron	13	0.003	0.100	0.130	0.559	2.600	3.950	3.950
		Cadmium	50	0.001	0.022	0.025	0.025	0.050	0.090	0.500
		Chromium	53	0.005	0.025	0.025	0.050	0.190	0.250	0.320
		Cobalt	3	0.050	0.050	0.140	0.310	0.310	0.310	0.310
		Copper	15	0.010	0.030	0.050	0.070	0.138	0.158	0.158

EXHIBIT 4-34 (Continued)

Statistical Summary of Leachate Test Results by Leachate Test and All Fuels (mg/l)

Leach Procedure	Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value
		Iron	17	0.040	0.105	0.298	0.510	3.200	38.800	38.800
		Lead	53	0.005	0.025	0.025	0.230	0.300	0.400	0.700
		Manganese	16	0.004	0.052	0.079	0.200	0.530	10.900	10.900
		Mercury	50	0.000	0.001	0.001	0.001	0.002	0.010	0.010
		Molybdenum	11	0.050	0.050	0.160	0.250	0.400	0.610	0.610

		Nickel	40	0.005	0.025	0.025	0.121	0.176	0.241	0.410
		Potassium	2	2.000	2.000	6.500	11.000	11.000	11.000	11.000
		Selenium	50	0.001	0.003	0.050	0.050	0.050	0.100	2.500
		Silver	51	0.002	0.020	0.025	0.025	0.050	0.110	0.250
		Thallium	3	0.045	0.045	0.050	0.070	0.070	0.070	0.070
		Vanadium	27	0.025	0.110	0.340	0.450	0.490	1.640	40.000
		Zinc	19	0.003	0.020	0.069	0.111	1.040	4.460	4.460
TCLP + EP	Fly Ash	Aluminum	20	0.040	0.270	0.745	15.630	24.085	72.535	120.800
		Antimony	23	0.007	0.050	0.339	1.000	1.260	1.290	1.520
		Arsenic	62	0.001	0.025	0.050	0.050	0.125	0.250	0.600
		Barium	69	0.025	0.060	0.250	0.540	1.030	2.600	42.000
		Beryllium	8	0.000	0.004	0.015	0.038	0.050	0.050	0.050
		Boron	21	0.030	0.250	0.410	0.760	0.980	1.270	1.400
		Cadmium	60	0.001	0.020	0.025	0.030	0.070	0.090	0.500
		Chromium	62	0.005	0.025	0.039	0.114	0.220	0.290	0.910
		Cobalt	5	0.005	0.050	0.050	0.110	0.270	0.270	0.270
		Copper	19	0.005	0.023	0.070	0.093	0.133	0.159	0.159
		Iron	23	0.010	0.120	0.360	0.600	0.792	0.900	7.790
		Lead	61	0.005	0.025	0.025	0.277	0.430	0.490	0.700
		Manganese	23	0.003	0.050	0.100	0.600	0.750	1.100	1.130
		Mercury	58	0.000	0.000	0.001	0.001	0.003	0.010	0.290
		Molybdenum	19	0.050	0.050	0.200	0.320	0.610	0.720	0.720
		Nickel	48	0.005	0.025	0.025	0.147	0.210	0.250	0.460
		Potassium	6	2.000	4.000	12.050	40.600	44.000	44.000	44.000
		Selenium	59	0.001	0.008	0.050	0.050	0.180	0.200	0.235
		Silver	58	0.004	0.022	0.025	0.035	0.050	0.060	0.240
		Thallium	5	0.035	0.045	0.045	0.050	0.050	0.050	0.050
		Vanadium	29	0.025	0.090	0.120	0.180	0.230	0.250	1.640
		Zinc	24	0.005	0.021	0.075	0.175	0.570	1.040	4.460
TCLP + EP	Combined Ash	Aluminum	25	0.050	0.290	2.000	4.230	10.700	11.500	18.670
		Antimony	23	0.000	0.005	0.100	0.280	0.590	1.000	1.200
		Arsenic	34	0.002	0.018	0.025	0.091	0.250	0.350	0.683
		Barium	35	0.005	0.050	0.210	0.620	1.003	1.301	10.500
		Beryllium	0							
		Boron	24	0.010	0.100	0.430	0.517	0.650	0.820	26.700
		Cadmium	32	0.003	0.004	0.005	0.015	0.040	0.050	0.096
		Chromium	34	0.003	0.025	0.028	0.090	0.141	0.240	0.250
		Cobalt	8	0.001	0.005	0.013	0.025	0.400	0.400	0.400
		Copper	27	0.003	0.010	0.030	0.085	0.096	0.132	0.593
		Iron	25	0.000	0.044	0.130	0.186	0.360	0.615	2.045
		Lead	31	0.001	0.025	0.050	0.126	0.190	0.260	1.000
		Manganese	27	0.003	0.010	0.230	0.392	0.619	0.633	0.660
		Mercury	31	0.000	0.000	0.000	0.001	0.002	0.005	0.100
		Molybdenum	22	0.025	0.050	0.081	0.150	0.270	0.380	0.410
		Nickel	26	0.005	0.020	0.037	0.112	0.340	0.420	0.460
		Potassium	7	1.554	7.300	15.000	17.000	24.000	24.000	24.000
		Selenium	34	0.001	0.009	0.023	0.110	0.250	0.260	0.350
		Silver	32	0.003	0.005	0.005	0.017	0.040	0.130	0.250
		Thallium	0							
		Vanadium	0							
		Zinc	25	0.003	0.005	0.023	0.147	0.380	0.480	1.400

EXHIBIT 4-35
Statistical Summary of Leachate Test Results by Leachate Test and Fuels = Coal (mg/l)

Leach Procedure	Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value
ASTM	Combined Ash	Aluminum	0							
		Antimony	1	0.003	0.003	0.003	0.003	0.003	0.003	0.003
		Arsenic	2	0.003	0.003	0.006	0.010	0.010	0.010	0.010
		Barium	2	0.270	0.270	18.635	37.000	37.000	37.000	37.000
		Beryllium	2	0.002	0.002	0.002	0.002	0.002	0.002	0.002
		Boron	2	0.005	0.005	0.048	0.090	0.090	0.090	0.090
		Cadmium	2	0.003	0.003	0.003	0.003	0.003	0.003	0.003
		Chromium	2	0.005	0.005	0.013	0.020	0.020	0.020	0.020
		Cobalt	2	0.005	0.005	0.005	0.005	0.005	0.005	0.005
		Copper	2	0.005	0.005	0.005	0.005	0.005	0.005	0.005
		Iron	2	0.005	0.005	0.005	0.005	0.005	0.005	0.005
		Lead	2	0.003	0.003	0.004	0.006	0.006	0.006	0.006
		Manganese	2	0.003	0.003	0.003	0.003	0.003	0.003	0.003
		Mercury	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Molybdenum	0							
		Nickel	2	0.005	0.005	0.005	0.005	0.005	0.005	0.005
		Potassium	0							
		Selenium	2	0.010	0.010	0.018	0.025	0.025	0.025	0.025
		Silver	2	0.005	0.005	0.005	0.005	0.005	0.005	0.005
		Thallium	2	0.001	0.001	0.001	0.001	0.001	0.001	0.001
		Vanadium	0							
		Zinc	2	0.005	0.005	0.033	0.060	0.060	0.060	0.060
OTHER	Bed Ash	Aluminum	0							
		Antimony	2	0.100	0.100	0.300	0.500	0.500	0.500	0.500
		Arsenic	2	0.050	0.050	0.065	0.080	0.080	0.080	0.080
		Barium	2	0.730	0.730	1.115	1.500	1.500	1.500	1.500
		Beryllium	2	0.030	0.030	0.040	0.050	0.050	0.050	0.050
		Boron	1	2.800	2.800	2.800	2.800	2.800	2.800	2.800
		Cadmium	2	0.050	0.050	0.103	0.155	0.155	0.155	0.155
		Chromium	2	0.050	0.050	0.114	0.177	0.177	0.177	0.177
		Cobalt	2	0.175	0.175	0.213	0.250	0.250	0.250	0.250
		Copper	2	0.050	0.050	0.117	0.184	0.184	0.184	0.184
		Iron	0							
		Lead	2	0.210	0.210	0.230	0.250	0.250	0.250	0.250
		Manganese	1	7.600	7.600	7.600	7.600	7.600	7.600	7.600
		Mercury	2	0.001	0.001	0.001	0.001	0.001	0.001	0.001
		Molybdenum	2	0.175	0.175	0.557	0.940	0.940	0.940	0.940
		Nickel	2	0.175	0.175	1.338	2.500	2.500	2.500	2.500
		Potassium	0							
		Selenium	2	0.010	0.010	0.045	0.080	0.080	0.080	0.080
		Silver	2	0.100	0.100	0.128	0.155	0.155	0.155	0.155
		Thallium	2	0.050	0.050	0.188	0.325	0.325	0.325	0.325
		Vanadium	2	0.290	0.290	1.845	3.400	3.400	3.400	3.400
		Zinc	2	0.250	0.250	0.310	0.370	0.370	0.370	0.370
OTHER	Fly Ash	Aluminum	1	111.000	111.000	111.000	111.000	111.000	111.000	111.000
		Antimony	4	0.003	0.066	0.315	0.500	0.500	0.500	0.500
		Arsenic	4	0.002	0.006	0.030	0.085	0.119	0.119	0.119
		Barium	6	0.363	0.580	4.100	8.000	11.900	11.900	11.900
		Beryllium	3	0.016	0.016	0.050	0.050	0.050	0.050	0.050
		Boron	1	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Cadmium	4	0.003	0.026	0.050	0.054	0.058	0.058	0.058
		Chromium	5	0.010	0.134	0.140	0.150	0.200	0.200	0.200
		Cobalt	3	0.086	0.086	0.250	0.250	0.250	0.250	0.250
		Copper	5	0.005	0.050	0.100	0.160	0.183	0.183	0.183
		Iron	1	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Lead	4	0.001	0.082	0.206	0.250	0.250	0.250	0.250
		Manganese	1	0.005	0.005	0.005	0.005	0.005	0.005	0.005
		Mercury	4	0.000	0.001	0.001	0.002	0.003	0.003	0.003
		Molybdenum	4	0.040	0.133	0.238	0.420	0.590	0.590	0.590
		Nickel	4	0.005	0.128	0.338	0.813	1.200	1.200	1.200
		Potassium	1	27.000	27.000	27.000	27.000	27.000	27.000	27.000
		Selenium	7	0.003	0.070	0.266	0.310	0.340	0.340	0.340
		Silver	4	0.005	0.029	0.076	0.100	0.100	0.100	0.100
		Thallium	3	0.050	0.050	0.144	0.500	0.500	0.500	0.500
		Vanadium	4	0.204	0.402	0.700	2.000	3.200	3.200	3.200
		Zinc	4	0.010	0.066	0.186	0.250	0.250	0.250	0.250
OTHER	Combined Ash	Aluminum	0							
		Antimony	3	0.017	0.017	0.050	0.500	0.500	0.500	0.500
		Arsenic	6	0.005	0.010	0.026	0.100	0.890	0.890	0.890
		Barium	5	0.280	0.820	1.820	2.550	5.300	5.300	5.300
		Beryllium	3	0.005	0.005	0.050	7.800	7.800	7.800	7.800
		Boron	2	0.037	0.037	0.069	0.100	0.100	0.100	0.100
		Cadmium	4	0.008	0.029	0.050	0.090	0.130	0.130	0.130
		Chromium	6	0.027	0.050	0.053	0.300	0.600	0.600	0.600
		Cobalt	2	0.025	0.025	0.138	0.250	0.250	0.250	0.250
		Copper	7	0.005	0.050	0.440	2.790	6.100	6.100	6.100

EXHIBIT 4-35 (Continued)
Statistical Summary of Leachate Test Results by Leachate Test and Fuels = Coal (mg/l)

Leach Procedure	Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value
		Iron	1	0.025	0.025	0.025	0.025	0.025	0.025	0.025
		Lead	5	0.014	0.045	0.250	0.250	1.540	1.540	1.540
		Manganese	1	0.025	0.025	0.025	0.025	0.025	0.025	0.025
		Mercury	4	0.001	0.001	0.002	0.006	0.010	0.010	0.010
		Molybdenum	6	0.057	0.140	0.495	0.614	1.200	1.200	1.200
		Nickel	4	0.025	0.035	0.148	0.575	0.900	0.900	0.900
		Potassium	0							
		Selenium	6	0.009	0.010	0.027	0.104	0.300	0.300	0.300
		Silver	4	0.009	0.009	0.055	0.150	0.200	0.200	0.200
		Thallium	3	0.050	0.050	0.460	0.500	0.500	0.500	0.500
		Vanadium	6	0.005	0.086	0.154	1.000	2.200	2.200	2.200
		Zinc	6	0.025	0.100	0.225	0.250	2.400	2.400	2.400
SPLP	Bed Ash	Aluminum	4	0.100	0.135	0.885	1.600	1.600	1.600	1.600
		Antimony	4	0.003	0.014	0.263	0.503	0.505	0.505	0.505
		Arsenic	3	0.003	0.003	0.003	0.005	0.005	0.005	0.005
		Barium	4	0.330	0.330	0.387	0.478	0.512	0.512	0.512
		Beryllium	2	0.025	0.025	0.025	0.025	0.025	0.025	0.025
		Boron	4	0.100	0.100	0.150	0.222	0.244	0.244	0.244
		Cadmium	4	0.003	0.004	0.005	0.011	0.016	0.016	0.016
		Chromium	4	0.025	0.046	0.071	0.075	0.075	0.075	0.075
		Cobalt	4	0.125	0.125	0.133	0.148	0.155	0.155	0.155
		Copper	4	0.013	0.013	0.029	0.048	0.050	0.050	0.050
		Iron	4	0.147	0.232	0.443	0.570	0.570	0.570	0.570
		Lead	4	0.240	0.245	0.250	0.334	0.418	0.418	0.418
		Manganese	4	0.025	0.031	0.037	0.044	0.050	0.050	0.050
		Mercury	3	0.000	0.000	0.001	0.100	0.100	0.100	0.100
		Molybdenum	4	0.125	0.125	0.153	0.210	0.240	0.240	0.240
		Nickel	4	0.102	0.114	0.125	0.181	0.236	0.236	0.236
		Potassium	4	0.125	0.688	1.365	2.090	2.700	2.700	2.700
		Selenium	3	0.003	0.003	0.003	0.013	0.013	0.013	0.013
		Silver	4	0.050	0.050	0.067	0.197	0.310	0.310	0.310
		Thallium	1	0.005	0.005	0.005	0.005	0.005	0.005	0.005
		Vanadium	2	0.038	0.038	0.038	0.038	0.038	0.038	0.038
		Zinc	4	0.009	0.030	0.059	0.065	0.065	0.065	0.065
SPLP	Fly Ash	Aluminum	4	0.100	0.115	0.140	0.260	0.370	0.370	0.370
		Antimony	4	0.003	0.014	0.083	0.187	0.233	0.233	0.233
		Arsenic	4	0.003	0.004	0.028	0.225	0.400	0.400	0.400
		Barium	4	0.214	0.337	0.543	0.674	0.722	0.722	0.722
		Beryllium	1	0.005	0.005	0.005	0.005	0.005	0.005	0.005
		Boron	4	0.070	0.085	0.170	0.250	0.260	0.260	0.260
		Cadmium	4	0.003	0.009	0.018	0.035	0.050	0.050	0.050
		Chromium	4	0.025	0.048	0.072	0.077	0.080	0.080	0.080
		Cobalt	4	0.025	0.035	0.091	0.146	0.155	0.155	0.155
		Copper	4	0.013	0.032	0.055	0.072	0.085	0.085	0.085
		Iron	4	0.050	0.072	0.114	0.143	0.150	0.150	0.150
		Lead	4	0.050	0.135	0.225	0.373	0.516	0.516	0.516
		Manganese	4	0.005	0.017	0.035	0.145	0.250	0.250	0.250
		Mercury	4	0.000	0.001	0.003	0.053	0.100	0.100	0.100
		Molybdenum	4	0.077	0.189	0.335	0.435	0.500	0.500	0.500
		Nickel	4	0.025	0.043	0.079	0.147	0.196	0.196	0.196
		Potassium	4	1.210	1.960	3.635	4.630	4.700	4.700	4.700
		Selenium	4	0.003	0.003	0.016	0.105	0.180	0.180	0.180
		Silver	4	0.010	0.019	0.029	0.038	0.046	0.046	0.046
		Thallium	1	0.005	0.005	0.005	0.005	0.005	0.005	0.005
		Vanadium	1	0.008	0.008	0.008	0.008	0.008	0.008	0.008
		Zinc	4	0.010	0.011	0.028	0.147	0.250	0.250	0.250
STLC	Bed Ash	Aluminum	0							
		Antimony	1	0.500	0.500	0.500	0.500	0.500	0.500	0.500
		Arsenic	1	0.010	0.010	0.010	0.010	0.010	0.010	0.010
		Barium	1	0.820	0.820	0.820	0.820	0.820	0.820	0.820
		Beryllium	1	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Boron	0							
		Cadmium	1	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Chromium	1	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Cobalt	1	0.250	0.250	0.250	0.250	0.250	0.250	0.250
		Copper	1	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Iron	0							
		Lead	1	0.250	0.250	0.250	0.250	0.250	0.250	0.250
		Manganese	0							
		Mercury	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
		Molybdenum	1	1.200	1.200	1.200	1.200	1.200	1.200	1.200
		Nickel	1	0.250	0.250	0.250	0.250	0.250	0.250	0.250
		Potassium	0							
		Selenium	1	0.010	0.010	0.010	0.010	0.010	0.010	0.010
		Silver	1	0.100	0.100	0.100	0.100	0.100	0.100	0.100
		Thallium	1	0.500	0.500	0.500	0.500	0.500	0.500	0.500

EXHIBIT 4-35 (Continued)

Statistical Summary of Leachate Test Results by Leachate Test and Fuels = Coal (mg/l)

Leach Procedure	Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value
		Vanadium	1	2.200	2.200	2.200	2.200	2.200	2.200	2.200

		Zinc	1	0.250	0.250	0.250	0.250	0.250	0.250	0.250
STLC	Fly Ash	Aluminum	0							
		Antimony	0							
		Arsenic	0							
		Barium	1	6.000	6.000	6.000	6.000	6.000	6.000	6.000
		Beryllium	0							
		Boron	0							
		Cadmium	0							
		Chromium	1	0.200	0.200	0.200	0.200	0.200	0.200	0.200
		Cobalt	0							
		Copper	1	0.100	0.100	0.100	0.100	0.100	0.100	0.100
		Iron	0							
		Lead	0							
		Manganese	0							
		Mercury	0							
		Molybdenum	0							
		Nickel	0							
		Potassium	0							
		Selenium	1	0.240	0.240	0.240	0.240	0.240	0.240	0.240
		Silver	0							
		Thallium	0							
		Vanadium	1	0.700	0.700	0.700	0.700	0.700	0.700	0.700
		Zinc	0							
STLC	Combined Ash	Aluminum	0							
		Antimony	0							
		Arsenic	1	0.570	0.570	0.570	0.570	0.570	0.570	0.570
		Barium	0							
		Beryllium	1	0.014	0.014	0.014	0.014	0.014	0.014	0.014
		Boron	0							
		Cadmium	0							
		Chromium	0							
		Cobalt	0							
		Copper	1	1.860	1.860	1.860	1.860	1.860	1.860	1.860
		Iron	0							
		Lead	1	0.430	0.430	0.430	0.430	0.430	0.430	0.430
		Manganese	0							
		Mercury	0							
		Molybdenum	0							
		Nickel	0							
		Potassium	0							
		Selenium	1	0.103	0.103	0.103	0.103	0.103	0.103	0.103
		Silver	0							
		Thallium	0							
		Vanadium	0							
		Zinc	0							
TCLP + EP	Bed Ash	Aluminum	1	2.000	2.000	2.000	2.000	2.000	2.000	2.000
		Antimony	1	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Arsenic	13	0.001	0.003	0.005	0.050	0.125	0.250	0.250
		Barium	13	0.050	0.380	0.620	1.000	5.000	8.400	8.400
		Beryllium	1	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Boron	3	0.900	0.900	2.600	3.950	3.950	3.950	3.950
		Cadmium	13	0.001	0.005	0.030	0.050	0.050	0.125	0.125
		Chromium	14	0.005	0.040	0.090	0.140	0.200	0.250	0.250
		Cobalt	3	0.050	0.050	0.140	0.310	0.310	0.310	0.310
		Copper	2	0.010	0.010	0.030	0.050	0.050	0.050	0.050
		Iron	3	0.090	0.090	0.430	3.200	3.200	3.200	3.200
		Lead	13	0.005	0.025	0.060	0.300	0.400	0.700	0.700
		Manganese	3	0.040	0.040	0.060	0.100	0.100	0.100	0.100
		Mercury	13	0.000	0.001	0.001	0.003	0.010	0.010	0.010
		Molybdenum	1	0.200	0.200	0.200	0.200	0.200	0.200	0.200
		Nickel	3	0.050	0.050	0.150	0.410	0.410	0.410	0.410
		Potassium	1	2.000	2.000	2.000	2.000	2.000	2.000	2.000
		Selenium	13	0.001	0.001	0.003	0.050	0.100	0.125	0.125
		Silver	13	0.005	0.020	0.040	0.060	0.125	0.250	0.250
		Thallium	1	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Vanadium	1	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Zinc	3	0.010	0.010	0.020	0.050	0.050	0.050	0.050
TCLP + EP	Fly Ash	Aluminum	2	1.000	1.000	1.000	1.000	1.000	1.000	1.000
		Antimony	2	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Arsenic	16	0.001	0.003	0.018	0.050	0.150	0.400	0.400
		Barium	23	0.035	0.300	0.550	1.100	4.800	8.000	42.000
		Beryllium	2	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Boron	6	0.030	0.050	0.330	0.760	1.400	1.400	1.400

EXHIBIT 4-35 (Continued)
Statistical Summary of Leachate Test Results by Leachate Test and Fuels = Coal (mg/l)

Leach Procedure	Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value
		Cadmium	17	0.001	0.005	0.020	0.050	0.080	0.125	0.125
		Chromium	17	0.005	0.030	0.080	0.130	0.220	0.220	0.220
		Cobalt	5	0.005	0.050	0.050	0.110	0.270	0.270	0.270
		Copper	3	0.005	0.005	0.010	0.060	0.060	0.060	0.060
		Iron	5	0.050	0.090	0.120	0.410	0.600	0.600	0.600
		Lead	16	0.005	0.025	0.050	0.260	0.400	0.700	0.700

		Manganese	5	0.003	0.040	0.050	0.050	0.050	0.050	0.050
		Mercury	17	0.000	0.000	0.001	0.003	0.005	0.010	0.010
		Molybdenum	3	0.050	0.050	0.140	0.300	0.300	0.300	0.300
		Nickel	6	0.005	0.030	0.050	0.140	0.460	0.460	0.460
		Potassium	2	2.000	2.000	3.000	4.000	4.000	4.000	4.000
		Selenium	17	0.001	0.005	0.015	0.125	0.200	0.200	0.200
		Silver	17	0.005	0.010	0.030	0.050	0.060	0.125	0.125
		Thallium	2	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Vanadium	2	0.050	0.050	0.050	0.050	0.050	0.050	0.050
		Zinc	5	0.010	0.010	0.050	0.050	0.140	0.140	0.140
TCLP + EP	Combined Ash	Aluminum	1	0.280	0.280	0.280	0.280	0.280	0.280	0.280
		Antimony	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
		Arsenic	7	0.002	0.010	0.020	0.050	0.200	0.200	0.200
		Barium	7	0.005	0.600	0.700	1.301	10.500	10.500	10.500
		Beryllium	0							
		Boron	2	0.160	0.160	13.430	26.700	26.700	26.700	26.700
		Cadmium	7	0.005	0.005	0.005	0.050	0.096	0.096	0.096
		Chromium	7	0.003	0.005	0.010	0.040	0.250	0.250	0.250
		Cobalt	2	0.007	0.007	0.203	0.400	0.400	0.400	0.400
		Copper	4	0.003	0.004	0.029	0.066	0.080	0.080	0.080
		Iron	2	0.100	0.100	0.230	0.360	0.360	0.360	0.360
		Lead	7	0.001	0.025	0.025	0.025	1.000	1.000	1.000
		Manganese	2	0.060	0.060	0.100	0.140	0.140	0.140	0.140
		Mercury	7	0.000	0.000	0.000	0.001	0.002	0.002	0.002
		Molybdenum	3	0.025	0.025	0.025	0.085	0.085	0.085	0.085
		Nickel	4	0.005	0.006	0.009	0.175	0.340	0.340	0.340
		Potassium	1	1.554	1.554	1.554	1.554	1.554	1.554	1.554
		Selenium	7	0.009	0.010	0.014	0.050	0.100	0.100	0.100
		Silver	7	0.004	0.005	0.005	0.025	0.050	0.050	0.050
		Thallium	0							
		Vanadium	0							
		Zinc	4	0.005	0.013	0.025	0.057	0.083	0.083	0.083

EXHIBIT 4-36
Statistical Summary of Leachate Test Results by Leachate Test and Fuels = Waste Coal (mg/l)

Leach Procedure	Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value
SPLP	Bed Ash	Aluminum	8	0.0500	0.2200	0.4150	0.5000	2.1300	2.130	2.130
		Antimony	4	0.0100	0.0550	0.2500	0.4250	0.4500	0.450	0.450
		Arsenic	8	0.0025	0.0040	0.0557	0.1295	0.1800	0.180	0.180
		Barium	6	0.1000	0.2100	0.2750	0.3400	0.3600	0.360	0.360
		Beryllium	1	0.0001	0.0001	0.0001	0.0001	0.0001	0.000	0.000
		Boron	5	0.0500	0.1000	0.1000	0.1200	0.2200	0.220	0.220
		Cadmium	5	0.0100	0.0130	0.0160	0.0300	0.0400	0.040	0.040
		Chromium	7	0.0250	0.0300	0.0500	0.0600	0.0670	0.067	0.067
		Cobalt	5	0.0800	0.1100	0.1250	0.1250	0.1500	0.150	0.150
		Copper	8	0.0200	0.0200	0.0350	0.0450	0.0600	0.060	0.060
		Iron	8	0.0500	0.0750	0.1125	0.2100	2.7900	2.790	2.790
		Lead	8	0.0500	0.0650	0.1700	0.3200	0.7100	0.710	0.710
		Manganese	7	0.0200	0.0300	0.0300	0.1900	0.7800	0.780	0.780
		Mercury	4	0.0001	0.0001	0.0002	0.0002	0.0003	0.000	0.000
		Molybdenum	5	0.0700	0.1500	0.1500	0.1600	0.2100	0.210	0.210
		Nickel	7	0.0500	0.0500	0.0900	0.1700	0.1700	0.170	0.170
		Potassium	7	3.5000	5.6000	7.1000	9.4000	18.6000	18.600	18.600
		Selenium	7	0.0010	0.0025	0.1097	0.1800	0.4000	0.400	0.400
		Silver	4	0.0050	0.0145	0.0270	0.0300	0.0300	0.030	0.030
		Thallium	0							
		Vanadium	0							
		Zinc	8	0.0150	0.0175	0.0500	0.0750	1.0300	1.030	1.030
SPLP	Fly Ash	Aluminum	10	0.0800	0.2200	0.5000	1.9400	12.5350	16.620	16.620
		Antimony	6	0.0050	0.0180	0.0654	0.1000	0.4700	0.470	0.470
		Arsenic	10	0.0020	0.0025	0.0146	0.0400	0.0710	0.100	0.100
		Barium	9	0.0500	0.1000	0.3300	0.5900	0.8923	0.892	0.892
		Beryllium	2	0.0001	0.0001	0.0002	0.0004	0.0004	0.000	0.000
		Boron	7	0.0500	0.0500	0.1000	0.6500	23.3168	23.317	23.317
		Cadmium	7	0.0060	0.0200	0.0200	0.0525	0.1000	0.100	0.100
		Chromium	10	0.0100	0.0500	0.0600	0.1200	0.1800	0.190	0.190
		Cobalt	6	0.0085	0.0250	0.0950	0.1250	0.1250	0.125	0.125
		Copper	10	0.0100	0.0200	0.0297	0.0500	0.0700	0.070	0.070
		Iron	10	0.0150	0.0750	0.1205	0.2000	0.5700	0.760	0.760
		Lead	10	0.0023	0.0500	0.1700	0.3100	0.4550	0.600	0.600
		Manganese	9	0.0100	0.0200	0.0300	0.0404	0.5700	0.570	0.570
		Mercury	9	0.0001	0.0001	0.0002	0.0003	0.0800	0.080	0.080
		Molybdenum	8	0.0232	0.0900	0.1700	0.2350	0.4000	0.400	0.400
		Nickel	9	0.0143	0.0500	0.0500	0.1400	0.1800	0.180	0.180
		Potassium	9	10.6894	19.3000	36.5000	48.5000	66.8000	66.800	66.800
		Selenium	9	0.0010	0.0025	0.0279	0.0723	0.4200	0.420	0.420
		Silver	7	0.0050	0.0050	0.0140	0.0300	0.0400	0.040	0.040
		Thallium	0							
		Vanadium	0							
		Zinc	10	0.0150	0.0200	0.0420	0.0700	0.6400	1.200	1.200
SPLP	Combined Ash	Aluminum	19	0.0100	0.7900	1.5900	2.8700	8.2800	8.850	8.850
		Antimony	15	0.0002	0.0050	0.0300	0.1300	0.3200	0.490	0.490
		Arsenic	19	0.0025	0.0100	0.0170	0.0250	0.1400	0.250	0.250
		Barium	18	0.0500	0.0500	0.1200	0.1500	0.3300	0.550	0.550
		Beryllium	0							
		Boron	15	0.0100	0.0630	0.1000	0.2400	0.4200	0.570	0.570
		Cadmium	13	0.0025	0.0025	0.0050	0.0100	0.0100	0.026	0.026
		Chromium	18	0.0250	0.0250	0.1000	0.1500	0.2800	0.280	0.280
		Cobalt	12	0.0007	0.0050	0.0205	0.0250	0.0250	0.032	0.032
		Copper	15	0.0050	0.0100	0.0100	0.0400	0.0790	0.250	0.250
		Iron	18	0.0001	0.0150	0.0600	0.1100	0.3100	0.330	0.330
		Lead	15	0.0050	0.0250	0.0250	0.1200	0.1600	0.160	0.160
		Manganese	17	0.0025	0.0050	0.0050	0.0500	0.3700	0.380	0.380
		Mercury	14	0.0001	0.0001	0.0002	0.0005	0.1000	0.100	0.100
		Molybdenum	18	0.0380	0.0580	0.0905	0.1900	0.2300	0.240	0.240
		Nickel	16	0.0050	0.0200	0.0250	0.0550	0.0900	0.120	0.120
		Potassium	16	5.2000	7.8350	12.8000	21.4500	27.2000	45.300	45.300
		Selenium	20	0.0010	0.0050	0.0100	0.0300	0.0500	0.130	0.210
		Silver	13	0.0025	0.0050	0.0050	0.0100	0.0100	0.020	0.020
		Thallium	0							
		Vanadium	0							
		Zinc	21	0.0025	0.0050	0.0170	0.0400	0.0800	0.220	0.441
TCLP + EP	Bed Ash	Aluminum	13	0.0500	0.1130	0.3100	1.9100	13.1400	20.600	20.600
		Antimony	12	0.0104	0.2960	0.3900	0.6500	0.9200	1.250	1.250
		Arsenic	14	0.0010	0.0100	0.0160	0.0220	0.0610	0.170	0.170
		Barium	12	0.0500	0.1000	0.2255	0.4260	0.8500	0.970	0.970
		Beryllium	2	0.0001	0.0001	0.1401	0.2800	0.2800	0.280	0.280
		Boron	10	0.0030	0.1000	0.1000	0.4300	0.5545	0.559	0.559
		Cadmium	10	0.0025	0.0090	0.0165	0.0300	0.0650	0.090	0.090
		Chromium	12	0.0180	0.0250	0.0250	0.0400	0.2200	0.320	0.320
		Cobalt	0							

EXHIBIT 4-36 (Continued)
Statistical Summary of Leachate Test Results by Leachate Test and Fuels = Waste Coal

(mg/l)

Leach Procedure	Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value
		Copper	13	0.0100	0.0360	0.0530	0.0700	0.1380	0.158	0.158
		Iron	14	0.0400	0.1050	0.2440	0.5100	1.0500	38.800	38.800
		Lead	13	0.0135	0.1700	0.2300	0.2750	0.3100	0.480	0.480
		Manganese	13	0.0040	0.0530	0.0980	0.2100	0.5300	10.900	10.900
		Mercury	10	0.0001	0.0001	0.0001	0.0001	0.0051	0.010	0.010
		Molybdenum	10	0.0500	0.0500	0.1600	0.2500	0.5050	0.610	0.610
		Nickel	12	0.0050	0.0985	0.1600	0.1760	0.2400	0.241	0.241
		Potassium	1	11.0000	11.0000	11.0000	11.0000	11.0000	11.000	11.000
		Selenium	10	0.0005	0.0025	0.0025	0.0100	1.2588	2.500	2.500
		Silver	11	0.0015	0.0050	0.0050	0.0200	0.0430	0.060	0.060
		Thallium	0							
		Vanadium	0							
		Zinc	15	0.0025	0.0200	0.0700	0.1110	1.0400	4.460	4.460
TCLP + EP	Fly Ash	Aluminum	18	0.0400	0.2590	0.4750	15.8300	24.2700	120.800	120.800
		Antimony	18	0.0070	0.1000	0.4800	1.0400	1.2900	1.520	1.520
		Arsenic	18	0.0025	0.0200	0.0390	0.0865	0.2600	0.600	0.600
		Barium	18	0.0500	0.1500	0.3050	0.5100	0.8300	1.030	1.030
		Beryllium	3	0.0001	0.0001	0.0033	0.0040	0.0040	0.004	0.004
		Boron	15	0.1000	0.2590	0.4100	0.7680	0.9800	1.270	1.270
		Cadmium	16	0.0025	0.0165	0.0220	0.0450	0.0800	0.100	0.100
		Chromium	18	0.0250	0.0500	0.0810	0.2600	0.3300	0.910	0.910
		Cobalt	0							
		Copper	16	0.0100	0.0525	0.0700	0.0965	0.1330	0.159	0.159
		Iron	18	0.0100	0.2360	0.3740	0.6700	0.9000	7.790	7.790
		Lead	18	0.0135	0.2600	0.2950	0.4600	0.5200	0.520	0.520
		Manganese	18	0.0100	0.0580	0.2700	0.6480	1.1000	1.130	1.130
		Mercury	14	0.0001	0.0001	0.0001	0.0010	0.0100	0.290	0.290
		Molybdenum	16	0.0500	0.0600	0.2100	0.4050	0.6100	0.720	0.720
		Nickel	17	0.0050	0.1150	0.1600	0.2090	0.2500	0.330	0.330
		Potassium	4	8.0000	12.0500	28.3500	42.3000	44.0000	44.000	44.000
		Selenium	14	0.0025	0.0080	0.0188	0.1500	0.1830	0.235	0.235
		Silver	14	0.0040	0.0050	0.0235	0.0400	0.0450	0.050	0.050
		Thallium	0							
		Vanadium	0							
		Zinc	18	0.0050	0.0400	0.1000	0.3500	1.0400	4.460	4.460
TCLP + EP	Combined Ash	Aluminum	24	0.0500	0.4550	2.4950	4.9150	10.7000	11.500	18.670
		Antimony	22	0.0001	0.0250	0.1000	0.2800	0.5900	1.000	1.200
		Arsenic	24	0.0060	0.0168	0.0250	0.0855	0.1480	0.300	0.683
		Barium	25	0.0050	0.0500	0.2000	0.3670	0.7450	1.003	1.016
		Beryllium	0							
		Boron	22	0.0100	0.1000	0.4300	0.5000	0.6100	0.650	0.820
		Cadmium	22	0.0025	0.0025	0.0050	0.0130	0.0190	0.027	0.040
		Chromium	24	0.0150	0.0250	0.0530	0.1000	0.1410	0.220	0.240
		Cobalt	6	0.0007	0.0050	0.0125	0.0250	0.0250	0.025	0.025
		Copper	23	0.0025	0.0100	0.0300	0.0860	0.0960	0.132	0.593
		Iron	23	0.0001	0.0150	0.1300	0.1860	0.2400	0.615	2.045
		Lead	21	0.0050	0.0250	0.0500	0.1260	0.1420	0.190	0.260
		Manganese	25	0.0025	0.0100	0.2300	0.3920	0.6190	0.633	0.660
		Mercury	21	0.0001	0.0001	0.0001	0.0002	0.0010	0.005	0.100
		Molybdenum	19	0.0250	0.0500	0.0810	0.2100	0.3800	0.410	0.410
		Nickel	22	0.0050	0.0250	0.0540	0.1120	0.2640	0.420	0.460
		Potassium	6	7.3000	14.5000	15.1000	17.0000	24.0000	24.000	24.000
		Selenium	24	0.0010	0.0048	0.0200	0.1550	0.2500	0.256	0.260
		Silver	22	0.0025	0.0050	0.0075	0.0150	0.0280	0.040	0.130
		Thallium	0							
		Vanadium	0							
		Zinc	21	0.0025	0.0050	0.0230	0.2340	0.3800	0.480	1.400

EXHIBIT 4-37
Statistical Summary of Leachate Test Results by Leachate Test & Fuels = Petroleum Coke (mg/l)

Leach Procedure	Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value
TCLP + EP	Bed Ash	Aluminum	0							
		Antimony	2	0.0500	0.0500	0.0500	0.050	0.050	0.050	0.050
		Arsenic	27	0.0250	0.0500	0.0500	0.050	0.050	0.250	0.300
		Barium	28	0.0250	0.0250	0.0250	0.085	0.250	0.330	0.740
		Beryllium	2	0.0050	0.0050	0.0150	0.025	0.025	0.025	0.025
		Boron	0							
		Cadmium	27	0.0100	0.0250	0.0250	0.025	0.025	0.025	0.500
		Chromium	27	0.0250	0.0250	0.0250	0.025	0.025	0.050	0.250
		Cobalt	0							
		Copper	0							
		Iron	0							
		Lead	27	0.0150	0.0250	0.0250	0.025	0.025	0.025	0.250
		Manganese	0							
		Mercury	27	0.0010	0.0010	0.0010	0.001	0.001	0.001	0.001
		Molybdenum	0							
		Nickel	25	0.0200	0.0250	0.0250	0.025	0.025	0.025	0.120
		Potassium	0							
		Selenium	27	0.0250	0.0500	0.0500	0.050	0.050	0.050	0.050
		Silver	27	0.0250	0.0250	0.0250	0.025	0.025	0.025	0.050
		Thallium	2	0.0450	0.0450	0.0575	0.070	0.070	0.070	0.070
		Vanadium	26	0.0250	0.1500	0.3400	0.450	0.490	1.640	40.000
		Zinc	1	0.5100	0.5100	0.5100	0.510	0.510	0.510	0.510
TCLP + EP	Fly Ash	Aluminum	0							
		Antimony	3	0.0500	0.0500	0.0500	0.050	0.050	0.050	0.050
		Arsenic	28	0.0250	0.0500	0.0500	0.050	0.050	0.100	0.250
		Barium	28	0.0250	0.0250	0.0750	0.115	0.330	0.380	0.710
		Beryllium	3	0.0050	0.0050	0.0250	0.025	0.025	0.025	0.025
		Boron	0							
		Cadmium	27	0.0100	0.0250	0.0250	0.025	0.025	0.050	0.500
		Chromium	27	0.0250	0.0250	0.0250	0.025	0.050	0.050	0.250
		Cobalt	0							
		Copper	0							
		Iron	0							
		Lead	27	0.0150	0.0250	0.0250	0.025	0.025	0.050	0.250
		Manganese	0							
		Mercury	27	0.0010	0.0010	0.0010	0.001	0.001	0.002	0.004
		Molybdenum	0							
		Nickel	25	0.0200	0.0250	0.0250	0.025	0.025	0.050	0.120
		Potassium	0							
		Selenium	28	0.0050	0.0500	0.0500	0.050	0.050	0.050	0.100
		Silver	27	0.0250	0.0250	0.0250	0.025	0.050	0.060	0.240
		Thallium	3	0.0350	0.0350	0.0450	0.045	0.045	0.045	0.045
		Vanadium	27	0.0250	0.0900	0.1200	0.190	0.230	0.250	1.640
		Zinc	1	0.0200	0.0200	0.0200	0.020	0.020	0.020	0.020
TCLP + EP	Combined Ash	Aluminum	0							
		Antimony	0							
		Arsenic	3	0.0500	0.0500	0.2500	0.350	0.350	0.350	0.350
		Barium	3	0.0400	0.0400	0.0850	1.000	1.000	1.000	1.000
		Beryllium	0							
		Boron	0							
		Cadmium	3	0.0050	0.0050	0.0050	0.050	0.050	0.050	0.050
		Chromium	3	0.0050	0.0050	0.0100	0.100	0.100	0.100	0.100
		Cobalt	0							
		Copper	0							
		Iron	0							
		Lead	3	0.0200	0.0200	0.1000	0.250	0.250	0.250	0.250
		Manganese	0							
		Mercury	3	0.0002	0.0002	0.0010	0.002	0.002	0.002	0.002
		Molybdenum	0							
		Nickel	0							
		Potassium	0							
		Selenium	3	0.0250	0.0250	0.2500	0.350	0.350	0.350	0.350
		Silver	3	0.0050	0.0050	0.0400	0.250	0.250	0.250	0.250
		Thallium	0							
		Vanadium	0							
		Zinc	0							

4.6 Generation and Co-Management of Non-FBC Materials with FBCB

Relative to other generators of fossil fuel combustion byproducts, operators of FBC units appear to co-manage non-FBC materials with their FBCBs relatively infrequently and in low volumes. As shown below in Exhibit 4-38, nine respondents reported that they co-manage one or more non-ash materials with their FBCBs. Co-managed materials include boiler blowdown, cooling tower blowdown, mine seepage water, regenerate water, water softening sludges, and water treatment sludges. Many of these materials are generated in low volumes (six of fifteen at less than 100 tpy), and most are wastewaters that are used to condition the FBCBs prior to disposal or beneficial use.

EXHIBIT 4-38

SUMMARY OF NON-FBC MATERIALS THAT ARE CO-MANAGED WITH FBCBs

Plant No.	Description	Tons Per Year
33	Spray Dryer Solids	913
1	Boiler Blowdown	14.8
16	NPDES	1796
19	Ash Conditioning	25285
31	Mine Water Clarifier Sludge	3600
36	Regenerate Waste	0.25
	Boiler Blowdown	0.09
	Cooling Tower Blowdown	3.75
38	Water Softening Sludge and Boiler Drum Blowdown	39583
6	Lime Sludge/Water Treatment Sludge	2000
	Brine Sludge/Water Treatment Sludge	500
	Dredged Soils/Settling Pond	2500
	Cooling Tower Blowdown	17.9
24	Water Treatment Sludge	50
	Plant Wastewater for Ash Conditioning	325000

In addition, survey respondents indicated that an even smaller number of plant turnaround wastes were co-managed with FBCB material. Specifically, five respondents indicated that they generated turnaround wastes that were co-managed with their FBCBs. These turnaround wastes include the following materials:

- silica sand/ash that is generated twice per year at a rate of 50 tons (1 respondent)
- fire-side boiler cleaning waste that is generated annually at a rate of 100 tons (1 respondent)
- bag house filters that are generated twice per year at a rate of 4 tons (1 respondent)
- general refuse that is generated twice per year at a rate of 1 tons (1 respondent)
- refractory material that is generated twice per year at rate of 8 tons (1 respondent)
- asphalt pavement that is generated twice per year at a rate of 30 tons (1 respondent)

- boiler slag that is generated twice per year at a rate or 20 tons (1 respondent)
- bed material that is generated annually at a rate of 80 tons (2 respondents each generating 80 tons).

These findings demonstrate that, a relatively minor component of the total FBCB material generated and managed in 1995 is unrelated to the combustion of fossil fuels. Specifically, a total of 401,637 tons of non-FBCB material was co-managed with 5,949,062 tons of FBCB material (<7 percent); the majority of these co-managed materials originated from the plant's water treatment and boiler operations. Finally, we note here that none of the respondents indicated that they used chromates in either their water treatment or boiler operations, or that they co-managed pyrites or other extraneous materials that may be of concern when disposed under certain conditions.

ERRATA

Note to Reader:

This chapter contains extensive empirical data on the physical and chemical characteristics of fuels and other inputs to fluidized bed combustion, and of the associated combustion byproducts. These data were primarily obtained from responses to the 1996 CIBO Special Project Survey. Some of the responses to this Survey contained anomalous and/or ambiguous responses, which, along with all of the other data provided, have been entered into the data base used to generate the exhibits and analyses contained in this chapter. In addition, it is likely that a small number of data entry or transcription errors have occurred as the large volumes of data received were entered into electronic form, combined, and in some cases, manipulated to achieve consistency in presentation (i.e., units). The Special Project has made concerted attempts to correct as many of these data accuracy problems as possible, but believes that a small number of errors remain. Readers are cautioned to interpret any extreme data values reported herein accordingly.

CHAPTER FIVE

CURRENT FFCB MANAGEMENT PRACTICES

5.0 Introduction

This chapter presents information on the manner in which fossil fuel combustion byproducts (FFCB) from fluidized bed combustion are put to productive use and the disposal practices employed by FBC operators.

5.1 Fluidized Bed Combustion Byproducts (FBCB) Management Practices

Options for management of FBCB may be grouped into two broad categories, as either disposal or beneficial use. Discussions in this chapter of quantities and proportions of FBCBs are based on results of the 1996 survey conducted for this report. Based upon these data, the CIBO Special Project estimates that one-fourth to one-third of all FBCBs are disposed and two-thirds to three-fourths are beneficially used. These data are presented in Exhibit 5-1. These proportions of general management practices may be compared to those of large utility boiler coal combustion byproducts (CCBs) for which the proportions are roughly reversed[101] (i.e., one-fourth to one-third utilized and two-thirds to three-fourths disposed). Approximately 82 percent of all beneficially used FBCBs are reportedly used in mine reclamation. This contrasts with the predominant utilization of utility CCBs, which is fly ash use as a substitute for Portland cement in concrete.

Determination of FBCBs management in any particular situation is dependent on several factors that include the material's value, regulatory framework, transportation costs, and potential subsidy from disposal avoidance. The material's commercial potential is largely determined by its value as a product or as a replacement to an existing product. Consequently, a particular FBCB's physical and chemical characteristics must be known to effectively determine its beneficial use potential. Each FBCB source will have unique characteristics; there are, however, general attributes of FBCB's that distinguish them from other fossil fuel combustion byproducts.

A general-level comparison of management practices applied to FBCBs and other FFCBs is presented in Appendix C.

5.1.1 Material Characteristics and Attributes

The mineral, physical, and chemical composition of FBCBs is largely determined by fuel, combustion conditions, emission control devices, and management methods.[102] Chemically, FBCBs generally have higher levels of sulfur and calcium than utility coal combustion fly and bottom ashes

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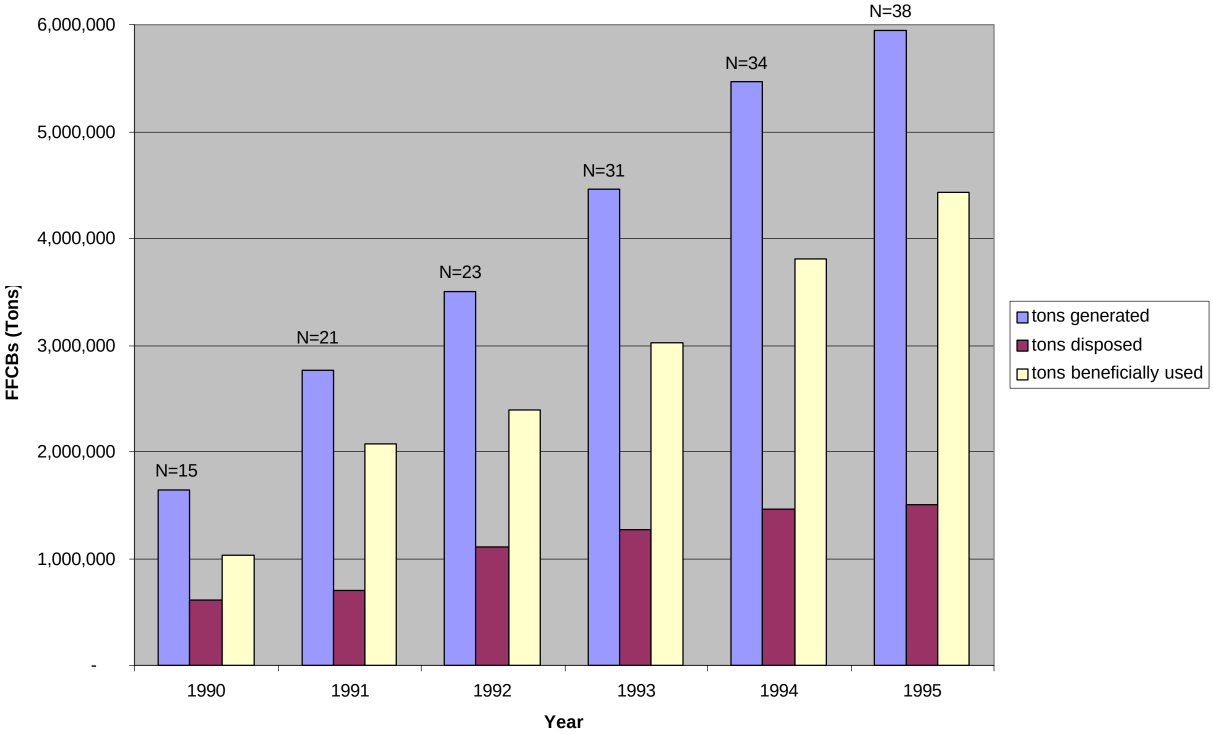
[101] American Coal Ash Association 1995.

[102] Raymond P. Morgan II et al. *Chemical Assessment of Fluidized Bed Ash*. 1995. International Ash Utilization Symposium Proceedings; Lexington, Kentucky.

Exhibit 5-1
Overall Generation and Management of FFCBs



because of sorbent addition and SO_2 capture during combustion. While certain utility (subbituminous) coal combustion fly ashes may have comparable calcium contents, it is the combination of relatively higher levels of calcium, and especially sulfur, that provide some of the most fundamental differences in FBCB performance in beneficial uses. The presence and levels of other major elements in the ultimate analysis may be very similar to those found in utility coal combustion byproducts, especially fly ashes. Although the elemental composition may be similar, FBCBs are quite different in actual compounds and minerals present because of the lower temperature of formation, addition of sorbent, and sorbent reaction products.

The major chemical compounds present in FBCBs are calcium compounds and aluminosilicates. Calcium is present primarily as available calcium oxide (CaO), and calcium sulfate ($CaSO_4$). Lower oxidation forms of calcium sulfur compounds may be present in some boilers.[103] Small amounts of sorbent calcium carbonate may escape heat or chemical reaction in the boiler. Calcium hydroxide may be present if moisture is added to dry FBCBs. Bed ashes generally have higher levels or a predominance of these calcium compounds, as compared to fly ashes. Higher levels of calcium and sulfur are found in FBCB bed ash; this is the result of containing most of the spent sorbent. Bed ash is generally more granular in appearance, usually like a fine sand, as opposed to the fly ashes which are more like a powder.

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[103] E.E. Berry, R.T. Hemmings, B.J. Cornelius, and E.J. Anthony. 1989. *Sulfur Oxidation States in Residues from Small-Scale Circulating Bed Combustors*. Materials Research Society Symposia Proceedings, pp. 9-22.

Fly ashes tend to have larger amounts of aluminosilicates relative to bed ashes. Fundamental differences exist in the aluminum silicates found in fly ashes (derived primarily from coal or waste coal) from FBCB versus conventional utility pulverized coal (PC) boilers. Utility PC fly ashes are formed at higher temperatures, causing the soil impurities in the coal to reform predominantly as aluminosilicate glass ashes. FBCB fly ashes are formed at lower temperatures so less or no glassy material is formed; aluminosilicates in FBCBs are more likely to be in the form of dehydroxylated clays. The majority of the FBCB fly ash aluminum and silicon is, in fact, found as these dehydroxylated clays; however, as with PC fly ashes, some crystalline silica as quartz, is usually present. Other elements may be present in the clays or as trace elements in other minor minerals present.

The presence of these clays with calcium oxide gives these ashes the potential for strong cementitious reactions. In addition, the presence of the clays with calcium sulfate imparts the potential for complex mineralogical reactions that are difficult to predict; these reactions may affect the long term physical characteristics of the materials.

In general, historical research on these materials has found little or no potential for environmental harm due to the presence of trace metals, and in certain beneficial uses ashes have been shown to provide environmental improvement.[104,105] The presence and potential leachability of trace metals, soluble salts, and alkalinity are, however, factors for environmental consideration when determining beneficial uses.[106]

The relatively high levels of calcium and sulfur in the FBCB result in several attributes that in combination, determine the materials' potential beneficial use:

1. The materials may be expansive (both in the short- and long-term), especially bed ash.

2. FBCBs may be cementitious, especially bed ash.

3. Cementitious reactions may develop significant strength (up to 1,000's of psi).

4. These materials may undergo long-term mineralogical reactions that change their physical characteristics.

5. The materials are alkaline with pH in water generally > 11 S.U.

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[104] C.C. Sun, and C.H. Peterson. *Fluidized Bed Combustion Residue Disposal Environmental Impact and Utilization.* 1980. Proc. 6th Intr. Conf. On Fluidized Bed Combustion.

[105] T.W. Grimshaw, et al. *Assessment of Fluidized Bed Combustion Solid Wastes for Land Disposal*. 1985. U.S. EPA Report, EPA 600/7-85/007a.

[106] Morgan, op. cit.

6. FBCBs, when dry, tend to have high water requirements.

7. Water addition may result in an exothermic reaction, especially with bed ashes.

Expansion may prove problematic and may occur from two sources: Initial CaO hydration, and subsequent mineralogical reaction. CaO hydration expansion is usually experienced as a rapid expansion at initial water addition and may be accompanied by significant heat generation.[107] This can be controlled to varying extents by prehydration of material.

Long term expansion and secondary mineralogical reactions that may affect strength and long term expansion are less predictable. Strength, if developed, may not endure due to subsequent mineral reactions.[108] Ettringite formation may cause expansion and fracturing of the FBCBs. Thaumasite formation may cause further degradation (fracture) and loss of strength. These characteristics, expansion and long-term mineralogical reactions, will tend to eliminate these materials from the most critical civil/structural applications, for which PC-generated CCBs might be used instead.

On the other hand, the high alkalinity, high water requirement, and greater chemical reactivity of FBCBs allows them to be used in certain beneficial uses not typically, or not as effectively, performed by PC CCBs. This is especially true in sludge stabilization applications. High alkalinity also allows for mitigating effects when used in coal mine reclamation. Finally, the presence of calcium and sulfur in high levels, relative to PC CCBs, provides the potential for greater beneficial use in agricultural applications.

5.2 FBCB Disposal Practices

According to 1996 Survey results, about one-fourth to one-third of FBCBs are disposed. This compares with the two-thirds to three-fourths of utility PC CCBs that reportedly are disposed. Quantities of material disposed by respondents to the 1996 Survey are presented by facility in Exhibit 5-2. Disposal occurs primarily in permitted solid waste landfills, though management in surface impoundments is practiced at four facilities in the midwest.

Most land disposal units are captive to the generator's site. Specific operations, construction (liner, cover, closure, etc.), and other requirements vary among states and are discussed in Chapter 8. Disposal in landfills usually occurs in individual cells. In general, after the ash has been moisture-conditioned it is placed and compacted in a cell. Compaction may be in specified

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[107] William E. Giles. *Problems Associated with Handling Various Types of Coal Combustion By-products in a Haulback Operation*. 1995 International Ash Utilization Symposium Proceedings; Lexington, Kentucky.

[108] Gregory J. McCarthy, et al. *Long Term Stability of Disposed Cementitous Coal Combustion By-products*. 1995 International Ash Utilization Symposium Proceedings; Lexington, Kentucky.

lift thicknesses and to permit-specified compaction levels. Compaction and placement requirements will vary with individual permits. Additional moisture may be required for dust control after placement. Permits generally require groundwater monitoring and surface water control.

EXHIBIT 5-2
LAND DISPOSAL OF FBCBs

Fac. ID	State	UNIT	UNIT TYPE	1990 Quantity	1991 Quantity	1992 Quantity	1993 Quantity	1994 Quantity	1995 Quantity	Units	Co-Disposal of Other Wastes
Plant #36	CA	Landfill	Monofill	0	0	17,646	17,646	17,646	17,246	tons	
Plant #39	CA	Landfill	Monofill	1,761	36,502	37,381	42,213	45,507	46,698	tons	
Plant #23	FL	Landfill	Other	0	0	0	0	118,575	37,914	tons	
Plant #35	GA	Landfill	Industrial/ Sub D	77,581	95,018	159,195	118,245	131,295	129,214	yd3	
Plant #42	LA	Landfill	Monofill	0	0	49,328	166,394	70,835	23,907	tons	
Plant #29	ND	Landfill	Industrial/ Sub D	64,185	50,123	45,387	59,248	49,672	29,577	tons	
Plant #24	PA	Landfill	Monofill	359,065	316,190	287,240	240,140	290,000	291,409	tons	
Plant #6	TX	Landfill	Industrial/ Sub D	0	0	272,547	253,124	225,446	210,730	tons	Brine Sludge, Dredged Soils, Lime Sludge
Plant #20	WI	Landfill	Industrial/ Sub D	0		8,000	41,900	41,900	41,900	yd3	Stoker and cyclone boiler ash and Wastepaper drinking sludge
Plant #12	IL	Surface Impoundment	Industrial/ Sub D	0	197,743	408,005	385,029	394,605	376,872	tons	
Plant #13	IA	Surface Impoundment	Industrial/ Sub D	0	0	0	49,874	71,648	83,849		
Plant #8	IA	Surface Impoundment	Industrial/ Sub D	0	0	0	49,874	71,648	83,849		
Plant #7	MN	Surface Impoundment	Industrial/ Sub D	4,000	4,600	4,500	7,000	6,000	6,400	Tons	Primary scrubber solids

Review of Exhibit 5-2 suggests that the quantities reporting to disposal are relatively consistent from year to year at the level of the individual facility, though total quantities being disposed are increasing due to additional FBC units and facilities coming on line in the early 1990's. Some pertinent characteristics of the individual disposal units are presented in Exhibit 5-3. Most of these units were constructed and put into service during the past ten years, with only one unit pre-dating enactment of land disposal regulations under RCRA. Liner types and configurations vary widely, with some units approaching RCRA Subtitle C (hazardous waste management) levels of protectiveness. On the other extreme, some units reportedly have no discrete liner system or are underlain by bedrock or *in situ* clay. This latter situation characterizes all of the surface impoundments being used for FBCB disposal by respondents to the 1996 Survey.

As indicated above, constituent release controls in the form of engineered structures and operating practices are employed by most facility operators that dispose of FBCBs on site. Dust suppression is used by all but one of the fifteen respondents managing FBCBs in a landfill or surface impoundment, and run-on and run-off controls have been installed and are operated by all but two (both of whom manage their materials in impoundments). Compaction and covering of material are both used by a large proportion of Survey respondents. Finally, all of the facility operators reporting that they land dispose FBCBs do so under the terms of a formal permit and/or closure plan. As discussed in greater depth in Chapter 8, many states have solid waste management regulations and programs that impose substantial waste management requirements, many of which are administered via permits.

Exhibit 5-4 presents information on the proximity of facilities that generate and land dispose FBCBs on site to a variety of EPA-defined sensitive environments. Three of the fifteen facilities are located (at least partially) within a 100-year flood plain, two are within a fault area, and one intersects an endangered species habitat. Two facilities are found in two different sensitive environment types; one facility in California is sited in both a flood plain and a fault area, and another, also in California, is in both a fault area and endangered species habitat. No Survey respondents that practice land disposal of FBCBs reported that their facilities are sited in wetlands or karst terrain.

5.3 FBCB Beneficial Use Practices

The major classifications of beneficial use considered in this report are the following:

Mine Reclamation
Stabilization Applications
Geotechnical Applications (Civil/Structural)
Agricultural
Cement/Concrete

EXHIBIT 5-3
FBCB LAND DISPOSAL UNIT CHARACTERISTICS

Public ID	State	Unit Type	Unit Description	Year First Received Material	Cumulative Quantity (In 1995)	Units	Remaining Useful Life (Years)	Liner Type	Dust Suppression	Run-on/ Run-off Controls	Compaction	Cover	Permit/ Closure Plan
Plant #36	CA	Landfill	Monofill	1988	300,000	yd3	0	Recompacted Clay/ Shale, Synthetic (Plastic)	Yes	Yes	Yes		Yes
Plant #39	CA	Landfill	Monofill	1990	210,067	tons	19	No Liner	Yes	Yes		Yes	Yes
Plant #23	FL	Landfill	Residual/landfill	1994	156,000	tons	18		Yes	Yes	Yes		Yes
Plant #35	GA	Landfill	Industrial/Sub. D	1988	824,600	yd3	7	Synthetic (40 ml HDPE)	Yes	Yes			Yes
Plant #42	LA	Landfill	Monofill	1992	146,790	tons	15		Yes	Yes			Yes
Plant #28	NE	Landfill	MSW	1994	161,341	tons	25.4	Recompacted Clay/ Shale, Synthetic (60 ml HDPE), GCL (dentofix) liner	Yes	Yes	Yes	Yes	Yes
Plant #29	ND	Landfill	Industrial/Sub. D	1990	270,000	gal3	22.5	Recompacted Clay/Shale	Yes	Yes	Yes	Yes	Yes
Plant #24	PA	Landfill	Monofill	1987	2,300,000	yd3	5.6	Insitu Clay/Shale	Yes	Yes	Yes	Yes	Yes
Plant #6	TX	Landfill	Industrial/Sub. D	1991	2,713,623	tons	11.2	Recompacted Clay/Shale	Yes	Yes	Yes	Yes	Yes
Plant #20	WI	Landfill	Industrial/Sub. D	1964	4,000,000	yd3		Insitu Clay/Shale, Drinking (clay) sludge w/permeability	Yes	Yes		Yes	Yes
Plant #12	IL	Surface Impoundment	Industrial/Sub. D	1991	1,762,254	tons	5	Insitu Clay/Shale	Yes	Yes		Yes	Yes
Plant #13	IA	Surface Impoundment	Industrial/Sub. D	1993	205,371	tons	1.5	Bedrock	Yes	Yes		Yes	Yes
Plant #8	IA	Surface Impoundment	Industrial/Sub. D	1993	205,371	tons	1.5	Bedrock	Yes		Yes	Yes	Yes
Plant #7	MN	Surface Impoundment	Industrial/Sub. D	1986	2,500,000	yd3	15	Recompacted Clay/Shale					Yes

EXHIBIT 5-4
FBCB LAND DISPOSAL-PROXIMITY TO SENSITIVE ENVIRONMENTS

Public ID	State	Unit Type	Unit Description	100 Year Floodplain	Wetland	Karst Terrain	Fault Area	Endangered Species Habitat
Plant #36	CA	Landfill	Monofill	Yes			Yes	
Plant #39	CA	Landfill	Monofill				Yes	Yes
Plant #23	FL	Landfill	Residual/ landfill					
Plant #35	GA	Landfill	Industrial/Sub. D	Yes				
Plant #42	LA	Landfill	Monofill	Yes				
Plant #29	ND	Landfill	Industrial/Sub. D					
Plant #24	PA	Landfill	Monofill					
Plant #6	TX	Landfill	Industrial/Sub. D					
Plant #20	WI	Landfill	Industrial/Sub. D					
Plant #12	IL	Surface Impoundment	Industrial/Sub. D					
Plant #13	IA	Surface Impoundment	Industrial/Sub. D					
Plant #8	IA	Surface Impoundment	Industrial/Sub. D					
Plant #7	MN	Surface Impoundment	Industrial/Sub. D					

The major factors used to determined potential beneficial use are material properties, regulatory environment, and economic factors. Desired material properties are specific to the intended application. States containing facilities that generate large quantities of CCBs and FBCBs tend to have addressed beneficial use through specific regulations or policies (see Chapter 8). Economic factors must be considered on a case by case basis.

In all beneficial uses, it is vital to know critical physical and chemical parameters related to the use. Low specification utilizations are considered to have fewer critical and less stringent specifications for the use (e.g., use as backfill material at strip mines). High specification utilizations have more critical and stringent specifications (e.g., use as raw feed in cement production). Based on the survey conducted in support of this report, approximately two-thirds to three-fourths of FBCBs are beneficially used. According to survey results, this proportion has increased somewhat since 1991. Total quantities sent to specific applications by all 1996 Survey respondents are presented in Exhibit 5-5, while facility-level data is provided by specific end-use application in Exhibit 5-6.

5.3.1 Mine Reclamation

Mine reclamation is by far the dominant management practice applied to FBCB, on a volume basis. Survey results indicate that approximately 60 percent of the FBCBs generated, and 80 percent of those beneficially applied, are used for this purpose. These quantities are used almost entirely for coal surface mine reclamation. This does not, however, preclude the use of the materials in the reclamation of other types of mines and mined lands. Certain states have specific environmental regulations that allow for FBCBs and other CCBs to be used in subsurface mine reclamation. States that have specific regulatory programs tend to have vast historical coal mining operations and high concentrations of FBC boilers within their borders, most notably Pennsylvania.[109]

As displayed in Exhibit 5-6, ten of the sixteen facilities reporting use in mine reclamation are located in Pennsylvania; nine of these ten employ 100 percent of their byproduct material in this application, while the remaining facility came on line in 1995, and sent 72 percent of its material to mine reclamation. Other facility operators in California, Connecticut, Illinois, Missouri, New York, and Oklahoma also made use of this management practice, often sending most or all of their FBCBs to placement in former coal mines.

As indicated in Exhibit 5-7, most facility operators condition their FBCBs with water prior to placement in the mine, which is generally performed under permit. Half of the sixteen survey respondents managing their FBCBs in mining applications report that they collect environmental monitoring data associated with this practice, and that these data can be made available.

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[109] Pennsylvania Rules and Regulations, Title 25 Environmental Resources, Sections 287.663 and 287.664.

EXHIBIT 5-5
OVERALL BENEFICIAL USE OF FBCBs

	1990		1991		1992		1993		1994		1995	
Tons Generated	1,642,372		3,504,769		3,504,769		4,452,815		5,463,588		5,949,062	
Tons Disposed	612,799	37%	1,104,780	32%	1,104,780	32%	1,279,402	29%	1,460,506	27%	1,508,317	25%
As Mining Applications	965,312	59%	2,148,323	61%	2,148,323	61%	2,474,053	56%	2,982,033	55%	3,629,409	61%
As Waste Stab./Solid.	1,300	0%	55,035	2%	55,035	2%	178,437	4%	311,602	6%	351,095	6%
As Structural Fill	0	0%	73,369	2%	73,369	2%	231,546	5%	256,204	5%	270,982	5%
As Other	2,161	0%	3,781	0%	3,781	0%	39,081	1%	142,907	3%	79,124	1%
As Agriculture	62,961	4%	113,480	3%	113,480	3%	91,621	2%	118,910	2%	65,500	1%
As Flowable Fill	0	0%	0	0%	0	0%	0	0%	0	0%	30,531	1%
As Cement	0	0%	5,567	0%	5,567	0%	0	0%	0	0%	5,588	0%
Total Beneficially used	1,031,734	63%	2,399,555	68%	2,399,555	68%	3,014,738	68%	3,811,656	70%	4,432,229	75%

EXHIBIT 5-6
FACILITY-LEVEL BENEFICIAL USE DATA

Beneficial Use	State	Facility ID	Total FFCB Used (tons)						Percent of FFCB Generated					
			1990	1991	1992	1993	1994	1995	1990	1991	1992	1993	1994	1995
As Mining Applications	CA	Plant #3				19,534	28,275	29,000				100%	100%	100%
	CT	Plant #40		176,868	158,724	163,002	142,257	134,786		100%	100%	100%	100%	82%
	IL	Plant #12						46,232						11%
	MO	Plant #10					11,123	10,086					100%	100%
	NY	Plant #17		7,499	23,447	15,843	711	4,715		18%	63%	40%	2%	12%
	OK	Plant #33	5,098	259,980	325,405	254,757	392,028	504,999	100%	83%	88%	53%	79%	95%
	PA	Plant #11						214,645						72%
	PA	Plant #15		109,471	252,431		264,094	287,396		114%	100%		100%	100%
	PA	Plant #16		488,866	488,866	488,866	488,866	488,866		100%	100%	100%	100%	100%
	PA	Plant #18	424,449	347,360	388,188	365,080	364,906	317,497	100%	100%	100%	100%	100%	100%
	PA	Plant #19	176,700	210,224	224,022	221,220	265,462	274,150	100%	100%	100%	100%	100%	100%
	PA	Plant #24	359,065	316,190	287,240	240,140	290,000	291,409	100%	100%	100%	100%	100%	100%
	PA	Plant #26				244,436	343,395	326,320				100%	100%	100%
	PA	Plant #31				296,120	231,800	391,204				100%	100%	100%
	PA	Plant #32						147,000						100%
	PA	Plant #9				165,055	159,116	161,104				100%	100%	97%
As Waste Stab./Solid.	CA	Plant #3						11,600						40%
	CA	Plant #4						25,419						90%
	IA	Plant #8				22,216	8,384	1,128				18%	6%	1%
	IL	Plant #12						20,564						5%
	LA	Plant #42			1,219	17,270	125,014	153,017			2%	9%	38%	80%
	MI	Plant #43						5,000						51%
	MN	Plant #30	1,300	1,500	2,300	2,500	2,300	3,425	72%	75%	70%	71%	66%	81%
	MN	Plant #7						400						6%
	NY	Plant #17		28,159	8,000	8,251	6,302	776		69%	22%	21%	14%	2%
	OK	Plant #33		48,811	43,516	65,783	88,731	20,438		16%	12%	14%	18%	4%
	TX	Plant #6				62,417	80,871	109,328				15%	22%	29%

EXHIBIT 5-6 (continued)
FACILITY-LEVEL BENEFICIAL USE DATA

Beneficial Use	State	Facility ID	Total FFCB Used (tons)						Percent of FFCB Generated					
			1990	1991	1992	1993	1994	1995	1990	1991	1992	1993	1994	1995
As Structural Fill	CA	Plant #2						1,477						5%
	CA	Plant #4						2,824						10%
	HI	Plant #25					43,914						96%	
	IN	Plant #41		18,000		20,000		24,000		100%		100%		100%
	PA	Plant #1			24,952	112,082	147,253	98,874			18%	78%	100%	82%
	PA	Plant #11						83,610						28%
	TX	Plant #6			48,417	99,464	65,037	60,197			13%	24%	18%	16%
As Other	CA	Plant #3						2,900						10%
	CA	Plant #36						4,754						16%
	CA	Plant #36						7,900						26%
	HI	Plant #25				36,411		41,317				96%		100%
	IN	Plant #22	2,161	4,121	1,545	1,337	535		100%	100%	100%	100%	100%	
	IN	Plant #41						120						0.5%
	LA	Plant #42					135,670	15,513					41%	8%
	OK	Plant #33		3,339	648	1,308	6,702	6,620		1%	0.2%	0.3%	1%	1%
	OK	Plant #33			1,588	25					0.4%	#####		
As Agriculture	CA	Plant #2	27,856	27,781	27,165	28,722	25,655	28,054	100%	100%	100%	100%	87%	95%
	CA	Plant #36			15,354	15,354	15,534				47%	47%	47%	
	CA	Plant #4	28,019	27,533	29,019	29,622	31,999		100%	100%	100%	100%	100%	
	HI	Plant #25				1,620	1,874					4%	4%	
	IA	Plant #8	7,086					507	4%					0.4%
	IL	Plant #12						3,358						1%
	NY	Plant #17				15,290	36,791	33,231				39%	84%	86%
	OK	Plant #33		52	25	1,013	7,057	350		0.02%	0.01%	0.2%	1%	0.1%
	TX	Plant #6			41,917						12%			
As Flowable Fill	CT	Plant #40						30,531						18%
As Cement	CA	Plant #36						100						0.3%
	NY	Plant #17		5,268	5,567			88		13%	15%			0.2%
	PA	Plant #9						5,400						3%

EXHIBIT 5-7
FBCB PRODUCTIVE APPLICATION METHODS AND POTENTIAL IMPACTS

Beneficial Use	State	Facility ID	1995	Conditions Prior to Use	Mixing/ Co-management	Permit	Monitoring Data Available
As Mining Applications	CA	Plant #3	29,000				
	CT	Plant #40	134,786	Yes		Yes	
	IL	Plant #12	46,232				
	MO	Plant #10	10,086			Yes	
	NY	Plant #17	4,715	Yes		Yes	Yes
	OK	Plant #33	504,999	Yes	Yes	Yes	Yes
	PA	Plant #11	214,645	Yes		Yes	
	PA	Plant #15	287,396	Yes		Yes	Yes
	PA	Plant #16	488,866	Yes	Yes	Yes	
	PA	Plant #18	317,497	Yes		Yes	Yes
	PA	Plant #19	274,150	Yes	Yes	Yes	Yes
	PA	Plant #24	291,409	Yes	Yes	Yes	Yes
	PA	Plant #26	326,320	Yes		Yes	Yes
	PA	Plant #31	391,204	Yes	Yes	Yes	
	PA	Plant #32	147,000	Yes			
	PA	Plant #9	161,104	Yes		Yes	Yes
As Waste Stab./Solid.	CA	Plant #3	11,600				
	CA	Plant #4	25,419	Yes		Yes	
	IA	Plant #8	1,128			Yes	
	IL	Plant #12	20,564				
	LA	Plant #42	153,017	Yes			Yes
	MI	Plant #43	5,000	Yes			
	MN	Plant #30	3,425	Yes		Yes	
	MN	Plant #7	400	Yes		Yes	
	NY	Plant #17	776	Yes		Yes	Yes
	OK	Plant #33	20,438	Yes	Yes		Yes
	TX	Plant #6	109,328	Yes	Yes		
As Structural Fill	CA	Plant #2	1,477	Yes		Yes	
	CA	Plant #4	2,824	Yes		Yes	
	HI	Plant #25		Yes	Yes	Yes	
	IN	Plant #41	24,000	Yes	Yes	Yes	Yes
	PA	Plant #1	98,874	Yes	Yes		
	PA	Plant #11	83,610	Yes		Yes	
	TX	Plant #6	60,197	Yes	Yes		
As Other	CA	Plant #3	2,900				
	CA	Plant #36	4,754	Yes		Yes	Yes
	CA	Plant #36	7,900	Yes		Yes	Yes
	HI	Plant #25	41,317	Yes	Yes	Yes	
	IN	Plant #22		Yes	Yes		Yes
	IN	Plant #41	120	Yes	Yes	Yes	Yes
	LA	Plant #42	15,513	Yes			Yes
	OK	Plant #33	6,620	Yes	Yes		Yes
	OK	Plant #33		Yes	Yes		Yes
As Agriculture	CA	Plant #2	28,054	Yes		Yes	
	CA	Plant #36		Yes		Yes	Yes
	CA	Plant #4		Yes		Yes	
	HI	Plant #25		Yes	Yes	Yes	
	IA	Plant #8	507			Yes	
	IL	Plant #12	3,358				
	NY	Plant #17	33,231	Yes		Yes	Yes
	OK	Plant #33	350	Yes	Yes		Yes
	TX	Plant #6		Yes	Yes		
As Flowable Fill	CT	Plant #40	30,531	Yes			
As Cement	CA	Plant #36	100	Yes		Yes	Yes
	NY	Plant #17	88	Yes		Yes	Yes
	PA	Plant #9	5,400	Yes			Yes

The attributes of the material that make it useful in this application are its high pH, relative bulk inertness, and small particle size relative to the coal refuse with which it may be mixed. Its expansive nature can be advantageous in underground mine reclamation and remediation. General specifications for a non-toxic material and pH above neutral are consistently met by FBCBs. This application is considered a low specification use.

Beneficial use of FBCBs in mine reclamation projects can be accomplished in at least three general categories of application: (1) use as a structural fill, or component of structural fill, to reclaim original contours in surface mines; (2) mixing with coal refuse to produce plant growth media at surface mines; and (3) use as a grout to fill underground mines. The discussions in this section will be limited to surface mine reclamation, though it should be noted that FBCBs have been used successfully in underground mine reclamation. This has been done in consideration of environmental effects and shown to provide mitigation of acid mine drainage.[110,111,112,113] The use of these byproducts in the filling of underground mines has yielded acceptable results, but is not frequently practiced due to prohibitive placement costs. In critical areas of subsidence, grouts and flowable fills may be the preferred solution.[114]

The use of FBC byproducts alone, or with other CCBs or mine refuse, as a fill material for mine backfill, is, as shown above, by far the largest volume beneficial use of FBCBs. Also, mixing with refuse at or near the surface of mine reclaim sites can make acidic and low moisture retaining refuse capable of supporting greater plant growth.[115] Both methods of byproduct use in

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[110] William W. Aljoe. *Injection of Alkaline Ashes Into Underground Coal Mines for Acid Mine Drainage Abatement.* 1996. Thirteenth Annual International Pittsburgh Coal Conference Proceedings.

[111] T.E. Ackman, J.R. Jones, and A.G. Kim. *Water Quality Changes at Three Reclaimed Mine Sites Related to the Injection of Coal Combustion Residues*. 1996. Thirteenth Annual International Pittsburgh Coal Conference Proceedings.

[112] Kristin M. Egers, et al. *Mapping of the Frazee Mine, The Western Maryland Coal Combustion By-products/Acid Mine Drainage Initiative, Part II of III*. 1996. Thirteenth Annual International Pittsburgh Coal Conference Proceedings.

[113] Paul F. Ziemkicwicz and W. J. Head, *Use of FBC Ash to Control Acid Mine Drainage from Abandoned Room and Pillar Mines.* Proceeding, Coal-Energy and the Environment, 19th Annual Pittsburgh Coal Conference, 1993.

[114] E.E. Berry, R.T. Hemmings and B.J. Cornelius. 1991. *Commercialization Potential of AFBC Concrete Part 2 Volume 2; Mechanistic Basis for Cementing Action.* EPRI GS-7122 Research Project 2708-4.

[115] Barry R. Stewart, and W. Lee Daniels. *Beneficial Reuse of Coal Fly Ash to Improve Plant Growth on Coarse Coal Refuse.* 1995 International Ash Utilization Symposium Proceedings; Lexington, Kentucky.

reclamation may be used at a common site effectively. FBC byproducts may be used effectively in conjunction with conventional PC coal ashes as backfill.

The benefits of this utilization include removal of safety hazards, where steep walls are removed by improving contours, improved overall ground water quality in areas where low pH is created by acid mine drainage, improved vegetative growth when used in conjunction with refuse, and return of the land to productive use.

Most reclamation is performed under specific regulatory programs that are environmentally monitored, as described above. General environmental safeguards at mine reclamation projects include control of fugitive dust, ground water monitoring, placement area and volume restrictions, surface drainage considerations, slope restrictions, cover requirements, pH restrictions, placement requirements, periodic chemical testing of byproducts, and water table separation requirements.[116]

Coal refuse and mine fires - In several coal mining regions, spontaneous combustion and other causes have created problems with smoldering coal refuse piles and deep mine fires. Both ponded ash and conditioned ash have been used to prevent these fires and to fill areas devastated by such fires. Ash is mixed with water at the site to form a slurry and injected into the fire zone through pipes and boreholes. In some cases, dry fly ash can be pneumatically conveyed into the voids in a deep mine or voids created by the fire, thereby filling voids and isolating combustion areas in burning refuse piles and deep mine fires. The ash serves to cut off the supply of oxygen from the fire zone and can provide support to the fire-damaged structure of the mine or refuse pile.

Mine subsidence - Large quantities of fly ash have been used to stop or prevent surface subsidence above mined areas.[117] Dry fly ash injected pneumatically, slurried fly ash, and fly ash/cement grouts have all been used to fill subsurface voids from abandoned mines to protect industrial, commercial, public, and residential developments from mine subsidence damage.

5.3.2 Stabilization Applications

FBCBs are employed to stabilize and solidify a variety of industrial wastes and treatment residuals. As shown in Exhibit 5-6, operators of eleven facilities in nine states made use of some portion of the FBCBs generated within their operations to stabilize wastes. Two facilities managed more than 100,000 tons of FBCBs in this manner during 1995. Most of the other facilities among the eleven used relatively small quantities (25,000 tons or less) and percentages of their material in stabilization applications.

As shown in Exhibit 5-7, while FBCBs used for stabilization are generally conditioned prior to use, they are usually not mixed or co-managed with other materials. Several facility operators

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[116] Pennsylvania Rules and Regulations. *op. cit.*

[117] Tim N. Kyper, P.E. James L. Snodgrass, P.E., and Thomas A. Gray, P.E. GAI Consultants, Inc., *Disposal of Coal Combustion By-Products in Underground Coal Mines*. 1995 International Ash Utilization Symposium Proceedings; Lexington, Kentucky.

stabilize wastes with FBCBs under permit, and a few collect environmental monitoring data associated with this activity.

Stabilization is a treatment process that induces a physicochemical reaction in the waste to form insoluble compounds that binds toxic elements or compounds in a stable crystal lattice. In other words, stabilization is a process by which a waste is converted to a more chemically stable form, thereby resulting in a less leachable product. FBCBs (and other CCBs) can be used to stabilize a wide variety of waste and secondary materials, including chemical and petrochemical wastes, hazardous wastes, particularly corrosive and metal-bearing wastes, and a number of biosolids and sludges. Wastes in the latter category may be generated by agricultural, food processing, pulp and paper, and other industrial activities, as well as municipal wastewater treatment plants.

5.3.3 Geotechnical Applications

Geotechnical applications for CCBs for projects such as highways, airports, commercial land development, and public infrastructure systems constitute a substantial portion of construction activities. In addition to use in concrete, CCBs have been successfully employed in geotechnical projects in several ways, including the following:

Flowable Fill
Grouts
Roller Compacted Concrete
Structural Fill Embankments
Base and Subbase
Asphalt Filler, and
Soil Stabilization.

According to 1996 Survey data (see Exhibit 5-6), FBCBs generated at eight facilities are used in one or more geotechnical applications. These facilities are located in California, Connecticut, Hawaii, Indiana, Pennsylvania, and Texas. In some instances, these applications comprise the predominant management practice applied to the material, while in others, geotechnical applications account for a relatively modest percentage of the quantity generated. As shown in Exhibit 5-7, all survey respondents reporting such use of FBCBs condition their material prior to use and most of these activities are conducted under permit.

The following discussion presents information on the use of coal combustion byproducts generally in geotechnical applications. While not specific in most cases to FBCBs, this information should apply broadly to various categories and sources of CCBs, including FBCBs, because we focus here mainly on factors that influence or limit the use of ash materials in particular applications.

Flowable fills - Mixtures of coal ash, cement, and water have been used as construction backfill in areas where conventional backfilling may be difficult or undesirable. These fluid mixtures flow into areas to be filled and result in a fill with properties equal to or exceeding traditional backfill materials. A mixture of coal ash, water, sand, and a small amount of cement is typical. In some cases in which a high CaO fly ash is used, no cement is required. The savings in using flowable fills results from the reduction in time, equipment, and manpower needed and the superior performance obtained, as compared to use of conventional materials. Flowable fills are especially useful in restricted areas where access for placement and compaction is difficult and where minimal subsequent settlement is desired. Flowable fills are particularly useful in filling utility trench excavations under streets in urban locations and other applications where load bearing ability is important.

Grouting - Grout is used to strengthen or decrease the permeability of structures and subsurface strata by filling voids, and cementing cracks, fissures, and other openings. Fly ash adds several useful properties to grout mixes. The fine, uniform particle size, spherical shape, and Pozzolanic activity of fly ash are all useful qualities. Grouts containing fly ash have been employed in filling abandoned mine openings to prevent ground subsidence and in oil wells. Ash use in oil well grouting dates back to 1949. In this application, the pumpability, reduced bleeding, and lower heat of hydration obtained with fly ash grouts relative to other materials are especially desirable properties. The American Petroleum Institute has a standard specification (API-5 FLY ASH) for the use of fly ash in grout mixtures. This specification is based on the provisions of ASTM C618 covering the use of fly ash in concrete.

Roller compacted concrete - Roller compacted concrete (RCC) is a fill material that is placed using conventional earthmoving equipment (dump tucks, bulldozers, vibratory compactors). RCC mixes are used for mass concrete in dams, thick pavement bases and similar applications. These mixtures are used in mass concrete applications where material is placed using earth moving equipment to reduce the placement and forming costs that are normally associated with standard concrete construction methods. RCC mixes may have a lower water content and higher ash content than conventional concrete mixes.

Fly ash, as well as other CCBs, is a major component of RCC and contributes to the strength and cost-effectiveness of the material. The United States Bureau of Reclamation completed the construction of the Upper Stillwater Dam using Roller Compacted Concrete containing fly ash. Tyger Construction, the general contractor, began the project in December 1983, and completed construction during 1988. The dam is 188 feet high, 2,673 feet long, and 187 feet deep at its widest point, and consists of 1.24 million cubic yards of RCC designed with a compressive strength of 4,000 p.s.i. after one year. A total of almost 200,000 tons of low CaO fly ash was used in the project.

Soil stabilization - Coal ash has been used to supplement or replace Portland cement or lime in soil stabilization applications. Standardized mix design procedures have been developed to incorporate use of ash as an ingredient. Design specifications typically include compaction moisture content, strength, and dimensional stability criteria. Procedures for curing, placement, and other considerations are typically included. Specifications for fly ash use in soil stabilization have been adopted by several government agencies, including the Federal Aviation Administration, Federal Highway Administration, U.S. Army Corps of Engineers, and the Bureau of Reclamation.

Lime-fly ash base and subbase - Lime-fly ash (LFA) mixtures are blends of hydrated lime and fly ash mixed with native materials or blended with crushed stone or other aggregates. LFA mixtures have been used as base and subbase beneath flexible asphalt pavements. The mixtures are blended in a central mixing plant or in place, compacted, cured, and topped with an asphalt wearing surface. The superior strength and durability of LFA mixtures as compared to aggregate alone allow LFA mixtures to serve as an economic alternative to conventional pavement in many situations. These pavements have been most widely used by state and local highway departments in the midwestern United States.

Cement treated bottom ash base and subbase - Cement treated bottom ash has been used as a substitute for conventional crushed stone or gravel base for secondary roads. This product has been especially useful in locations where bottom ash is plentiful and natural aggregates are relatively scarce or expensive. Though not as widely used as LFA mixtures, this product has proven to be a practical application of CCBs in some locales.

Structural fill embankments - CCBs are a lightweight, inexpensive material for constructing fills. In this application, CCBs have been used to convert sites with unsuitable topography into valuable, productive property. These materials can be placed, spread, and compacted using the same equipment as conventional fill materials. Placement to a controlled density and configuration can produce stable fills for site developments, roadways and parking areas, and building construction.

In the United States, the use of CCBs in structural fills dates back to at least 1971**.** Since then, several million tons have been used in successful land development projects. These sites include housing developments, shopping malls, industrial parks, and other commercial, residential, and industrial developments. Transportation costs and material availability normally determine if CCBs are a practical alternative to competing native materials. When available in sufficient quantities within competitive haul distances, CCBs have proven to be an excellent borrow material for creating structural fills. The most common material used for structural fills has been low CaO fly ash. High CaO fly ash, bottom ash, FBC ash, stabilized FGD materials, and other types of CCBs also have been successfully used as structural fills.

Many state transportation departments are taking advantage of the beneficial properties and low cost of CCBs to construct roadway embankments. Highway engineers have recognized that the availability of these inexpensive fill materials eliminates the need for traditional cut-and-fill designs which often involve expensive excavation. After concrete, structural fills are now the largest volume use of CCBs in the United States.

Use of CCBs in highway embankments has been most prevalent in Europe and in urban projects in the United States where borrow materials are limited. Recently, the use of CCBs in highway embankments has become more prevalent as a result of experience gained through demonstration projects sponsored by ash producers and highway departments. Increased future use is anticipated due to the success of these projects and the experience and familiarity gained by highway designers and other prospective users.

5.3.4 Agricultural Applications

All agricultural utilizations account for approximately 2 percent of the FBC byproducts generated (see Exhibit 5-6). Among respondents to the 1996 Survey, agricultural use is significant as a management practice only at three facilities in California, and one in New York. The operators of two of the California facilities manage close to 100 percent of the generated material in this way. Five additional respondents (in Hawaii, Iowa, Illinois, Oklahoma, and Texas) report having used FBCBs in agricultural use during the past six years, though several appear to have chosen other use applications as of 1995. As in other applications, the FBCBs are typically conditioned with water prior to use, and are managed (applied) under permit (see Exhibit 5-7).

FBCBs have been used or tested in agricultural applications as a liming agent (for pH adjustment), as a plant nutrient additive, and as a soil amendment to improve the physical characteristics of soils. The primary attribute of FBCBs that make them desirable for these applications is their calcium content, which is desirable both for pH adjustment and calcium nutrient value. The presence of other nutrients, especially sulfur, potassium, phosphorus, and micronutrients (Fe, Mg, B, Cu, and Zn) also make it desirable as a plant nutrient source.[118] Limited experimentation also has been performed on use of these byproducts as a calcium source in animal feed, with mixed results.[119,120,121]

The primary potential problems associated with the use of these materials are leachable metals concentrations (especially Mo, B, As, and Se),[122] soluble salts, and food chain effects. Whether metals pose a problem or confer a benefit is often dependent on the particular crop or soil condition because the metals B, Mo, and Se also may be required as plant nutrients.[123] Consequently, the questions of addressing potential problems and acceptable use can be reduced to appropriate testing of material and proper application.

Evidence of no health, environmental, or crop harm, and proof of benefit, is usually required for agricultural use approval, and is unquestionably recommended for use of any new FBCB source

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[118] W.L. Stout, M.R. Dally, T.L. Nickerson, R.L. Svendsen, G.P. Thompson. *Agricultural Uses of Alkaline Fluidized Bed Combustion Ash: Case Studies*. 1995 International Ash Utilization Symposium Proceedings; Lexington, Kentucky.

[119] John W. Merkley, Donald M. Mitchell and A. Lee Cartwright. *Fluidized Bed Combustion Residue as An Inorganic Calcium Source in Poultry Feed*. Work Performed Under Contract No. DE-A121-86MC23160 for U.S. Department of Energy by Agricultural Research Services.

[120] Nancy J. Cahill, R.L. Reid, M.K. Head, J.L. Hern, and O.L. Bennett. *Quality of Diets with Fluidized Bed Combustion Residue Treatment*: I. Rat Trials. J. Environ. Qual., Vol. 17, no.4, 1988. p. 550.

[121] D.M. Mitchell , J.D. May and O.L. Bennett. *Effect of Fluidized Bed Combustion Residue on Performance and Physiology of Broilers.* 1983. Poultry Science 62:2378-2382.

[122] Morgan, op. cit.

[123] R.F. Korcak. Draft. *Agricultural Utilization of Coal Combustion Byproducts. In* Agricultural Utilization of Municipal, Animal and Industrial Byproducts. USDA Agricultural Research Service.

by state Departments of Agriculture. In practice, this may prove difficult and/or expensive. Several approaches and combinations of approaches have been used to accomplish this in the past and include the following: use of existing standards for pollutant concentrations; chemical testing; greenhouse studies; and field testing. The approach used will depend on the beneficial use, and agency and user requirements. Environmental safeguards also must be established, which include safe application rates and methods, dust control, precautions to prevent run-off or ground water contamination (application methods), and chemical testing to assure that loading rates (if applicable) are not exceeded.

Leachable metals concerns may be addressed through established metals concentration standards in 40 CFR Part 503 "Standards for the Use and Disposal of Sludge". These standards have been applied in some instances to limit use of FBCBs as a liming agent. Further discussion of this issue is presented in Chapters 7 and 8 of this Report.

Guidance for application of FBCBs may also be obtained from USDA's *Manual for Applying Fluidized Bed Residue to Agricultural Land,*[124] which is included as Appendix F. Considerations not addressed in the EPA Part 503 standards or RCRA regulations include other metals, especially boron, and soluble salts. Established chemical leachate tests may be performed to screen acceptability of FBCBs.[125] EPA Part 503 regulations and the current USDA Manual may not adequately consider mobility and interactions of metals. Other diagnostic tests exist (e.g., ASTM D5435 - *Standard Diagnostic Soil Test for Plant Growth and Food Chain Protection*) for these purposes. Arguably, a single volumetric measurement may not be the best approach, especially when considering oxyanions, chemical interactions, and food chain effects.[126]

Use of FBCBs in agricultural applications is limited at this time due to the relatively short time they have been available, the lack of specific environmental regulatory programs addressing their use, lack of established specifications, the unconventional handling required (or need to incur costs to make the material manageable), limited distribution area due to generator locations, and limited user familiarity with the products and their potential value.

Liming Agent - Extensive research has been performed by the USDA for use of FBCB as a liming agent. This research includes testing on various food and forage crops, and uptake in the crops

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[124] W.L Stout, J.L. Hern, R.F. Korcak, and C.W. Carlson. 1988. *Manual for Applying Fluidized Bed Residue to Agricultural Land*. U.S. Department of Agriculture, Agriculture Research Service, ARS-74, 15pp.

[125] J.D. Roades. 1982. Soluble Salts. *In* A.L. Page (ed.), *Methods of Soil Analysis, Part II* Agronomy 9:167-179.ASA Madison, WI.

[126] Joseph P. Senft and Dale E. Baker. *Background Concentrations of Metals in Soil, Nitrogen and Patogens in Sludges and EPA 503 Regulatory Limits*. 1995 International Ash Utilization Symposium Proceedings; Lexington, Kentucky.

and animals that are fed treated crops.[127,128,129,130,131] Crops tested include apples, peanuts, peaches, corn, soybeans, tall fescue, alfalfa, swiss chard, cabbage, tomatoes, lettuce, turnips, pecans, buckwheat, blueberries, oats, broccoli, beets, and snap beans. General conclusions from these crop studies and uptake studies are that when applied properly, FBCBs improve productivity and pose no significant environmental risks. No detrimental effects were found in animals fed diets produced on FBCB treated soils. No significant accumulation of metals was found in the plant species or foraging animals tested.

Calcium carbonate equivalent and calcium content are the primary parameters examined to determine the suitability of FBCB as a liming agent. Required minima for these parameters frequently eliminate some FBCB sources from being used. The higher calcium content typical of bed ash makes it a better liming agent than fly ash. As an agricultural liming agent FBCB has been tested extensively by USDA and found to be of benefit.[132]

Nutrient Source and Soil Amendment - Certain agricultural specifications for minimum calcium or calcium carbonate content may not be met by FBCBs. This may eliminate their use as a liming agent but still allow for use as a general soil amendment, in which they may provide significant benefit to plant growth due to nutrients present or physical changes imparted to the soil. In such instances, the material may be alternatively permitted for use as a soil amendment or nutrient product for any claimed benefit or nutrient content. Mixing FBCBs with other material may enhance desired characteristics. Consultation with specific state Departments of Agriculture is required to determine if such use of these materials is allowed and to obtain approval registration and meet licensing requirements. Knowledge of the chemical and physical properties of the

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[127] M.A. Cochran, H.D. Perry, J.P. Fontenot, V.G. Allen and O.L. Bennett. *Effect of Soil Amendment with Fluidized-Bed Combustion Residue on Forage and Soil Quality and nutritional Status of Steers Grazing Reclaimed Surface-Mined Pastures*. Animal Science research Report No. 6 Virginia Agricultural Experiment Station. 1986-87. Virginia Tech.

[128] W.L Stout, H.A. Menser, J.L. Hern, and O.L. Bennett. *Fluidized Bed Combustion Waste in Food Production.* 1979. Solid Waste Research and Development Needs for Emerging Coal Technologies, ASCE/ACS Workshop Proceedings.

[129] Whitsel et al. *Quality of Diets with Fluidized Bed Combustion Residue Treatment: II. Swine Trials*. J. Environ. Qual., Vol. 17, no. 4. 1988. p. 556.

[130] O.L. Bennett, et al. A Final Report submitted to the Department of Energy in partial fulfillment of the requirements under Contract No. DE-AI21-76ET 10391 (ARS-12-14-1001-712). *A Seven Year Study of Agricultural Uses of Atmospheric Fluidized Bed Combustion Residue (AFBCR).* 1986. Agricultural Research Service United State Department of Agriculture.

[131] O.L. Bennett, W.L. Stout, J.L. Hern, and R.L. Reid. 1980. *Status of Research on Agricultural Uses of Fluidized Bed Combustion Residue*. The Proceedings of the Sixth International Conference on Fluidized Bed Combustion.

[132] O.L. Bennett, op. cit.

specific byproduct source is critical, because such properties may vary widely among sources. Claims of crop or soil improvement must be documented through field testing.

Improvement to physical characteristics of soils, other than those discussed in mine reclamation, include the improvement of sodic and fragipan soils and other general soil improvement by improving infiltration and reducing soil loss. Pozzolanic characteristics of FBCBs may prove problematic with improper application and result in clumping of soil and reduced infiltration.[133]

Fragipan horizons are typically characterized by high silica content causing high bulk density, brittleness, hardness, and cementing action that can be restrictive to root penetration. FBCBs have been used at rates of up to 20 tons per acre on soils with fragipan horizons in uplands of the lower Mississippi Valley. Positive effects were observed that included reduced soil strength and raised pH.[134] Similarly, FBCBs have been used on other soils to successfully improve infiltration and consequently reduce soil loss to water erosion.[135] Currently, however, this application is not in common practice and is considered experimental at this time.

Potting and landscape soils - FBCBs residues can be used in the production of potting soil mixtures. When used in this application, these CCBs may provide air and water holding capacity, micro and macro nutrients, and improved texture. FBCBs are known to be a source for both electrolytes and alkalinity.[136] These CCBs can be added to peat moss, humus, compost, or pine bark mixtures to produce high quality soils. FBCBs also have been demonstrated to reduce the water repellency characteristics of peat moss and peat based soils.[137] The alkalinity of the material can be used to neutralize the acidic nature of acidic soils and pine bark derived soils, which will increase the effectiveness of fertilizers and provide a better growth medium for many types of plants.

Soil from stabilized sewage sludge - Dewatered sewage sludge can be combined with high CaO CCBs or a mixture of low CaO CCBs and cement, lime, or lime kiln dust to produce a safe and high quality soil. The fine particle size of CCBs and the available alkalinity of the CaO provide the characteristics to dry and pasteurize the pathogens in the sludge, reduce odors, and provide a granular consistency. The stabilized sludge product has valuable levels of calcium carbonate, nitrogen, organics, micro and macro nutrients, and residual bio-activity. The stabilized sludge

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[133] Korcak, op. cit.

[134] Fred E. Rhoton, James H. Edwards and L Darrell Norton. *Use of Fluidized Bed Combustion Ash to Ameliorate the Restrictive Nature of Fragipan Soils: Preliminary Lab Results*. 1995 International Ash Utilization Symposium Proceedings; Lexington, Kentucky.

[135] Darrell Norton. *Utilization of Desulfurization By-products as Electrolite Sources to Reduce Soil Surface Sealing*. 1995 International Ash Utilization Symposium Proceedings; Lexington, Kentucky.

[136] J.M. Reichart and L.D. Norton, 1994, Fluidized Bed Bottom Ash Effects on Infiltration and Erosion of swelling Soils, Soil Science Society of America Journal, V. 58, pp. 1483-1488.

[137] Hailong L. Wang, et.al. , Massey University; Palmerston North, *New Zealand. Amelioration of Water Repellency in a Peat Soil Using Fluidized Bed Boiler Ash.* 1995 International Ash Utilization Symposium Proceedings; Lexington, Kentucky.

product has many applications in the agricultural industry, including use as a liming material, soil conditioner, fertilizer, and landscaping soil.

5.3.5 Cement Applications

Cement applications include use of FBCBs as cement production raw feed, cement replacement in concrete, and synthetic aggregate. All cement applications combined use much less than 1 percent of all FBCBs generated. According to 1996 Survey results (as shown in Exhibit 5-6, above), operators of three facilities (in California, New York, and Pennsylvania) made use of FBCBs in this application, with the former two using only very small quantities in 1995, and the latter employing about 5,000 tons (about 3 percent of the quantity generated by the facility).

Use as Cement Raw Feed - FBCBs can provide a suitable source of aluminosilicates, calcium, and iron for use as a raw material for cement manufacturing. There has been limited, but successful, use of FBCBs for this purpose. Caution in its use does arise from the sulfur content present. Sulfur limitations in Portland cement are approximately 3 percent, in the form of SO_3. For this reason, raw feed using FBCBs must be carefully managed by some level of quality control. Also, because lower sulfur contents are found in FBCB fly ash versus bed ash, fly ash is generally more suitable for this application. Sulfur content also may be controlled to some extent by sorbent particle size and quantity.[138]

Use as Cement Replacement in Concrete - FBC fly ash is not typically used to replace cement in making concrete. ASTM specifications (ASTM C618) specifically *exclude* the use of ash from FBC boilers. Use in this application is restricted primarily because of potential expansion and sulfur reactions. Expansion may be either initial rapid expansion due to high available lime (CaO) or more long-term expansion due to ettringite formation and other mineralogical reactions. Some of these other mineral reactions may reduce strength over time. Higher sulfur concentrations in FBC fly ashes usually exclude the material from meeting the ASTM C618 specifications for this application. The sulfur specification is included to protect against sulfur attack. Sulfur attack may cause dimensional instability in concrete and reduction in cementing strength, due to sulfur's ability to degrade cement complexes.

Some FBC fly ashes have been known to be close to or actually marginally meet the ASTM specifications for this utilization. The ASTM specifications are, however, specific to PC ashes and do not consider fundamental differences between the PC and FBCB ashes.

This is a high specification and critical application. Even if the specifications could be met, FBCB use cannot be recommended due to the uncertainties associated with the underlying differences in the nature of PC and FBC boiler ashes, as discussed in Section 5.1.1. Less critical applications that may use to good advantage the cementitious and pozzalanic properties of FBC byproducts are grouts, flowable fills, and synthetic aggregates; even these less critical and lower specification

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[138] Robert Dawson et.al. *Controlling the Chemical Composition of Bag House Ash from a Circulating Fluidized Bed Boiler for Use in Cement*. 1995 International Ash Utilization Symposium Proceedings; Lexington, Kentucky.

applications must be approached with caution due to the nature of the material and the uncertain long term stability of their reaction products.

Synthetic Aggregate - The cementitious properties and low unit weight of these byproducts make them tempting candidates for use as raw materials for synthetic aggregates. Use of these byproducts in this application requires considerable research into the long-term strength and expansive characteristics of the specific source being considered for use. The critical nature of the project application also will have a bearing on the use of synthetic aggregates.

Less critical applications for synthetic aggregates may be preferred. These would include synthetic aggregates created for ease of handling the FBCBs, use of a synthetic aggregate as an extender in natural aggregates, aggregate in non-critical fill or reclamation applications, and other similar uses. Documented loss of strength of some of these materials over time and expansion are reasons to carefully consider critical uses in this application.[139] This does not absolutely preclude the manufacture of durable aggregate, which would require extensive long term testing, freeze/thaw and wet/dry considerations, and possible mix design work. FBCBs tend, however, to perform poorly in wet/dry and freeze/thaw tests. There is limited evidence that shows FBCBs may be acceptable as aggregate asphaltic filler, but generally it is not anticipated that this material will make a hard and durable aggregate by itself.[140] In addition, cost for this approach is currently considered prohibitive.

5.4 Trends in Beneficial Uses

Applications of FBCBs discussed in Section 5.3 provide a fairly comprehensive listing of current and potential FBCB beneficial uses. Some of these uses have been growing in popularity, and are being employed at more facilities and in more locations around the country, as depicted in Exhibit 5-8. The biggest potential for beneficial use is through increasing quantities sent to existing types of applications, particularly in agriculture and geotechnical uses. More common use of FBCBs in these applications will require reduction or modification of the same barriers that limit the use of other coal combustion byproducts.

The common barriers to more extensive use are the stigma attached to labeling FBCBs as a solid waste, resistance to change from use of established competitive products, the lack of specific environmental regulatory programs encouraging their use, a general lack of established specifications specific to FBCBs, limited distribution area due to generator locations, and limited user familiarity.

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[139] M.M. Wu, R.A. Winschel and G.E. Wasson. *Composition Effects on Durability of Aggregates Made from Coal Combustion By-products*. 1995 International Ash Utilization Symposium Proceedings; Lexington, Kentucky.

[140] E.E. Berry and E.J. Anthony. *Evaluation of Potential Uses of AFBC Solid Wastes*. 1987 Materials Research Society Symposium Proceedings. Vol. 86 pp. 353-364.

Use also will increase as blending of FBCBs, as a major or minor ingredient, is employed to achieve the desired attributes in applications that are limited due to deleterious characteristics (especially expansive and strength problems of these byproducts) or to take advantage of its superior qualities in certain applications. The appearance of FBCBs is relatively recent in reuse markets and acceptance will require time and further product development efforts.

EXHIBIT 5-8
GEOGRAPHIC DISTRIBUTION OF 1996 SURVEY RESPONDENTS AND PRODUCTIVE USE APPLICATIONS

	1990		1991		1992		1993		1994		1995	
	Number of Facilities	**States**	**Number of Facilities**	**States**	**Number of Facilities**	**States**	**Number of Facilities**	**States**	**Number of Facilities**	**States**	**Number of Facilities**	**States**
Facilities Generating FBCBs	15	CA, GA, IA,IL, MN, ND, OK, PA	21	CA, CT, GA, IA, IL, IN, MN, ND, NE, NY, OK, PA	23	CA, CT, GA, IA, IL, LA, MN, ND, NE, NY, OK, PA, TX	31	CA, CT, GA, HI, IA, IL, IN, LA, MI, MN, ND, NE, NY, OK, PA, TX, WI	34	CA, CT, FL, GA, HI, IA, IL, IN, LA, MI, MN, MO, ND, NE, NY, OK, PA, TX, UT, WI	38	CA, CT, FL, GA, HI, IA, IL, IN, LA, MI, MN, MO, ND, NE, NY, OK, PA, TX, UT, WI
Facilities Disposing FBCBs	9	CA, GA, IA, IL, MN, ND	9	CA, GA, IA, IL, MN, ND	12	CA, GA, IA, IL, MN, ND, PA, TX	15	CA, GA, IA, IL, LA, MI, MN, ND, PA, TX, WI	16	CA, FL, GA, IA, IL, LA, MI, MN, ND, TX, UT, WI	18	CA, FL, GA, IA, IL, LA, MI, MN, ND, PA, TX, UT, WI
Use in Mining Applications	4	PA, OK	8	CT, NY, OK, PA	8	CT, NY, OK, PA	11	CA, CT, NY, OK, PA	13	CA, CT, MO, NY, OK, PA	16	CA, CT, IL, MO, NY, OK, PA
Use in Waste Stab./Solid.	1	MN	3	MN, NY, OK	4	LA, MN, NY, OK	6	IA, LA, MN, NY, OK, TX	6	IA, LA, MN, NY, OK, TX	11	CA, IA, IL, LA, MI, MN, NY, OK, TX
Use in Structural Fill	0		1	IN	2	PA, TX	3	IN, PA, TX	3	HI, PA, TX	6	CA, HI, PA, TX
Use in Other	1	IA	2	IA, OK	3	IA, OK	4	HI, IA, OK	3	HI, IA, LA, OK	7	CA, HI, IN, LA, OK
Use in Agriculture	3	CA, IA	3	CA, OK	5	CA, TX	6	CA, HI, NY, OK	6	CA, HI, NY, OK	5	CA, IA, IL, NY, OK
Use in Flowable Fill	0		0		0		0		0		1	CT
Use in Cement	0		1	NY	1	NY	0		0		3	CA, NY, PA

CHAPTER SIX

DOCUMENTED DAMAGES FROM FOSSIL FUEL COMBUSTION BYPRODUCTS

6.0 Introduction

Section 8002(n)(4) of RCRA requires that EPA's study of fossil fuel combustion byproducts examine "documented cases in which danger to human health or the environment from surface runoff or leachate has been proved." EPA has conducted several similar studies of damages from various special wastes in preparation for regulatory determinations for each waste.[141] In conducting these studies, EPA has defined danger to human health or the environment in the following manner. First, danger to human health includes both acute and chronic effects (e.g., directly observed health effects such as elevated blood lead levels or loss of life) associated with management of the waste. Second, danger to the environment includes the following types of impacts:

(1) Significant impairment of natural resources (e.g., contamination of any current or potential source of drinking water, with contaminant concentrations exceeding drinking water and/or aquatic ecological standards);

(2) Ecological effects resulting in degradation of the structure or function of natural ecosystems and habitats; and

(3) Effects on wildlife resulting in damage to terrestrial or aquatic fauna (e.g., reduction in species' diversity or density, or interference with reproduction).

This chapter describes the approach we have employed to address the §8002(n)(4) requirement, including the methods used to identify potential cases, information on potential damage cases, and our interpretation of the significance of our findings. In addition, this chapter provides a discussion of the limitations associated this analysis.

"Tests of Proof"

The statutory requirement is that EPA examine proven cases of danger to human health or the environment. Accordingly, the CIBO Special Project has attempted to use EPA's "tests of proof" to determine if documentation available on a case provides evidence that danger/damage has occurred. (These are the criteria used by the Agency in the *Report to Congress on Special Wastes from Mineral Processing*, and the *Report to Congress on Cement Kiln Dust*.) These "tests of proof" consist of three separate tests; a case that satisfies one or more of these tests is considered "proven." The tests are as follows:

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[141] See, for example, U.S. EPA, *Report to Congress on Special Wastes from Mineral Processing*. Office of Solid Waste. July 1990 and U.S. EPA. *Report to Congress on Cement Kiln Dust*. Office of Solid Waste. December 1993.

- Court decision. Damages are found to exist through the ruling of a court or through an out-of-court settlement.

- Scientific investigation. Damages are found to exist as part of the findings of a scientific study. Such studies could include both formal investigations supporting litigation or a state enforcement action, and the results of technical tests (such as monitoring of wells). Scientific studies must demonstrate that damages are significant in terms of impacts on human health or the environment. For example, information on contamination of a drinking water aquifer must indicate that contamination levels exceed drinking water standards.[142]

- Administrative ruling. Damages are found to exist through a formal administrative ruling, such as the conclusions of a site report by a field inspector, or through existence of an enforcement action that cited specific health or environmental damages.

In addition, the environmental or human health impact must be associated with the specific special waste(s) in question, i.e., be attributable to one or more special wastes, for damages to be "proven" for purposes of this application.

6.1 Methodology

To evaluate the tests of proof, we conducted a three-tiered procedure to identify prospective damage cases. We first searched electronic databases of court cases to identify judicial rulings on damages from FFCB. Next, we reviewed monitoring data on ground water and surface water quality reported in the Special Project survey, focusing on those instances in which a facility operator indicated that one or more environmental quality standards had been exceeded. Finally, we reviewed a report prepared by the Pennsylvania Bureau of Mining and Reclamation (PABMR) on the use of FFCB in mining reclamation. Note that this methodology is intentionally over-broad, in that it addresses all by-products from fossil fuel combustion, not just fluidized bed combustion byproducts (FBCB). The Special Project chose this approach so as to find and evaluate any and all potentially relevant information.

Court Cases

We conducted a broad-based search of the Lexis on-line library of all reported federal and state decisions in an attempt to locate cases alleging damage to the environment or public health as a result of the disposal or beneficial use of FFCBs. Initially, the search was focused on FFCBs, but only tax and intellectual property cases could be found using such search terms. We then expanded the search to include the terms "ash waste," "coal ash," "coal waste," and "ash" all coupled with disposal and environment. While the initial search yielded over 280 cases, only 104 included the term "coal." These cases were reviewed on-line and 14 cases were identified as warranting more detailed review.

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[142] We recognize that comparison of drinking water standards and constituent levels in groundwater is not routine. But because of the lack of benchmark standards for constituents in leachate, we believe it is a useful comparison.

Survey Data

In its survey of FBC plants, the Special Project asked several questions relating to any environmental damages that had been documented from the disposal or use of FFCB. We reviewed the responses to these questions, focusing on ground water and surface water monitoring reports. For facilities at which constituents in ground water or surface water exceeded regulatory contaminant levels, we examined historical monitoring data, upgradient/upstream monitoring data, current and historical land use, and explanations of exceedances provided by the respondents.

Pennsylvania Report

As part of the Special Project's work to identify existing regulatory controls, we consulted with the Pennsylvania Department of Environmental Protection, Bureau of Mining and Reclamation regarding their program for the beneficial use of FFCB in mine reclamation. As a result of this consultation, the Bureau of Mining and Reclamation prepared a report summarizing the program; this report is discussed more fully in Chapter 8. A part of the Bureau of Mining and Reclamation ("PABMR") report addressed what problems the Bureau had encountered since the use of coal combustion byproducts in mine reclamation had been initiated.

Limitations of the Damage Case Analysis

The CIBO Special Project has, as described above, diligently reviewed the available literature, (including court cases), conducted a thorough analysis of information submitted by operators of FBC units, and solicited and reported data supplied by state regulatory officials concerning the environmental performance of FBCB management methods. The approaches used by the Special Project in conducting this work parallel closely those used by EPA in identifying and evaluating potential damage cases in previous RCRA § 8002 studies. Accordingly, some of the same caveats that have accompanied these previous studies apply to the current analysis as well. First, no computer-based search can be exhaustive because only court decisions are published. Cases that are filed but settled out of court will not appear in the on-line databases. No attempt was made to discover regulatory agency decisions on this matter because not all decisions are reported and no relevant decisions would be expected given the application of the Bevill Amendment.[143] In addition, any cases that do not fit within the search parameters will likewise be missed. We attempted to use all of the search terms that would turn up relevant cases, but no assurances can be given that every relevant case was located and reviewed. Likewise, the review involves a fairly significant degree of judgment as to relevance. The goal of the search was to locate cases in which FFCBs were found to cause damage to the environment or the public health.

Second, the survey data we reviewed involved only current disposal sites, so unless a facility had been using the same disposal area for years, we could not evaluate long term effects of FFCB management. In addition, there was a variety of disposal sites described by the respondents - some were dedicated disposal units, while others were mining reclamation sites. While mine reclamation and disposal in

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[143] Although state governments can disregard the Bevill Amendment, in practice, few have done so, presumably because they have been awaiting federal guidance on this topic.

secure disposal units are the predominant practices applied to FFCBs, it is possible that not all land based management practices were represented in the survey responses. Further, not all of the respondents monitored ground and surface water near the disposal site.

Finally, in addition to potential problems with the representativeness and completeness of the data, management practices also limited our ability to determine the source of observed damage. FFCB disposal and use sites are often located in old mines or in areas heavily damaged by historic acid mine drainage; indeed, FFCBs are frequently applied as a remedial measure to neutralize the low pH of ground and surface waters of these sites. In such cases, it is often difficult to determine if the documented damages were caused by management of FFCBs, or if the historic practices may have caused or contributed to the observed damage. Similarly, FFCBs are or have been co-managed with other wastes such as waste coal or other process residues at many sites, further complicating the process of apportioning culpability for existing damages.

6.2 Findings

Court Cases

Of the 14 court cases selected for detailed review, most involved decisions relating to the authority and jurisdiction of the EPA, the reasonableness of EPA's regulations promulgated under various federal statutes, and questions of federal pre-emption of state and local laws and ordinances. One was a patent case relating to a process to convert ash into cement, and several cases involved Potentially Responsible Parties under CERCLA.

Two of the cases bear on the issue of damages resulting from disposal of ash from coal combustion, but neither directly addresses the factual issues of environmental or public health damage or grants a monetary award for any physical harm other than clean-up costs and attorneys' fees. A third case illustrates CERCLA's applicability to beneficial use programs and is cited by the court in one of the other cases. These three cases are discussed below.

U.S. v. Petersen

The first case is United States v. Petersen Sand and Gravel, Inc., 806 F.Supp. 1346 (N.D. Ill. 1992). In this case, the United States sued Petersen for clean-up costs incurred at a hazardous waste site under CERCLA. Petersen sued seven other parties for contribution. Among the wastes disposed at the site was some volume of fly ash originating at coal-fired electricity generating plants owned by Commonwealth Edison Company. The hazardous nature of the fly ash was assumed by the court and all parties involved, meaning that it contained one or more "hazardous substances,"(e.g., heavy metals, as defined by CERCLA).

Commonwealth Edison was one of the third party defendants from which Petersen sought contribution. However, Commonwealth Edison had arranged for an intermediate party (American Fly Ash) to take all of its fly ash with the mandate to sell that portion of the ash which qualified for beneficial reuse. American Fly Ash sold such qualifying ash to Skokie Valley Asphalt Company for use as road base filler. Skokie Valley, however, stored the ash on the site and did not beneficially reuse all of it. Because Commonwealth Edison and American Fly Ash had sold a commercially viable product, it was not a "waste" and therefore the court granted summary judgment in favor of Commonwealth Edison and American Fly Ash. With respect to Skokie Valley's improper disposal of the fly ash at the site, questions of material fact existed with respect to successor liability and the court did not grant Skokie Valley's motion for summary judgment.

There is no subsequent reported decision, so the case is either ongoing or has been settled out of court.

Douglas County, Nebraska v. Gould, Inc.

Another case is Douglas County, Nebraska v. Gould, Inc., 871 F.Supp. 1242 (D.Neb. 1994). In this case, one of the defendants, Madewell, processed used batteries, disposing of certain materials, and producing lead plates sold to the market from other parts. In this case, lead has already been determined to be a hazardous substance, so the application of CERCLA became the only issue. Gould purchased the lead plates which contaminated the site for which Douglas County was seeking clean-up costs, including from Madewell.

The Court found that Madewell did not arrange for disposal or treatment of lead under CERCLA. The term disposal, noted the Court, necessarily includes the concept of waste. Because Madewell sold the results of its process (lead plates) to Gould for a market price, there was no "waste" and therefore, no disposal. As long as such transaction is not a sham to avoid statutory jurisdiction, the sale of a hazardous substance which has value will not constitute disposal under CERCLA. Citing to Petersen, the Court also observed that seller liability for the later misuse by the buyer of useful, but hazardous ingredients, was not intended by CERCLA's authors; "such liability would chill permissive manufacturing."

While the Gould court's holding could be viewed to protect FBC operators from downstream misuse of FFCBs even if such by-products were classified as hazardous, the decision does nothing to diminish EPA's jurisdiction and authority over downstream users. If FFCB were to be classified as hazardous, CERCLA liability on downstream users could severely restrict downstream beneficial use. The protection ostensibly afforded to FFCBs by the Gould court is also inapplicable to the extent that the fossil fuel combustion by-products do not attain a "market value." That is, to the extent that by-products provided for beneficial uses are still "wastes," the FFCB will still be considered to be disposing of the by-products, and thus will be within the ambit of CERCLA.

Eagle-Picher v. EPA

The last case is Eagle-Picher Industries, Inc. v. United States Environmental Protection Agency, 759F.2nd 922 (D. C. Cir. 1985). In this case, petitioners were mining enterprises and an electric utility company (Virginia Electric and Power Company - “Vepco”). The petitioners contention was “... that their facilities were improperly included by the Environmental Protection Agency on a nationwide list of priority sites under the Comprehensive Environmental Response, Compensation and Liability Act of 1980, 42 U. S. C. §§ 9601 *et. seq.* (1982) (‘CERCLA’ or the ‘Act’)”. 759 F.2nd at 925. The mining companies owned facilities that contained mining wastes located in Oklahoma, Kansas, New Mexico, and South Dakota. “Vepco’s Chisman Creek, Virginia, site contains fly ash waste, a by-product of the combustion of coal and small amounts of coke.” 759F.2nd at 926.

The challenge was based on an exclusion in the definition of "hazardous substance" set forth in section 101(14) of CERCLA. The definition excludes any waste whose regulation under the Solid Waste Disposal Act had been suspended by Congress (e.g., Bevill wastes). While not of importance to this report, the pivotal debate in Eagle-Picher was whether the exclusion applied to the entire definition, or just one subparagraph.

Without distinguishing between the fly ash and the mining wastes, the court observed that EPA's classification was based upon the fly ash containing arsenic, cadmium, and selenium. Vepco and the mining concerns argued that all mining wastes and fly ash contained trace amounts of substances that qualify as hazardous substances and would render meaningless the exclusion in the definition of "hazardous substance." While it appears that this would have been a persuasive argument for the court, the court berated Vepco's case preparation by observing that "Unfortunately for petitioners, they have cited nothing in CERCLA, its legislative history, or the record in this case demonstrating that all or virtually all mining wastes and fly ash have constituents which are `hazardous substances.' We have nothing more than petitioners' bare assertions on this point." 759 F.2d at 928. Without this factual record upon which the court could use legislative intent to interpret the statute, the court was unwilling to reject the plain meaning of the statutory definition. The court did not reach Vepco's argument that the fly ash could not be regulated as a hazardous substance under CERCLA because it was not shown to cause imminent and substantial danger.

Although the courts did not, and were not asked to, address whether the coal ash in question was environmentally hazardous, or caused any damage to health or the environment, the cases do bear directly on the issue facing the EPA and Congress. First, Eagle-Picher indirectly confirms Congressional intent not to impose excessive burdens or regulations on high-volume, low-hazard materials. More importantly, the regulation of all FFCBs as "hazardous wastes" under RCRA would be, in many respects, redundant. As indicated by Petersen and Douglas County, where such material actually is a hazardous substance (a fact-specific situation), the courts have upheld its regulation, and the liability for remediation thereof, under CERCLA. Thus, where the facts support a conclusion that a particular disposal site or method for FFCBs would pose imminent danger to the environment or to public health, the EPA already has an adequate regulatory avenue through which to address the situation.

Survey Data

In our review of the data in the Special Project survey, we found five facilities that reported an exceedance of a primary MCL in either ground water or surface water. All of these sites, plus an additional three sites, also reported exceedances of secondary MCLs in either the ground water or surface water. At seven of these eight facilities, the contamination can be clearly attributed to either historic or upgradient / upstream contamination. At the remaining facility (facility 23) the survey response did not contain enough information to evaluate the source of the contamination (i.e., no upgradient or historical data were provided, nor was information on historic uses of the site or surrounding areas.) A summary of environmental conditions at each of these eight facilities is included below.

Facility 7

The disposal unit is a Subtitle D surface impoundment, which receives scrubber solids and FBCBs. The 102-acre pond has an 18 inch recompacted local clay liner. Run-off is collected and recycled back to the pond. Leachate collection will occur when the unit is closed, at which time the liquids from the unit will be pumped to a new pond for use in plant process systems. The ground water discharges to the Mississippi River. Constituents in ground water have exceeded primary and secondary MCLs. The facility operator indicated that nitrate contamination has resulted from agricultural sources, and sulfate contamination has resulted from agricultural plus coal and FBCB influences.

Based on the low leachable concentrations of nitrate and sulfate in the FBCBs, along with the small percentage of FBCBs in the unit, it is likely that the FBCBs are not a significant contributor to the contamination. The fact that the upgradient concentrations are about equal to the downgradient concentrations also supports this conclusion.

Facility 11

This disposal (reclamation) site consists of two abandoned mines. Constituents in ground water reportedly have exceeded primary and secondary MCLs, and constituents in surface water have exceeded secondary MCLs. The facility operator indicated that the downgradient monitoring wells are severely affected by acid mine drainage infiltrating into the shallow ground water system, and that the surface water comes into contact with coal and coal refuse from a previously operated coal preparation plant.

FFCB were first placed in the abandoned mines in 1995. The facility operator provided limited historical data for some ground water constituents showing historical contamination. Based on this known historical contamination, the location of the disposal area in abandoned mines, and the very low TCLP concentrations for the constituents of concern, we conclude that ground water contamination resulted from acid mine drainage as indicated by the operator. More complete historical data were provided for surface water, demonstrating contamination as far back as 1989.

Facility 16

Up until 1995, the disposal facility (an old mining site) received coal refuse. In 1995, the facility began receiving FBCBs in addition to coal refuse, as a means of reclamation. The site has an in-situ clay/shale liner. Run-off is collected, treated, and discharged to surface water. Leachate is collected, neutralized, sent to settling ponds, and then discharged to surface water. Ground water is located in a perched aquifer below the site, and an abandoned deep mine complex beneath the site. There is no current use for either "aquifer." Constituents in ground water have exceeded secondary MCLs. The facility operator indicated that the perimeter of the site (3 sides) is surrounded by "pre-Act" (i.e., prior to enactment of the Surface Mining Control and Reclamation Act of 1977) abandoned deep mine and surface mine activities. This reclamation site has a subchapter F State of Pennsylvania DER mining permit. The facility included historical data which indicate consistent downgradient contamination of all named constituents.

Facility 19

FBCB are placed in an abandoned strip mine, which is underlain by abandoned underground mines that have filled with water. There are many abandoned surface mines in the area. Constituents in ground water have exceeded primary and secondary MCLs. Constituents in surface water have exceeded secondary MCLs. The facility operator indicated that the upgradient and downgradient groundwater monitoring wells are both in the "mine pool." This is not an aquifer but a network of flooded mines and is highly contaminated by the sulfuric acid-laden water and leached out metals from the highly disturbed area geology.

The data provided by the survey respondent indicate historical ground water contamination. The low pH also suggests that the contamination is coming from acid mine drainage, and not from the ash disposal area, because if the ash were the sole source of contamination, the pH would be expected to be alkaline rather than acidic. The concentrations of some constituents in the upgradient ground water also exceed the MCLs. While there are no data indicating pre-ash disposal surface water conditions, the historical ground water contamination suggests that the surface water also has been contaminated by run-off from abandoned mines.

Facility 23

The disposal unit is a residual landfill with a recompacted clay/shale base with 2 layers of geotextile and one 60 mil HDPE liner system. Run-off from the unit passes through a sediment control pond. Leachate is collected and sent to a holding/settling/evaporation pond. Ground water samples exceeded primary and secondary MCLs for lead on two occasions in September and December 1995. Test results since December 1995 have shown lead concentrations at less than detectable values. The 1995 test results may have been naturally occurring, but transient concentrations, laboratory error, or contamination. All other test results were within applicable primary and secondary drinking water standards.

Very limited information was provided from which to evaluate the source of the contamination (i.e., no upgradient or historical data were provided, nor was information on historic uses of the site or surrounding areas.)

Facility 24

This disposal site is a mine reclamation area, lined with in-situ clay/shale.   Run-off is collected and treated with lime to adjust pH before discharge to surface water. There is no leachate collection system. Two mine pools are under the site. The water from these mine pools is used for commercial and industrial processes. The site has one upgradient and five downgradient monitoring wells. Constituents in ground water and surface water exceeded secondary MCLs. The facility operator indicated that the elevated constituent concentrations resulted from acid mine drainage.

No data are provided, so we cannot tell if there has been historical contamination and/or upgradient contamination. However, because the "aquifers" are both "mine pools," it is likely that some, if not all, of the contamination is from acid mine drainage, as suggested by the facility operator. This theory is further supported by the fact that they treat run-off from the unit for low (acidic) pH. If the unit were the primary source of contamination, the run-off should have an alkaline pH rather than an acidic pH.

Facility 29

The disposal site is a special use landfill permitted by the state regulatory authority. A minimum of five feet of compacted clay lines the sides and bottom of the disposal area. Run-off and leachate are collected in a sump, and pumped to a clay-lined evaporation pond when necessary. Ground water that occurs in small, perched water tables both up- and down-gradient of the disposal area is of highly variable quality, and may not meet primary and secondary MCLs. Similarly, surface water that is sampled from an intermittent stream that flows through agricultural land upstream from the site does not meet all secondary MCLs. Upgradient surface and ground water constituents generally are at higher concentrations than have been measured downgradient.

Facility 32

FBCB are disposed in an existing strip mine as a method of reclamation. The mine itself has a recompacted clay/shale liner. The aquifer under the site is a "pre-existing mine pool" in which total dissolved solids (TDS) levels are frequently elevated and pH levels are low. No leachate collection system exists. Run-off is collected in sedimentation ponds and evaporated.

The facility operator has included historical data (1989) indicating previous elevated levels of sulfate, iron, and manganese in excess of secondary MCLs. Although TDS levels were not available in the 1989 data, the reported high sulfate levels for that period do indicate elevated TDS, which is typically associated with pre-existing mine pools. The facility operator indicated that downgradient samples had high concentrations before FBCB were put into the reclamation site in 1995. The acidic pH level can be explained both by upgradient contamination and the acid mine drainage, both non-FBCB associated activities.

PABMR Report

Fluidized bed combustion byproducts have been used in various mining applications in Pennsylvania since at least 1990. Since 1990, Pennsylvania Bureau of Mining and Reclamation (PABMR) records show a total of 37 violations of the state’s regulations or permit conditions for the beneficial use of coal ash in mining applications. The 37 violations have occurred at a total of seven different sites that receive coal combustion byproducts from 14 different combustion units. Since 1990, the average occurrence rate for violations is one violation every three years per combustion unit. It should be noted that most violations occurred in the early years of the beneficial use program while operators were developing procedures to comply with the PABMR requirements. All 37 violations have been corrected.

The violations cited by the PABMR are summarized in Table 6-1.

Table 6-1
PABMR Reported Violations of Regulations or Permit Conditions for Beneficial Use of FBC Byproducts

Description of Violation	Number of Occurrences
Failure to control fugitive dust during placement of coal ash	11
Failure to properly compact the coal ash	7
Contact of coal ash with standing water in the permitted area	7
Lack of groundwater monitoring data submittal to PABMR	6
Lack of cover over the coal ash	1
Improper placement of coal ash	1
Failure to construct a sump in the coal ash area (permit condition)	1
Failure to remove coal silt accumulation from silt basin prior to coal ash placement (permit condition)	1
Failure to submit mapping of coal ash placement to PABMR	1
Lack of erosion and sediment controls in the coal ash area	1

6.3 Summary and Conclusions

As a result of our investigation into damages from FFCBs, we have not found any clear cut cases of environmental damages resulting from FFCB management practices. Specifically, while noting the limitations described in section 6.1, our three-tiered approach to identifying proven cases of damage did not find any such cases. Our review of court cases did not locate any documented environmental impairment cases. In addition, with the exception of one facility with very limited data, the ground and surface water contamination cases appear to be related to pre-existing conditions, such as historical contamination or upstream contamination. Finally, the problems described in the Pennsylvania report generally occurred during early years of the program, and often were related to failure to meet technical or administrative requirements (compaction, reporting, etc.), as opposed to documented constituent releases or environmental degradation.

Thus, the evidence developed for this report does not suggest that any clear-cut cases of damage to human health or the environment have occurred as a consequence of managing FBCBs, at least according to the criteria that EPA has historically used in evaluating the "documented damage" dimension of Bevill waste status.

CHAPTER SEVEN

POTENTIAL RISKS ASSOCIATED WITH THE DISPOSAL AND BENEFICIAL USE OF FOSSIL-FUEL COMBUSTION BY-PRODUCTS

7.0 Introduction

This chapter presents an analysis of the potential risks associated with the disposal and beneficial use of by-products from fluidized bed combustion of fossil fuels. To distinguish these by-products from other fossil-fuel combustion by-products, in this chapter we will refer to these by-products as fluidized bed combustion by-products (FBCBs). The purpose of this analysis is to identify the risks, if any, to human health and the environment and evaluate whether FBCBs should be regulated as a hazardous waste based on its risks.

Section 8002(n)(3) of RCRA, requires EPA to consider adverse effects on human health and the environment from disposal and utilization of FBCBs. The purpose of this chapter is to evaluate the potential risks associated with the disposal and beneficial use of FBCBs in order to help EPA comply with this statutory mandate.

Because of limited resources, we did not perform a quantitative risk assessment. Instead, we identified previous studies of similar materials and compared the materials to demonstrate the similarities and identify any differences we then extrapolated the results of risk studies for those materials to FBCBs. We chose EPA's risk assessment for large-volume coal combustion wastes from electric utilities (hereafter LVCC) based on the following attributes:

- Chemical and physical similarities to FBCBs
- The assessment analyzed risks from multiple pathways
- The assessment was specifically developed to address the Bevill Amendment study factor requirements and provides an example of the methods used and types of results that are needed to meet the current Bevill Amendment requirements
- The potential risks associated with LVCC and FBCBs originate from similar constituents (metals present in the respective input materials to each process).

We included two major FBCBs beneficial uses, agricultural application and mine reclamation, for risk evaluation. These beneficial uses were selected because of the predominance of their use and their higher potential for migration of metals to receptors. The risk assessment for the Part 503 Rule[144] serves as a

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[144] 40 CFR Part 503 - Standard for the Use or Disposal of Sewage Sludge, Subpart B - Land Application. EPA developed this Rule to protect public health and the environment from (continued...)

benchmark for risks from agricultural application of FBCBs. This benchmark was chosen because land applied biosolids have similar metal constituents to FBCBs, and the pathways of exposure are the same as those for agricultural application of FBCBs. Our research did not reveal any extensively reviewed and published risk assessments of wastes or materials similar to the FBCBs used in mine reclamation. Therefore, the risk evaluation of FBCBs beneficially used in mine reclamation relies on recently published studies and case studies.

The basic approach to the evaluation of risks in this chapter is to compare previous studies of risk for similar wastes to the potential risks of FBCB disposal and reuse taking into account the differences in composition among the wastes.

The contents of each of the remaining sections of this chapter are described below.

- Section 7.1 describes our analytical methodology.
- Section 7.2 provides background on the generation, management, and beneficial uses of FBCBs.
- Section 7.3 presents preliminary risk screening results.
- Section 7.4 evaluates the risks from disposal of FBCBs.
- Section 7.5 evaluates the potential risks from agricultural use of FBCBs.
- Section 7.6 evaluates potential risks from FBCB use in mine reclamation.
- Section 7.7 discusses other beneficial uses.
- Section 7.8 summarizes the risks associated with disposal and reuse of FBCBs.

7.1 Risk Evaluation Methods for Fluidized Bed Combustion By-products

The first step in the assessment was to perform a preliminary risk screening. The screening compared conservative health-based environmental criteria with constituents in FBCBs. This step was followed by a more in-depth examination of the potential risks to human health and the environment from FBCBs by comparing the composition and physical properties of FBCBs to similar combustion wastes and by-products and extrapolating the results of risk studies for those materials to FBCBs. Bulk constituent concentrations, leaching test results, environmental damage cases, management methods, disposal practices and beneficial reuse information for FBCBs and similar materials were used in the comparative

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[144] (...continued)
reasonably anticipated adverse effects of pollutants that may be present in sewage sludge that are land applied based on a comprehensive multipathway risk assessment. The risk assessment followed well-established procedures developed by the National Academy of Sciences to analyze risks to humans, animals, plants, and soil organisms by direct and indirect exposures.

analysis. Using this information, FBCB exposure pathways were compared to exposure pathways for similar wastes to identify differences that might affect the extrapolation of risk.

Data Sources for Risk Evaluation

We used the following sources of data to evaluate the potential risks from disposal and beneficial use of FBCBs.

- The CIBO special project database containing results of a FBC boiler owner survey, including ash composition and leaching test data, fuels used, management and use information, and environmental monitoring data.
- Data from literature searches on the uses and effects of ash, including FBCBs.
- Characterization information from industry and government sources, including Foster Wheeler Development Corporation, state agencies, and CIBO members.
- EPA risk assessments of similar materials, including LVCC and biosolids.

7.2 Background on Fluidized Bed Combustion By-product Management

This section presents background information on FBCBs that was used to evaluate and compare FBCBs to similar wastes.

Disposal Practices

The generation of FBC ash has rapidly increased from 1.6 million tons per year in 1990 to 5.9 million tons per year in 1995 as more FBC units have come into operation. Accordingly, the quantity of FBC ash disposed annually has increased, but not at the same rate as generation. A growing percentage of the ash is being beneficially used, reducing the percentage of ash being disposed per year from 38 percent in 1990 to 25 percent in 1995, even though the volume of ash being disposed is currently increasing.

Beneficial Uses of Fluidized Bed Combustion By-products

FBCBs is beneficially use in three main applications: engineering and construction, mine reclamation, and agricultural soil amendment. Beneficial use of FBCBs has widened from 1990, when almost all beneficial use of ash (93 percent) was in mine reclamation applications. In 1995, 18 percent of the beneficial use of ash was in structural fill, waste stabilization, cement or agriculture, and 82 percent was used in mine reclamation.[145]

7.3 Risk Screening Results

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[145] CIBO Special Project on Non-utility Fossil-Fuel By-product Classification. Fossil-Fuel Fluidized Bed Combustion By-products Survey.

This section presents a preliminary screening of the potential risks from disposal and beneficial use of FBCBs. The preliminary risk screening follows the method described in the Federal Register Notice for the final regulatory determination of four large-volume wastes from the combustion of coal by electric utilities dated August 8, 1993. Our effort began with a preliminary risk screen before the CIBO FBC boiler owner survey was complete. The earlier risk screen involved comparing a partial set of FBCB sampling results for bulk constituents and leaching tests to previously used health-based risk screening criteria. Specifically, the screening criteria included levels developed for the Reports to Congress for mineral processing wastes, cement kiln dust, and LVCC. The earlier screening results are presented in Appendix G. The screening of partial data suggested that risk from a number of FBCB constituents could not be eliminated from further evaluation. However, the screening results from partial data are not a reliable indicator of risk because the results may be biased toward certain FBCBs. For example, if at the time the preliminary screening was performed, there was a larger proportion of ash representing petroleum coke fuel sources than represent the actual proportion in the complete data set, the mean concentration of certain constituents could be higher and others lower than the means for the complete data set. Thus for accuracy, after all the survey data was collected, the complete FBCBs data set was again screened using up-to-date regulatory and health-based limits.

The risk screening analysis is a process that applies conservative simplified risk screening values to FBCBs constituents and pathways to determine if they are potentially of risk concern. This conservative approach does not directly reflect real-world risks, because the assumptions do not take into account whether exposure pathways are complete or receptors exist, or if waste attenuation or dilution occurs within the environment. The purpose of the screen, however, is to eliminate constituents, wastes, and pathways that are demonstrated to be clearly low risk. Risk screening is the first step in the process of risk assessment and is not used as a measure of actual risk, but as a method of filtering out those constituents that do not pose a significant hazard. Risk screening has been a part of a number of large-scale risk assessments, and the criteria used to evaluate the exposure pathways have undergone changes due to the availability of more accurate and complete toxicity information. A comparison of screening criteria used in the Reports to Congress on mineral processing wastes, cement kiln dust, and LVCC, presented in Appendix G, shows that over time the number of constituents included in the risk screenings has increased and a number of the screening criteria have become more stringent.

The risk screen compared waste characterization data with screening-level criteria. The screening level values for groundwater are based on the primary Maximum Contaminant Levels (MCL) and for surface water on Ambient Water Quality Criteria (AWQC) for freshwater chronic toxicity for non-human effects. To evaluate the ingestion and inhalation pathways, we used Superfund generic soil screening levels developed for pathways constituting a residential exposure scenario.[146] The soil screening levels for the ingestion exposure route are more stringent than for the inhalation exposure route for the constituents in FBCBs with the exception of mercury and chromium VI. Thus, the ingestion screening levels were used for all constituents except mercury and chromium which used the more stringent inhalation screening levels. For groundwater and surface water pathways, we compared leachate test results directly with the groundwater and surface water screening-level values. For ingestion and inhalation routes, we compared bulk constituent concentrations from samples directly with the Superfund soil screening level values. All

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[146] EPA, 1994. *Soil Screening Guidance*. EPA/540/R-94/101. December 1994.

constituents that exceeded a screening-level value in more than 10 percent of samples or exceeded the criteria by more than a factor of 10 in any sample, were identified as potentially of concern.

Exhibits 7-1a, b, and c present the risk screening levels and the constituents that exceeded the preliminary risk screen, for fly ash, bed ash, and combined ash, respectively. The data employed include characterization results for all available facilities and fuel types. The risk screen using up-to-date screening values only identifies aluminum and boron as low risk constituents that can be eliminated from further evaluation. The remaining constituents were considered further in our risk analysis.

7.4 Land Disposal

This section presents an analysis of risks from land disposal of FBCBs by examining the similarities of FBCB characteristics and disposal practices to LVCC which is also land disposed, and for which disposal risks have previously been assessed. Following the discussion of FBCBs and similar materials in order to establish the appropriateness of the comparison, the FBCB risks are estimated by extrapolating from the LVCC risk assessment.

7.4.1 Previous Studies of Land Disposal Risks

In this section, we will review the risk assessment of LVCC. In the section that follows, the physical and chemical characteristics, management practices and exposure pathways for LVCC and FBCBs are compared to assess the applicability of the results to FBCBs. Using these comparisons, we then extrapolated the LVCC risk results to FBCBs.

Large-Volume Coal Combustion Wastes (LVCC)

In 1988, as required by RCRA Section 8002(n)(3), EPA began a comprehensive study of the adverse effects on human health and the environment, if any, from the disposal and utilization of fly ash waste, bottom ash waste, slag waste, flue gas emission control waste, and other by-product materials generated primarily from the combustion of coal and other fossil fuels. The purpose of the study to was to determine whether these fossil-fuel combustion wastes should be regulated a hazardous waste under Subtitle C.

EXHIBIT 7-1a

PRELIMINARY RISK SCREENING OF FBCBs[1,2,3]

Constituent	Bed Ash			
	HBL (mg/L)	AWQC (mg/L)	Incidental Ingestion (mg/kg)	Inhalation (mg/kg)
Aluminum	***0.05***	NA	1000000	NA
Antimony	***0.014***	***0.03***	***31***	NA
Arsenic	***0.00002***	0.19	***0.37***	NA
Barium	2.45	NA	5500	NA
Beryllium	***0.000008***	***0.0053***	***0.15***	NA
Boron	3.15	NA	7000	NA

Cadmium	***0.0175***	***0.0011***	39	NA
Chromium (III)[4]	37	0.21	78000	NA
Chromium (VI)[4]	0.175	***0.011***	NA	140
Cobalt	NA	NA	4700	NA
Copper	1.3	***0.012***	38000	NA
Iron	***0.3***	***1***	NA	NA
Lead	***0.015***	***0.0032***	400-500	NA
Manganese	4.9	NA	390	NA
Mercury	0.0105	***0.000012***	NA	***7***
Molybdenum	0.175	NA	390	NA
Nickel	0.7	***0.16***	1600	NA
Potassium	NA	NA	NA	NA
Selenium	***0.175***	***0.005***	390	NA
Silver	0.175	***0.00012***	390	NA
Thallium	***0.0028***	***0.04***	***6.3***	NA
Vanadium	***0.245***	NA	***550***	NA
Zinc	10.5	***0.11***	23000	NA

1. Based on comparing risk screening values to CIBO Survey sample results.
2. Shaded areas indicate that the screening value was exceeded in more than 10% of samples.
3. Bold italicized numbers indicate that the screening value was exceeded in the maximum sample concentration by more than 10 times the screening value.
4. CIBO survey sample results for total chromium only. Total chromium concentration was compared to risk screening values.

EXHIBIT 7-1b

PRELIMINARY RISK SCREENING OF FBCBs[1,2,3]

Analyte	Fly Ash			
	HBL (mg/L)	AWQC (mg/L)	Incidental Ingestion (mg/kg)	Inhalation (mg/kg)
Aluminum	***0.05***	NA	1000000	NA
Antimony	***0.014***	***0.03***	***31***	NA
Arsenic	***0.00002***	0.19	***0.37***	NA
Barium	***2.45***	NA	5500	NA
Beryllium	***0.000008***	0.0053	***0.15***	NA
Boron	3.15	NA	7000	NA
Cadmium	***0.0175***	***0.0011***	39	NA
Chromium (III)[4]	37	0.21	78000	NA
Chromium (VI)[4]	0.175	***0.011***	NA	140
Cobalt	NA	NA	4700	NA
Copper	1.3	***0.012***	38000	NA
Iron	***0.3***	1	NA	NA
Lead	***0.015***	***0.0032***	400-500	NA
Manganese	4.9	NA	***390***	NA
Mercury	***0.0105***	***0.000012***	NA	***7***
Molybdenum	0.175	NA	390	NA
Nickel	0.7	0.16	1600	NA
Potassium	NA	NA	NA	NA
Selenium	0.175	***0.005***	390	NA
Silver	0.175	***0.00012***	390	NA
Thallium	***0.0028***	***0.04***	6.3	NA
Vanadium	***0.245***	NA	***550***	NA
Zinc	10.5	***0.11***	23000	NA

1. Based on comparing risk screening values to CIBO Survey sample results.
2. Shaded areas indicate that the screening value was exceeded in more than 10% of samples.
3. Bold italicized numbers indicate that the screening value was exceeded in the maximum sample concentration by more than 10 times the screening value.
4. CIBO survey sample results for total chromium only. Total chromium concentration was compared to risk screening values.

EXHIBIT 7-1c

PRELIMINARY RISK SCREENING OF FBCBs[1,2,3]

Analyte	Combined Ash			
	HBL (mg/L)	AWQC (mg/L)	Incidental Ingestion (mg/kg)	Inhalation (mg/kg)
Aluminum	***0.05***	NA	1000000	NA
Antimony	***0.014***	***0.03***	31	NA
Arsenic	***0.00002***	0.19	***0.37***	NA
Barium	***2.45***	NA	5500	NA
Beryllium	***0.000008***	***0.0053***	***0.15***	NA
Boron	3.15	NA	7000	NA
Cadmium	0.0175	***0.0011***	39	NA
Chromium (III)[4]	37	0.21	78000	NA
Chromium (VI)[4]	0.175	***0.011***	NA	***140***
Cobalt	NA	NA	4700	NA
Copper	1.3	***0.012***	38000	NA
Iron	0.3	1	NA	NA
Lead	***0.015***	***0.0032***	400-500	NA
Manganese	4.9	NA	390	NA
Mercury	0.0105	***0.000012***	NA	7
Molybdenum	0.175	NA	390	NA
Nickel	0.7	0.16	1600	NA
Potassium	NA	NA	NA	NA
Selenium	0.175	***0.005***	390	NA
Silver	0.175	***0.00012***	390	NA
Thallium	***0.0028***	***0.04***	6.3	NA
Vanadium	0.245	NA	550	NA
Zinc	10.5	***0.11***	23000	NA

1. Based on comparing risk screening values to CIBO Survey sample results.
2. Shaded areas indicate that the screening value was exceeded in more than 10% of samples.
3. Bold italicized numbers indicate that the screening value was exceeded in the maximum sample concentration by more than 10 times the screening value.
4. CIBO survey sample results for total chromum. Total chromium concentration was compared to risk screening value.

To assess the potential threat to human health and the environment posed by fossil-fuel combustion wastes, EPA and other agencies and organizations sponsored several studies. The findings of these efforts were presented in the 1988 Report to Congress.[147] The major finding of the Report to Congress was that most coal combustion wastes do not exhibit any of the four hazardous characteristics defined in the RCRA Subtitle C hazardous waste standards. However, data indicated that hazardous constituents had migrated to groundwater at a small number of disposal sites. Because the magnitude of the exceedances above primary drinking water standards was generally small, EPA concluded that only a limited risk of potential exposure to human and ecological populations existed from fossil-fuel combustion wastes. The risks were not quantified in the Report to Congress.

In June 1993 using additional data collected and presented in a Notice of Data Availability (NODA),[148] EPA completed a supplemental analysis of potential risks to human health and the environment from LVCC wastes. This analysis was used to address the Section 8002(n) factors on which a regulatory determination must be based. Using the risk analysis findings, EPA concluded that regulation of four LVCC wastes (fly ash, bottom ash, boiler slag, and flue gas emission control waste) under RCRA Subtitle C is unwarranted, because of limited risks posed by the wastes and the existence of generally adequate state and federal regulatory programs.

EPA used a two-step process in the supplemental analysis to evaluate potential risks from fly ash, bottom ash, boiler slag and flue gas desulfurization (FGD) sludge. The first step, a risk screening, was conducted to eliminate constituents and pathways posing little or minimal potential risk. The second, more in-depth analysis evaluated real-world exposure pathways remaining from the risk screen.

The risk screen compared constituent concentrations and leachate data to screening criteria for four pathways: groundwater, surface water, inhalation, and ingestion. Constituents that exceeded the screening levels were selected for further evaluation. The screening criteria were developed to be conservative; thus, EPA determined that constituents in a particular exposure pathway that passed the risk screen were clearly not of concern. The screening levels were developed using various regulatory criteria current at the time for the different pathways or by establishing health-based levels. Two groundwater screening values were used, primary MCLs and health-based levels calculated using IRIS cancer slope factors (CSF) and non-cancer reference doses (RfD). A 10-fold dilution factor was applied to the values to simulate leachate dilution prior to reaching a receptor. For surface water, freshwater chronic AWQCs for non-human effects with a 100-fold dilution factor were used. Ingestion and inhalation screening levels also were derived from IRIS CSFs and RfDs. The incidental ingestion screening levels assumed ingestion of the solid waste. The inhalation screening levels were derived assuming adult residential exposure to particulate whole waste material. EP and TCLP results and total constituent analysis results were compared with the screening levels. Constituents, wastes, and pathways were evaluated further where screening levels were exceeded at more than 10 percent of the sites or where the maximum at a facility exceeded 10 times the screening level.

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[147] EPA, 1988. *Report to Congress, Waste from the Combustion of Coal by Electric Utility Power Plants*. February 1988.

[148] EPA, 1993. *Notice of Data Availability and Request for Comments,* 58 Federal Register, 8273. February 1993.

Boiler slag was demonstrated to pose a low risk through all pathways, and EPA eliminated it from further evaluation because of the waste's physical characteristics and constituent concentrations. For all four wastes, the ingestion pathway also was eliminated from further analysis, based primarily on the limited population near coal combustion waste disposal sites. According to the Report to Congress, 71 percent of coal combustion units have no population within 1 kilometer and those living nearby are not likely to be living in close contact with the ash. Thus, EPA concluded that ingestion of the waste at levels of concern was not likely to occur. The Agency expected that contact with the waste would be further limited because 75 percent of the coal ash is generated in states with cover requirements at closure.

In the supplemental analysis, EPA also evaluated the potential for human health risk from the inhalation pathway using MMSOILS, a multipathway risk modeling system. Risks were found to be negligible. The estimated lifetime cancer risk ranged from 1.5×10^{-10} for FGD sludge to 3.9×10^{-10} for fly ash. EPA considers cancer risks below the range of 10^{-4} to 10^{-6} to be acceptable risk. The maximum non-cancer hazard ratio was estimated for barium of 1.2×10^{-5}, five orders of magnitude below the effects threshold.

To evaluate the potential risk to human health and the environment from the wastes in the groundwater and surface water pathways, EPA examined actual damage cases. Groundwater monitoring data from case studies were used in both the groundwater and surface water exposure pathway analyses. When analyzing this data, EPA took into account that many of the sites co-managed coal combustion wastes with other wastes, and thus the extent to which other wastes contributed to any groundwater contamination could not be conclusively determined. The Agency also considered that other sources of contamination nearby may exist, including naturally occurring high levels of certain contaminants. Based on the available data, EPA determined that the potential for human exposure to groundwater contamination exists but actual human exposure is very limited. The conclusion is based on the finding of only nine sites with groundwater contamination out of 49 sites. EPA concluded that the following were mitigating factors:

- The nine sites were older and had disposal units that were not completely lined.
- The coal combustion sites are not located in populated areas.
- Only 29 percent of the sites have residents within one kilometer.
- Only 34 percent of the sites have public drinking water systems within five kilometers.

For the surface water pathway, EPA concluded that harmful discharge of untreated coal combustion waste to surface water is not likely because of Clean Water Act controls, but that a few of the waste constituents have the potential to affect vegetation and aquatic organisms by migration through groundwater to nearby surface water. However, EPA predicts that natural attenuation processes would dilute contaminants below levels of concern.

Applicability of LVCC Study Results to FBCBs

In this section, we compare FBCBs to LVCC in terms of generation, chemical, and physical characteristics, and disposal practices.

FBCBs and LVCC wastes are generated in similar processes. High-volume coal combustion utility wastes are those waste streams generated in the boiler furnace (fly ash, bottom ash, boiler slag) and in the cleaning of coal combustion flue gas (FGD sludge). Coal combustion ash is the noncombustible waste remaining after coal is burned and is characteristic of the coal itself. Other noncombustibles result from minerals present in the coal and fired along with it. FGD wastes are created when sulfur dioxide in the flue gases is removed before emissions are released from the stack. FGD is generally accomplished in scrubber systems by passing flue gas through either wet or dry adsorbents. The adsorbents are usually limestone or lime-based reagents with which the sulfur dioxide reacts. The reagent and reacted sulfur dioxide are the remaining waste. In contrast, FBC boilers burn coal and other fossil fuels, and by injecting limestone in the furnace during combustion, capture sulfur dioxide in the furnace before the combustion gases exit to the flue. Thus, the FBCB ash is similar in composition to coal combustion ash and FGD waste combined. Moreover, the pHs of FBCBs and FGD are within the same range of 12 to 12.5.[149]

Exhibit 7-2 compares the constituent concentrations in FBCBs from the CIBO survey to concentrations in coal combustion ash using the ratios of the median and maximum concentrations. Exhibit 7-3 lists mean constituent concentrations in FBCBs and FGD wastes reported in a recent published study.[150] The ratios demonstrate that most of the FBC waste constituent concentrations are lower than the concentrations found in coal combustion ash. The exceptions are arsenic, mercury, selenium, silver and vanadium in bed ash, and mercury and vanadium in fly ash.

In FBC bed ash, the arsenic bulk concentration is two times greater then in coal combustion bottom ash but the maximum concentration is lower. Mercury, selenium, silver, and vanadium also are as much as an order of magnitude higher in FBC than in coal combustion bottom ash. However, the FBC bed ash concentrations for selenium are lower than typically found in FGD wastes. Although the FBC bed ash median concentrations of mercury and silver are higher than in coal combustion bottom ash, 95 percent of the samples are within the maximum concentration range for coal combustion bottom ash. The presence of ash from waste coal likely accounts for the higher median mercury concentration in FBC bed ash. Excluding waste coal ash samples reduces the median concentration for mercury in FBC bed ash to 0.1 mg/kg which is within the range for FGD wastes. Ash from petroleum coke accounts for the higher median vanadium concentration in FBC bed ash. However, petroleum coke use accounts for only 6 percent of the FBC ash. Excluding petroleum coke ash reduces the median for vanadium in FBC bed ash to 54 mg/kg, which is lower than the median concentration of vanadium in coal combustion bottom ash.

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[149] J. Bigham, W. Dick, L. Forster, F. Hitzhusen, R. Haefner, 1993. *Land Application Uses for Dry FGD By-products, Phase 1 Report*. Ohio State University, Ohio Agricultural Research and Development Center. April 1993.

[150] *Ibid*.

EXHIBIT 7-2

COMPARISON OF COAL COMBUSTION ASH (CC) AND FLUIDIZED BED COMBUSTION (FBC) ASH

Constituent	Bed/Bottom Ash		
	Ratio of Medians (FBC/CC)	Ratio of Maxs (FBC/CC)	Comments
Arsenic	2.20	0.71	
Barium	0.04	0.08	
Boron	0.02	0.60	
Cadmium	0.58	2.98	Ratio of FBC 95th percentile to CC max = 0.48
Chromium	0.13	0.74	
Cobalt	0.16	2.17	Ratio of FBC 95th percentile to CC max = 0.85
Copper	0.13	0.20	
Lead	0.35	1.00	
Manganese	0.37	1.16	
Mercury	4.35	50.00	Ratio of FBC 95th percentile to CC max = 0.26
Selenium	3.33	3.21	More than 10% FBC > CC max
Silver	2.50	662.75	Ratio of FBC 95th percentile to CC max = 0.95
Vanadium	27.14	26.32	More than 10% FBC > CC max
Zinc	0.26	0.50	

Constituent	Fly Ash		
	Ratio of Medians (FBC/CC)	Ratio of Maxs (FBC/CC)	Comments
Arsenic	0.41	1.13	
Barium	0.19	6.42	Ratio of FBC 95th percentile to CC max = 0.78
Boron	0.23	0.02	
Cadmium	0.20	0.72	
Chromium	0.20	0.05	
Cobalt	0.12	2.28	Ratio of FBC 95th percentile to CC max = 0.95
Copper	0.23	0.28	
Lead	0.45	0.52	
Manganese	0.59	77.33	Ratio of FBC 95th percentile to CC max = 0.88
Mercury	3.60	126.67	Ratio of FBC 95th percentile to CC max = 0.57
Selenium	0.45	8.95	Ratio of FBC 95th percentile to CC max = 0.12
Silver	0.83	4.88	Ratio of FBC 95th percentile to CC max = 0.62
Vanadium	11.60	17.54	More than 10% FBC > CC max
Zinc	0.20	0.07	

1. Based on CIBO Survey sample results and CC ash results from EPA, 1988.
2. Shaded areas indicate that the ratio of FBC ash concentration to CC ash concentration is greater than 1.

EXHIBIT 7-3

COMPARISON OF MEAN CONSTITUENT CONCENTRATIONS IN FLUE GAS DESULFURIZATION (FGD) By-products AND FLUIDIZED BED COMBUSTION (FBC) By-products[1,2]

	FGD				FBC	
	Spray Dryer	**Duct Injection**	**LIMB[3]**	**Other**	**Bed Ash**	**Cyclone Ash[4]**
Arsenic	67	44	2.1	1.7	2.3	3.1
Barium	0.3	0.2	0.3	0.02	0.01	0.02
Boron	240	418	374	319	142	280
Beryllium	4	5.3	10.8	15.1	1.6	5.5
Cadmium	2.1	4.9	2.1	1.7	2.3	3.1
Cobalt	27	14	46	41	8.9	20.6
Copper	40	31	48	250	176	36
Chromium	49	28	53	76	17	39
Lead	29	38	59	30	11	33
Manganese	127	133	176	171	207	206
Nickel	52	29	81	71	33	52
Selenium	13	10	15	8.1	3.6	6.7
Vanadium	52	89	107	122	15	68
Zinc	108	124	208	163	119	111

1. "Phase 1 Report, Land Application Uses for Dry FGD By-products," Ohio State University, Agricultural Research and Development Center, April 1, 1993.
2. Concentration in mg/kg.
3. LIMP-Limestone injection multistage burners.
4. Same as fly ash.

The median concentration of mercury in FBC fly ash is about three times greater than in coal combustion bottom ash, but typical of the concentrations found in FGD wastes if FBC ash samples from waste coal are eliminated. (Waste coal ash has mercury levels higher than the ash from other fuel sources; waste coal ash comprises 52 percent of the ash represented in our sample of active plants.) The median vanadium concentration in FBC fly ash is one order of magnitude greater than in coal combustion fly ash. However, inclusion of ash from petroleum coke accounts for the higher median vanadium concentration in FBC fly ash. Excluding petroleum coke ash reduces the median vanadium concentration in FBC fly ash to 61 mg/kg which is lower than then median concentration of vanadium in coal combustion bottom ash.

FBCBs and coal combustion wastes also are similar in particle size diameters (Exhibit 7-4). Particles with diameters smaller than 10 microns are respirable in human lungs and thus pose an

EXHIBIT 7-4

PARTICLE SIZE DIAMETERS OF COAL COMBUSTION By-products AND FBCBs[1,2]

	LVCC		FBCBs
Fine Sand, 5-100 microns	Fly Ash	FGD Dry Sludge	Fly Ash
Fine gravel, 0.1 to 10 mm	Bed Ash		Bed Ash

1. "Phase 1 Report, Land Application Uses for Dry FGD By-products," Ohio State University, Agricultural Research and Development Center, April 1, 1993.
2. EPA, 1988. Report to Congress.

inhalation risk. About 1 percent of bed ash and 56 percent of fly ash is finer than 25 microns in diameter.

Based on the preceding analysis, coal combustion by-products, specifically LVCC, are chemically generally similar to FBCBs. The small differences are attributable to the differences in the types of fuel burned in FBCBs. For the majority of constituents, the concentrations in FBCBs are lower than in coal combustion ash. Those constituents that are higher in FBCBs than in coal combustion by-products are present in concentrations of a similar magnitude to the constituent concentrations in FGD. Particle size studies also indicate that FBC ash and coal combustion ash are generally similar.

LVCC wastes and FBCBs are land disposed in the same types of management units, generally in landfills or surface impoundments. More than 55 million tons of LVCC wastes were land disposed in 1988,[151] whereas the 39 CIBO survey respondents collectively disposed only 1.5 million tons of FBCBs in 1995.[152]

Most utility waste management facilities studied in the 1988 Report to Congress were not designed to provide a high level of protection against leachate release. Only about 25 percent of all facilities had liners to reduce off-site migration of leachate, although 40 percent of the generating units built since 1975 have liners.[153] In contrast, of the 39 FBCB generators responding to the CIBO survey, only 18 facilities managed their FBCBs in landfills or surface impoundments. Eleven of 18 (61 percent) of the surveyed land disposal units had some type of base barrier and/or leachate collection systems. The base barriers range from an in situ clay base to a engineered synthetic liner. These lined units managed about 90 percent of the FBCBs disposed in 1995.

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[151] *Ibid.*

[152] CIBO Survey. *Op. cit.*

[153] EPA, 1988. Report to Cognress. Op cit.

State regulations surveyed for the 1988 Report to Congress and the NODA indicate that for about 75 percent of coal ash generated, state requirements specify cover requirements at unit closure. In addition to having to meet state closure requirements, at the surveyed FBCB facilities, nearly half use dust suppression measures, and over a third of the facilities compact or cover the FBCB management units as part of efforts to reduce airborne transport of waste off-site.

Compared to 29 percent of the approximately 500 LVCC sites with a population within a kilometer, nineteen of the 39 (49 percent) FBCB generator facilities surveyed report a residential population within 2 miles (3.2 km) of a by-products management unit. Twelve of the facilities have landfills or surface impoundments with a residential population within one mile (1.6 km) of the site. However, it is not likely that individuals living in the vicinity of these FBCB disposal units come in direct contact with the FBCBs because of waste management practices typically used to reduce migration of the waste from the disposal units. A review of environmental management practices at the 12 disposal units with residential populations within one mile indicates that all the units use dust suppression management practices, except one unit which is a surface impoundment. In addition, all of the units, except the surface impoundment, either compact or cover their waste.

Extrapolation of Risks to FBCBs

Following the process used in the supplemental risk assessment of LVCC wastes, Exhibit 7-5 presents the FBCB wastes, exposure pathways and constituents that remain for further analysis after the initial risk screening. The screening results for LVCC are included in Exhibit 7-5 for comparison. Constituents in FBCBs were identified as exceeding the screening levels if more than 10 percent of the samples for a constituent exceeded the screening level for a particular constituent pathway or the maximum constituent concentration was greater than 10 times the screening level. Across all pathways and waste types, the same constituents remained for further analysis in LVCC and FBCBs. By pathway, however, the constituents differ between LVCC and FBCBs. In general, LVCC had more constituents exceed the screening level in each of the pathways than FBCBs. For example, for the groundwater pathway, antimony, arsenic, beryllium, cadmium, and thallium exceed the screening levels in both LVCC and FBCBs, but lead, nickel, molybdenum, selenium, and vanadium exceed screening levels only in LVCC.

All surveyed FBCB disposal units, with a population within one mile of the unit, use dust suppression practices and must meet state closure cover requirements similar to those of LVCC facilities. Thus, populations living near these FBCB wastes are not likely to be living close contact with the ash. Following the reasoning used by EPA in the 1993 risk assessment of LVCC wastes, the ingestion pathway for exposure to FBCBs is assessed to be a low risk pathway. As for LVCC, this pathway is eliminated from further consideration, based on the limited population potentially exposed and the unlikely contact with the waste. Thus, inhalation, groundwater, and surface water pathways for FBCBs remain for further risk analysis.

EXHIBIT 7-5

COMPARISON OF CONSTITUENTS THAT EXCEEDED LVCC RISK SCREENING LEVELS FOR LVCC AND FBCBs[1,2]

Pathway	LVCC Waste				FBC Waste		
	Fly Ash	Bottom Ash	Boiler Slag	FGD Waste	Fly Ash	Bed Ash	Combined Ash
Groundwater				Antimony	Antimony	Antimony	Antimony
	Arsenic	Arsenic		Arsenic	Arsenic	Arsenic	Arsenic
	Beryllium			Beryllium	Beryllium	Beryllium	Beryllium
	Cadmium				Cadmium		
	Lead			Lead			
	Nickel						
				Mercury			
	Molybdenum						
				Selenium			
				Thallium	Thallium	Thallium	Thallium
	Vanadium						
Surface Water	Aluminum			Aluminum	Aluminum	Aluminum	Aluminum
							Beryllium
	Cadmium						
	Copper						
	Lead				Lead	Lead	Lead
	Mercury			Mercury			
	Nickel						
				Selenium			
	Silver	Silver		Silver	Silver	Silver	Silver
Inhalation	Arsenic	Arsenic	Arsenic	Arsenic	Arsenic	Arsenic	Arsenic
	Beryllium						
	Chromium	Chromium	Chromium	Chromium		Chromium	Chromium
						Nickel	
Ingestion	Arsenic	Arsenic		Arsenic	Arsenic	Arsenic	Arsenic
				Lead			
						Vanadium	

1. Based on screening levels developed in the LVCC Risk Assessment from "Supplemental Analysis of Potential Risks to Large-Volume Coal Combustion Waste," July, 1993. Different screening criteria were developed for each pathway.
2. Leaching test results were compared to risk screening levels for groundwater and surface water pathways and total constituents sample results were compare to
risk screening levels for inhalation and ingestion pathways.
3. All leaching test results (TCLP, EP, STLC, SPLP, ASTM and other) were used for FBCB wastes; whereas, only EP and TCLP leaching test results were used for LVCC wastes.

Exhibit 7-6 compares the LVCC concentrations used to model inhalation risk and the highest mean concentrations (among fly, bed, and combined ash categories) for constituents in FBCBs. The LVCC constituent concentrations used in the quantitative risk modeling for the LVCC are substantially higher the mean concentrations for constituents in FBCBs. Based on the bulk constituent sampling results reported by FBCB generators, at least 90 percent of the FBCBs generated would result in a lifetime cancer risk by the inhalation pathway from disposal no greater than 1.5×10^{-10} to 3.9×10^{-10} under the same assumptions used in the LVCC study. In the LVCC study, barium had the highest non-cancer hazard quotient. The mean FBCB barium concentration is about 70 percent of the LVCC concentration used to model non-cancer risk. Thus, extrapolating from LVCC, the non-cancer hazard quotient for barium in FBCBs would be 70 percent of the hazard quotient for LVCC, or 8.4×10^{-6}, six orders of magnitude below the effects threshold. Because the ratio of LVCC and FBC constituent concentrations is closest to unity for barium, this hazard quotient would also be the expected maximum non-cancer hazard quotient for any FBCB constituents.

EXHIBIT 7-6
COMPARISON OF LVCC INHALATION RISK MODELING CONSTITUENT CONCENTRATIONS[1] AND FBCBs CONSTITUENT CONCENTRATIONS

	LVCC Wastes		**FBC Wastes**	
	Fly Ash	**FGD Sludge**	**Largest Mean**	**LVCC/FBC[2]**
Antimony	205	24	49	0.2
Arsenic	86	70	25	0.3
Barium	10,800	2,300	7,700	0.7
Beryllium	2,100	8.8	4.9	0.0
Cadmium	76	82	1.6	0.0
Chromium	657	470	66	0.1
Lead	273	527	26	0.1
Mercury	11	39	6.6	0.6
Nickel	1,270	191	381	0.3
Vanadium	5,000	261	3,700	0.7

1. EPA "Supplemental Analysis of Potential Risks to Human Health and the Environment form Large-Volume Coal Combustion Waste," July, 1993.
2. Calculated using the larger concentration of the two LVCC wastes (FGD Sludge and Fly Ash) used in the risk modeling.

Following a similar methodology to that used in the LVCC risk assessment for the groundwater pathway, five FBCB facilities reported in the CIBO Survey that on-site groundwater monitoring samples exceeded either the primary or secondary MCL at the facility's waste management unit. The exceedances and conditions at these facilities are described in Chapter Six - Documented Damages from Fossil-Fuel Combustion By-products. These exceedances, however, did not necessarily reflect releases of FBCB constituents from disposal units. Three of the sites were abandoned mine reclamation sites where FBCBs is used to neutralize mine acid drainage, leachate, and/or spoils. The facility explanations for these exceedances indicate that the contamination existed before use of

FBCBs and originated from the acid mine drainage. At a fourth site, exceedances of MCLs are found in both upgradient and downgradient wells. Selenium and nitrate concentrations are slightly higher in the downgradient well, while other contaminants are higher in the upgradient well. Thus, the possibility that an upgradient source is responsible for the groundwater contamination cannot be ruled out. At the fifth site, exceedances of MCLs are found downgradient, while upgradient groundwater is not monitored. However, this disposal unit has a recompacted clay/shale base with two layers of geotextile, one 60 millimeter HDPE liner, and a leachate and runoff collection system. The possibility of an upgradient source cannot be ruled out given the lack of upgradient data and the protective liner underlying the site. Because of the lack of sites where releases are demonstrated to be directly related to disposal of FBCBs, we conclude that the groundwater pathway does not pose a risk.

Only two of the FBCB sites with groundwater MCL exceedances have drinking water wells within one mile of the site. Both sites are abandoned mine reclamation sites where FBCBs is used to neutralize acid mine drainage. At one site the exceedances were for secondary MCLs only. Degraded groundwater in these areas was present before FBCB use at the mine, and any contamination of drinking water supply wells that might occur most likely would be attributable to the acid mine drainage.

Following a similar methodology to that used in the LVCC risk assessment for the surface water pathway, three FBCB management units were identified where surface water samples exceeded secondary MCLs only, and one unit was identified where surface water samples exceeded secondary MCLs and national ambient water quality control standards (AWQCS). However, these exceedances did not necessarily reflect releases of FBCB constituents from disposal sites. Three of the sites involve abandoned mine reclamation using FBCBs beneficially, and thus the contamination is likely attributable to acid mine drainage runoff. At the fourth site, upgradient concentrations were significantly higher than downgradient concentrations, and thus are likely attributable to an upgradient source independent of the disposal facility. Because of the lack of sites where releases are demonstrated to be directly related to disposal of FBCBs, we conclude that the surface water pathway does not pose a risk.

Exhibit 7-7 summarizes the results of extrapolating LVCC risks to FBCB risks. Using similar methods to those used in the LVCC risk assessment, risks to the human health and environment for each pathway are assessed to be low and likely to be lower than the overall risk from LVCC.

EXHIBIT 7-7

SUMMARY OF LVCC AND FBCBs RISKS

Pathway	LVCC		FBCBs	
	Method	Results	Method	Results
Direct Ingestion	Risk screening; evaluate waste management and receptors.	**Low Risk** - Few receptors, little contact due to management practices.	Similar to LVCC Method	**Low Risk** - Few receptors, little contact due to management practices.
Inhalation	Risk screening; quantitative risk transport/fate modeling using MMSOILS.	**Cancer Risk** Fly ash, 3.9×10^{-10} FGD waste, 1.5×10^{-10}. **Hazard Index** Barium, 8.4×10^{-5}	Comparison with LVCC constituents, LVCC risk extrapolated to FBCBs	**Cancer Risk** $<1.5 \times 10^{-10}$ **Hazard Index** Highest risk - barium, $<8.4 \times 10^{-6}$
Groundwater	Risk screening; examine damage cases.	**Low Risk** - Limited exposure; 9 older unlined damage cases; no population.	Similar to LVCC Method	**Low Risk** - 5 damage cases; upgradient source or acid mine drainage pool; no demonstrated release directly attributable to FBCBs disposal.
Surface Water	Risk screening; examine damage cases.	**Low Risk** - Discharge unlikely; natural attenuation will dilute.	Similar to LVCC Method	**Low Risk** - 4 damage cases; upgradient source or acid mine drainage runoff; no demonstrated release directly attributable to FBCBs disposal.

Factors which support the assessment that FBCB risks are likely to be no greater or possibly lower than LVCC are summarized below.

- FBCB generation and disposal volumes are substantially smaller than for LVCC. In 1995, the FBC boilers providing data (representing 40% of all FBC boilers) generated about 5.9 million tons of waste, about 5 percent of the volume generated by coal-fired power plants.[154] In 1988 about four-fifths of the waste generated at coal-fired electric utility power plants was typically disposed in surface impoundments and landfills. In contrast, between 1990 and 1995, about one-third to one-quarter of FBCBs was disposed in a landfill or surface impoundment.[155]

- Of the quantities that are land disposed, a greater proportion of FBCBs is disposed in lined disposal units (90 percent) compared to LVCC wastes (25 percent as reported in the 1988 Report to Congress).

- Almost all FBCB disposal units with a population within one mile of the unit use dust suppression practices, reducing the potential for dust exposure.

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[154] *Ibid*.

[155] *Ibid*.

7.5 Agricultural Application of FBCBs

This section examines the risks of agricultural application of FBCBs by evaluating the risks of similar materials that are being used for agricultural soil amendment. These similar materials include coal combustion ash and sewage sludge.

For many years, lime and limestone have been used by farmers to neutralize soil acidity to optimum conditions for crops and plants to grow, to add plant nutrients to support growth, and to supply other nutrients to enhance beneficial soil microbial activities. A number of studies have demonstrated that the high free lime content allows FBCBs to serve as an effective limestone substitute.[156,157] In 1995, 1.5 percent of FBCBs generated, or about 65,000 tons, was put to agricultural use. Although the volume of FBCBs generated has increased since 1990, the volume beneficially used in agriculture has changed very little (for comparison, 63,000 tons in 1990). Currently, eight states specifically authorize the use of coal combustion by-products for land application. Other states regulate coal combustion by-products as nonhazardous solid wastes. Some of these states have provisions to allow beneficial nonhazardous solid wastes uses which include agricultural land application if the by-products meet specific requirements. Thus, there are clearly established precedents for allowing the use of materials similar to FBCBs as agricultural soil amendments. The discussion which follows explores whether there is any reason to believe that such use of FBCBs might be associated with unacceptable risks. Again, the method used is to compare the composition of FBCBs to other materials that have already been accepted as soil amendments.

7.5.1 Previous Studies of Land Application of Similar Materials

A number of researchers have studied or are currently evaluating the utility of coal ash and other fossil fuel combustion by-products as soil amendments. In addition, EPA has performed a comprehensive multipathway risk assessment of land application and management of biosolids (sludge) to support the 40 CFR Part 503 Rule. In all of these studies, the focus was on the adverse effects of toxic metals (and arsenic) contained in the materials. Coal and fossil fuel combustion by-products have many physical and chemical characteristics in common with FBCBs and thus the studies can apply to FBCBs as well. Although treated sewage sludge is generated from a completely difference source, and has characteristics that differ from FBCBs, the types of metals found in it are similar to the metals of concern in FBCBs and the exposure pathways associated with agricultural use of FBCBs are similar to those arising in the agricultural use of sewage sludge. This section discusses some of the major studies of coal ash and sewage sludge land application and interprets their results in terms of the potential risks that might be posed by similar use of FBCBs.

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[156] L. Young, J. L. Cotton, 1994. *Beneficial Uses of CFB Ash*. International Pittsburgh Coal Conference. September 1994.

[157] J. Bigham et al. 1993. *Op. cit*.

Sewage Sludge

In 1993, EPA developed a comprehensive risk-based rule, known as the "Part 503" Rule, to protect public health and the environment from the anticipated adverse effects of pollutants that may be present in sewage sludge that is used or disposed. Much of the rule was based on the results of scientifically conducted, extensively reviewed, risk assessments following well-established procedures developed by the National Academy of Sciences. The risk assessment analyzed risks to humans, animals, plants, and soil organisms from exposure to pollutants in sewage sludge through 14 different pathways. This approach considered multiple direct and indirect exposure pathways to assess individual and population risks. The risk assessment provided a scientific basis for determining acceptable changes in trace element concentrations in soils when sewage sludge is land applied. The risk assessment defined acceptable changes as those that remain protective of public health and the environment. Based on these results, EPA set pollutant concentration limits above which sludge could not be applied to protect highly exposed individuals, thus further safeguarding the general public.

In the Part 503 Rule, a number of different exposure pathways were evaluated for each pollutant. The pathway with the lowest pollutant limit was identified as the "limiting pathway", and the lowest limiting concentration was used to establish the land application standards. The Part 503 Rule pollution concentration limits (PCL) or "Table Limits" are risk-based limits derived by assuming a 1,000-metric ton/hectare application of biosolids in which the cumulative pollutant rates would be met but not exceeded. This limit is the maximum concentration in the biosolid below which it can be applied without recordkeeping requirements to track cumulative pollutant loadings. The PCLs were set at concentrations identified in the risk assessment as health-protective or the 99th percentile concentration for each pollutant in sludge, whichever was more stringent.

The Part 503 Rule also establishes ceiling concentration limits (CCLs). These limits set maximum allowable concentrations of pollutants in the biosolid above which land application is prohibited. Ceiling concentration limits are either the 99th-percentile concentration for each pollutant or the pollutant limits identified in the risk assessment, whichever was least stringent. If the pollutant concentration in a biosolid is below the CCL and above the PCL, it can be land applied but must meet the cumulative pollutant loading rate limits (CPLRs). The CPLRs are the maximum masses of specific pollutants that can be applied annually and over a lifetime. These levels correspond to the application rates resulting in incremental soil concentrations identified in the risk assessment as being protective of human health and the environment.

Exhibit 7-8 presents the proportion of FBCB samples with constituent concentrations below the risk-based limits for land application. It can be seen that for the bulk of the constituents (seven of ten) in FBCB fly ash, bottom ash, and combined ash, all or almost all of the samples were below the Part 503 limits. The exceptions include arsenic, where between 78 and 85 percent of the samples were below the limits, molybdenum, where between 58 and 100 percent of the samples were below the limits, and nickel where between 63 and 88 percent below the health-based or ceiling limit. These findings imply that, if Section 503 rules were used to limit the land application of FBCBs, the vast

EXHIBIT 7-8

PERCENTILE OF FBCB SAMPLES WITH CONSTITUENT CONCENTRATIONS BELOW RULE 503 POLLUTANT LIMITS FOR LAND APPLICATION

Pollutant	Highly Exposed Individual of Limiting Pathway	503 Risk-Based Pollutant Limit mg-pollutant/ kg-biosolid	503 Pollutant Concentration Limit mg-pollutant/ kg-biosolid (monthly average)	503 Ceiling Limit mg-pollutant/ kg-biosolid	Proportion of Survey Samples Below 503 Pollution Limits (Risk-Based/Ceiling)		
					Fly Ash	**Bed Ash**	**Combined Ash**
Arsenic	Child Eating Biosolids	41	41	41	78% / 78%	85% / 85%	79% / 79%
Cadmium	Child Eating Biosolids	39	39	85	100% / 100%	100% / 100%	100% / 100%
Chromium	Plant Phytotoxicity	3,000	NA	NA	100% / N.A.	100% / N.A.	100% / N.A.
Copper	Plant Phytotoxicity	1,500	1,500	4,300	100% / 100%	100% / 100%	100% / 100%
Lead	Child Eating Biosolids	300	300	840	100% / 100%	100% / 100%	100% / 100%
Mercury	Child Eating Biosolids	17	17	57	95% / 99%	88% / 90%	96% / 100%
Molybdenum	Animal Eating Feed	18	18	75	70% / 95%	58% / 96%	78% / 100%
Nickel	Plant Phytotoxicity	420	420	420	73% / 73%	63% / 63%	88% / 88%
Selenium	Child Eating Biosolids	100	100	100	95% / 95%	100% / 100%	100% / 100%
Zinc	Plant Phytotoxicity	2,800	2,800	7,500	100% / 100%	100% / 100%	96% / 96%

majority of the wastes could be applied without even any recordkeeping requirements, and only a small portion of the FBCBs would exceed the ceiling limits which would prohibit this use.

These comparisons are somewhat misleading, however, especially the ceiling limit. All of the Part 503 limits are derived assuming an application rate of 1,000 metric-ton/hectare, which is a credible maximum rate for sewage sludges. In contrast, the expected maximum application rates for FBCBs based on current practices are on the order of 3 to 5 tons/acre (6.7 to 11.2 metric tons/hectare) per year and reapplication after 3 to 5 years with a maximum of 10 applications. This 30 year application period is based on the expected operating lifetime of an FBC facility.[158] Exhibit 7-9 shows the cumulative pollutant loadings that would occur at the expected FBCBs application rate using 95th-percentile constituent concentrations, and compares them to the CPLR limits for sewage sludge. At the high end application rate (5 tons/acre) and reapplication every 3 years for a maximum of 10 applications, the pollutant loadings would range from one to three orders of magnitude below the CPLR limits for most constituents. Projected lifetime loading rates for two constituents (mercury and molybdenum) exceed the CPLR limits by a small margin. This indicates that the vast majority of the FBCBs streams can be land-applied without risk of significant adverse effects to humans or the environment.

Coal Ash

The California Integrated Waste Management Board (CIWMB) considered drafting a regulation controlling land application of coal ash where the major goals were to protect human health and the environment.[159] For most pollutants, the Part 503 limits discussed above have been selected. CIWMB has recommended, however, that molybdenum and selenium levels should be set lower than the Part 503 Rule levels.[160] The Board's assessment indicates that selenium is expected to be present in coal ash in the oxidized form at higher concentrations than found naturally in soils. Because plant uptake of the oxidized form of selenium is greater than the reduced form, the element could bioaccumulate in plants at levels that might be toxic to livestock. The assessment also indicated that molybdenum uptake is increased in higher pH soils and the liming potential of coal ash would cause

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[158] To use FBCBs as a substitute lime source to reduce soil acidity (a major recurring soil fertility problem in humid regions), the lime equivalency of FBCBs must be greater than 30 percent. The application rate is determined by the lime requirement of the soil. Guidelines for application of FBCBs are contained in the"Manual for the Application of Fluidized Bed Combustion Residue to Agricultural Lands" developed by the USDA (Appendix F to this Report). The range of 3 to 5 tons/acre per year is an application rate that represents the mean to maximum application rate in current practice.

[159] California Integrated Waste Management Board (CIWMB). *Draft Non-hazardous Ash Operations and Facilities Regulatory Requirements*. April 10, 1997. The CIWMB subsequently decided that existing state regulatory programs were adequate and did not promulgate these proposed regulations. See Section 8.3 of this Report for further information.

[160] Reynolds, Allison, 1996. *Peer Review of Molybdenum and Selenium Levels for Nonhazardous Ash Land Applications*. California Environmental Protection Agency. November 15, 1996.

molybdenum to bioaccumulate at a higher rate than assumed in the Part 503 studies and could achieve levels that might be toxic to livestock. To avoid the higher accumulation in plants, California proposed a maximum annual application rate of 0.5 lb/acre or a cumulative loading of 5 lb/acre for molybdenum and 0.25 lb/acre annual maximum rate or cumulative loading of 5 lb/acre for selenium.

EXHIBIT 7-9

HIGH-END AGRICULTURAL APPLICATION CUMULATIVE LOADING RATES FOR FBCB[1]

Constituent	Highest 95th Percentile Concentration (mg/kg)	FBCB Source	Annual Pollutant Loading (kg/hectare)	Lifetime Pollutant Loading (kg/hectare)	Part 503 CPLR Limit (kg/hectare)
Arsenic	158	Fly/Waste Coal	0.59	17.70	41
Cadmium	14	Bed/Coal	0.05	1.56	39
Chromium	140	Fly/Waste Coal	0.52	15.60	NA
Copper	408	Combined/Coal	1.52	45.70	1500
Lead	105	Fly/Waste Coal	0.39	11.76	300
Mercury	210	Bed/Waste Coal	0.78	23.52	17
Molybdenum	190	Bed/Waste Coal	0.71	21.28	18
Nickel	1440	Bed/Coal	5.38	161.28	420
Selenium	78	Fly/Waste Coal	0.29	8.73	100
Zinc	399	Bed/Coal	1.49	44.69	2800

[1] Calculated for ash from coal and waste coal fuel sources only.

Cumulative pollution loading (CPL) is calculated as follows:

CPL = pollutant concentration in biosolid x application rate
kg pollutant /ha = mg pollutant/kg biosolid x kg biosolid/ha

FBCB application rate: 5 tons/acre (11.2 metric ton/hectare)
FBCB expected application lifetime: 30 years with a maximum of 10 applications

Conversion factors:

1 ton/acre = 2.242 metric ton/hectare
0.001 metric ton/kg

Because high-end sample concentrations were used in estimates of application rates and cumulative loading, FBCBs with concentrations more representative of mean values would be expected to meet California's proposed limits with a 10 to 100-fold margin of safety for most constituents.

After proposing application rates for molybdenum and selenium that were lower than Part 503 limits, California solicited peer review comments on the limits before making a decision to finalize its regulation. On behalf of the Cogeneration Ash Coalition, Block Environmental Services (BES) submitted a response to California's risk analysis of coal ash land application. BES did not agree with the conclusions of California's study. BES evaluated published journal articles on plant uptake of selenium and molybdenum in ash versus biosolid-amended soil using methods outlined by EPA. Based on their data review selenium uptake from ash amended soil had lower slopes than for biosolid-amended soils. They concluded that the Part 503 Rule for selenium would be protective when applied to ash-amended soil. Similarly, the molybdenum uptake slope for ash-amended soils were reviewed and found to be lower for ash-amended soil than biosolid-amended soil. They concluded again that Part 503 rule for molybdenum would be protective when applied to ash-amended soil. As shown immediately above, FBCBs sample results for molybdenum and selenium, meet Part 503 rule limits for these constituents. FBCBs also can meet the stricter proposed California limits, further demonstrating that FBCBs would pose a low risk to human health and the environment from agricultural application.

Flue Gas Desulfurization By-products

The Ohio State University Agricultural Research and Development Center began a project in December 1990 to demonstrate high-volume uses of FGD by-products which may substitute for other materials now being used for land reclamation, agriculture, and soil stabilization. Ohio State examined FGD by-products from four FGD technologies and FBC facilities (FFCB was included as a subset of FGD by-products). The work for the project is being performed by Ohio State University with cooperation from the United States Geological Survey. One of the objectives of the project was to demonstrate the utilization of dry FGD by-products as a soil amendment material on agricultural lands.

The chemical composition of FGD by-products was analyzed and metals concentrations were characterized and compared to EPA 503 limits for land application. In Ohio State's study, arsenic was the only regulated element present in the FGD by-products at concentrations exceeding its application limit. The study did not indicate the proportion of samples that exceeded the limit. However, the standard deviations for the arsenic sample groups were large, indicating a wide range for arsenic concentrations (likely due to the small sample sizes). Only 6 bed ash and 10 fly ash samples from FBC were analyzed by Ohio State, whereas the CIBO survey data analyzed 195 FBCBs samples for arsenic. Based on the CIBO data, an average of about 80 percent of the samples analyzed for arsenic were less than the Part 503 Rule limits.

Greenhouse studies conducted by Ohio State, as part of the FGD by-products study, show that FGD by-products including FBCBs were all found to be highly effective in neutralizing soil acidity and ameliorating phytotoxic conditions in soil. When applied in amounts needed to neutralize acidity, plant growth improved and no signs of toxicity were observed.

7.5.2 State Regulation of Beneficial Use of Fossil Fuel Combustion By-products in Agriculture

Based on a 1996 report by the American Coal Ash Association,[161] eight states (Alabama, Illinois, Maryland, North Carolina, Ohio, Pennsylvania, Virginia, West Virginia) specifically authorize the use of coal combustion by-products as a soil amendment. In addition, Indiana is in the process of revising the guidelines that address the use of coal combustion by-products in agricultural land application. In general, the states that authorize the use of coal combustion by-products as a soil amendment require that leaching tests be performed on the material to determine if it exceeds state and federal hazardous waste regulations. If the material is determined to be RCRA non-hazardous, the Part 503 Rule land application standards are typically used as guidance to assess the suitability of a specific source of coal combustion by-product for land application.[162,163] A limited survey of state regulators, indicated that most states have adopted the federal Part 503 land application standards without modification of the pollutant limits. This again suggests that in many states, it is already legal to land apply FFCB.

7.5.3 Summary of Land Application Findings

Research has established the benefit of FBCB use in agriculture as a soil amendment. Data indicate a low risk for land application because a large proportion of FBCBs fall below Part 503 ceiling application limits and even the FBCBs with the highest constituent concentrations at expected application rates would not reach CPLR limits. The Part 503 Rule limits have been generally adopted by states into their own regulations with little modification. Several states that regulate coal combustion ash as a soil amendment have chosen to apply the Part 503 limits to beneficial use of these materials. Where background levels of certain metals are naturally high, there is concern that these limits may not adequately prevent metals from bioaccumulating to levels at which adverse effects on the environment might occur. The State of California evaluated this issue (see 7.5.1 above). At the expected application rates of 3 to 5 tons/acre, however, FBCBs would not reach the proposed application rate limits and cumulative loading limits, except in less than 5 percent of the CIBO Survey samples for selenium at the high-end application rate. Thus, a wide range of studies indicate that agricultural application of FBCB results in low risk to human health and the environment, and many states have acted to allow this practice.

7.6 Mine Reclamation

This section examines the beneficial use of FBCBs in abandoned coal mine reclamation projects. The major objective of mine reclamation is the abatement of acid mine drainage accompanied by the

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[161] American Coal Ash Association, 1996. *State Solid Waste Regulations Governing the Use of Coal Combustion By-products (CCBs).* June 1996.

[162] Personal Communication with Dr. Lee Daniels. Virginia Polytechnic University. Dr. Daniels' research field is land application of fly ash and he has gathered regulatory information for his research and from other sources.

[163] American Coal Ash Association, 1996. *Op. cit*.

mobilization of high concentrations of toxic metals that may cause harm to public health and safety and the environment. Common reclamation techniques include the neutralization of acid mine spoil, control of acid mine drainage, and re-establishment of vegetative cover to stabilize soil and reduce erosion. The alkaline characteristics of coal ash, especially FGD and FBC by-products, have been shown to be effective in neutralizing the mine spoils and drainage leachate. Ongoing studies by Ohio State University, the University of Pennsylvania, and others have demonstrated the utility of FBCBs in mine reclamation. The following sections summarize the results of some of these studies.

7.6.1 Studies of Similar Materials in Mine Reclamation

Ohio State's Phase 2 report[164] summarizes the findings of laboratory studies on the potential impact of dry FGD by-products on water quality in mined land reclamation by following changes in chemistry and composition of leachate from mine spoil-FGD mixes. Water soluble components and reaction products from mixes of two eastern Ohio acid mine spoils and by-products of three dry FGD technologies (lime injection multistage burner, pressurized FBC (PFBC), and spray dryer) were evaluated. Ohio State found that FGD by-products containing free lime initially yielded leachate pH values above 12, but that pH rapidly decreased with time. The leachates were generally dominated by calcium, sulfur, and chlorides. Magnesium concentrations were increased in leachates from PFBC-spoil mixes. In contrast, aluminum, and iron concentrations, which often reach toxic levels in acid mine spoil, decreased when FGD by-products were applied at rates of 10 percent by weight or greater. Arsenic, cadmium, chromium, copper, and nickel concentrations in leachate from treated spoils were below MCLs. The MCL for selenium was exceeded in 78 percent of the samples in the first leachate, but decreased to a 25 percent after 26 days of reaction.

In greenhouse experiments, FGD by-products were found to be highly effective in neutralizing spoil and soil acidity. When applied in amounts to neutralize acidity, plant growth improved and concentrations of aluminum, iron, manganese, nickel, and zinc in leachates and plant tissues decreased relative to plants grown in unamended spoil. However, at rates above the amounts required to neutralize acidity, FGD by-products promoted cementation, preventing plant root growth.

These studies suggest that mine reclamation using FBCBs as a neutralizing agent can result in substantial improvements in water quality and releases of toxic metals. No adverse effects of FGD usage (such as increased water pollution) were identified.

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[164] R. Stehower, W. Dick, J. Bigham, L. Forster, F. Hitzhusen, E. McCoy, S. Traina, W. Wolfe, 1996. *Land Application Uses for Dry FGD By-products, Phase 2 Report*. Ohio State University, Ohio Agricultural Research and Development Center. March 1996.

7.6.2 Case Studies

In a case study presented by Schueck and Scheetz[165] at the 15th annual meeting of the Association of Abandoned Mine Land Programs in 1993, FBC fly ash grout was used in acid mine drainage abatement. A reclaimed coal mine site in Pennsylvania was found to be producing severe acid mine drainage from buried pyrite-rich tipple refuse and pit cleanings. After the buried piles and resulting contaminant plumes were defined, the approach was to isolate the pyritic material from water and oxygen to prevent acid mine drainage production using FBC ash mixed with water to form a grout. A combination of geophysical mapping and monitoring well sampling was used to monitor changes in the water quality resulting from grouting. The initial post-grouting water quality data indicated a decrease in mine drainage from 50 percent to 90 percent in several of the downgradient wells. Concentrations of some pollutants in the mine drainage were also reduced.

Stehouwer et al[166] investigated the reclamation efficacy and impacts on soil and water quality of FBC by-products and yard waste compost on acidic mine spoils. Six 1-acre watersheds were constructed on acidic abandoned mine land spoil. Two watersheds each were reclaimed with borrow soil, FBC, or an FBC/compost mix. One year after reclamation, the FBC and FBC/compost compared well with the traditional soil reclamation practice. Vegetative cover was nearly 100 percent for all areas, thereby reducing erosion rates. Successful revegetation is attributable to increased pH and decreased concentrations in aluminum and iron in the minespoil. No detrimental environmental effects were observed or measured as a result of using FBC in minespoil reclamation. Concentrations of trace elements in all water samples were very low (arsenic, barium, cadmium, chromium, copper and selenium below detection or below MCLs) and showed almost no treatment effects (i.e., contributions from the FBC to water concentrations of pollutants were very low).

In another unpublished case study by the University of Pennsylvania,[167,168] alkali-activated fly ash and FBC bed ash cement was used as a capping material for acid mine drainage mitigation at a site in Karthus Township, Pennsylvania. The 100-acre mine site was backfilled after closing in the 1980's. The mine drainage is from a single seep which is strongly acidic. The approach to abatement involved capping the entire reclaimed mine site with the alkali-activated ash cement to prevent rain water from entering the spoil piles. This demonstration project is about 95 percent complete. Preliminary results indicate that the cap is effectively diverting water from infiltrating into the backfill, thus eliminating the need to extract and treat backfill water. The trace metals concentrations in the backfill water are

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[165] Joseph Schueck and Barry Scheetz, 1993. *Acid Mine Drainage Abatement from Small, Buried Piles of Tipple Refuse using Fluidized Bed Fly Ash Grout*. 15th Annual Meeting of the Association of Abandoned Mine Land Programs. September 1993.

[166] R.C. Stehouwer, W.A. Dick and R. Lai, 1996. *Acidic Minespoil Reclamation with FBC By-product and Yard-waste By-product*. 13th Annual National Meeting of the American Society for Surface Mining and Reclamation. May 1996.

[167] Barry Scheetz, Project Director, Unpublished University of Pennsylvania project summary.

[168] Personal Communication with Joseph Schueck. Pennsylvania Department of Environmental Protection, Bureau of Mining and Reclamation.

en times lower than the MCLs. In addition, there has been an observed increase in the quantity of macro invertebrate species and native trout in an adjacent stream attributable to the decrease in contaminated runoff released to the stream.

The results of these studies again confirm the broad interest in the use of FBCBs as a mine reclamation agent, and support the effectiveness and lack of adverse effects associated with these uses.

7.6.3 State Regulations on the Beneficial Use of Fossil Fuel Combustion Wastes in Mine Reclamation Projects

Based on a 1996 report by the American Coal Ash Association[169] and a limited survey conducted by ICF Kaiser, ten states (Illinois, Indiana, Kentucky, New Jersey, North Dakota, Ohio, Oklahoma, Pennsylvania, Virginia, and West Virginia) authorize the use of some type of coal combustion by-products (CCBs) in mine reclamation. The majority of these states at a minimum require testing to prove that the CCBs for use in mine reclamation are non-hazardous. Only three of the states (New Jersey, North Dakota, and Oklahoma) do not have specific guidelines or requirements for CCB use in mine reclamation, but indicated that use is considered case-by-case basis. Summarized below are the general requirements or major considerations for the states that authorize some type of reuse of CCBs in mine reclamation.

Illinois

The state of Illinois authorizes the use of CCBs in mine subsidence, fire control, sealing, and reclamation. The use must meet requirements specified by the Illinois State Code, and guidance issued by the Illinois Department of Mines and Minerals and the Illinois Environmental Protection Agency. Requirements include leachate testing for metals, dust controls, groundwater monitoring, and in some cases, the placement of liners.

Indiana

CCBs are not generally regulated by the state of Indiana for use in mine reclamation provided testing of metals and other water quality indicators meet specific numeric guidelines. The state allows CCBs to be used for mine subsidence and fire control and in mine sealing.

Kentucky

The State of Kentucky authorizes the use of CCBs (specifically fly and bottom ash, scrubber sludge, and FBC ash) in mine stabilization and reclamation. The State requires erosion and sedimentation controls, testing to establish the material as non-hazardous, and that the material not be placed within a specified distance from a wetland. The permit application requires that extensive hydrologic information on the mine be provided for review. Other requirements include groundwater

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[169] American Coal Ash Association. 1996. *Op. cit.*

monitoring, limitations on the thickness of the placement of by-product, and a minimum distance that by-product can be placed above groundwater.

<u>New Jersey</u>

The use of CCBs is considered on a case-by-case basis in the State of New Jersey.

<u>North Dakota</u>

The North Dakota Department of Health approves specific mix designs for fly ash use as a controlled low-strength material in underground mines.

<u>Ohio</u>

Before ash may be considered for beneficial use, it must meet Ohio TCLP limits and other limits for water quality. Fly and bottom ash may be specifically used in mine subsidence and fire control, mine sealing, and neutralization in active surface mines. Use in land reclamation of abandoned mines requires a site-specific plan approved by Ohio EPA. See Section 8.3 for further information.

<u>Oklahoma</u>

The reuse of CCBs is not specifically authorized by Oklahoma. However, fly and bottom ash generated outside the state must be constructively reutilized in active or inactive mine applications, i.e., not brought in and disposed in Oklahoma from out of state.

<u>Pennsylvania</u>

The state of Pennsylvania requires that CCBs must meet limits for maximum allowable concentrations for certain metals and water quality parameters before reuse. Coal ash in mining operations must comply with Pennsylvania's Clean Stream Law and advance written notice must be provided to the Bureau of Mining and Reclamation for coal ash use in mine subsidence and fire control and mine sealing. See Section 8.3 for further information.

<u>Virginia</u>

Virginia requires a 30-day notification of future projects in which CCB will be used. The notification must include information on the intended use, quantities to be used, and various site characteristics. CCB may be used in mine reclamation or mine refuse disposal if the CCB meets specified metals and pH limits.

<u>West Virginia</u>

The West Virginia Solid Waste Management Act sets pre-approved and acceptable beneficial uses of CCBs. Mining uses fall under the requirements of acceptable beneficial uses. CCBs may be used for the following mine-related operations.

- Alkaline source to neutralize potentially acid-producing materials
- Fill underground voids or to reduce acid mine drainage discharges
- Return disturbed areas to approximate original contour
- Seal underground mine openings.

7.6.4 Summary of FBCB Mine Reclamation Studies and Regulations

Based on our review of studies of coal ash, FGD and FBCBs used in coal mine reclamation, we conclude the FBCBs is demonstrated to be effective in neutralizing mine spoil acidity and acid mine drainage, and in promoting revegetation of mine reclamation sites. Although the data regarding leaching of trace elements is limited, the study results suggest that no significant increase in trace metal concentrations above existing conditions is occurring when FBCBs is used. Ohio State's work also indicates that in addition to pH improvements, the use of FBCBs may reduce leachable concentrations of certain phytotoxic elements in the spoils. We conclude that there are significant benefits from FBCBs use in mine reclamation and little or no evidence of adverse effects.

7.7 Other Beneficial Uses

As discussed in more depth in Chapter 5, other beneficial applications of FBCBs include use in several engineering and construction applications:

- Portland Cement Concrete
- Stabilized Roadbases
- Flowable Fill Applications
- Concrete Pavement Subsealing
- Track Concrete Pavements
- Structural Fills/Embankments

These uses generally pose a low risk to human health and the environment because constituents in FBCBs are stabilized by these uses and cannot migrate into the environment, thereby reducing the potential for exposure. Only use in structural fill and embankments poses a potential for constituent migration. This use of FBCBs requires that leachability and interaction with groundwater be tested on a site-specific basis, and dust control/erosion prevention measures be instituted. These measures are equivalent to those that are taken to control potential releases from other materials, such as large-volume coal ash.

7.8 Summary and Conclusions

This chapter analyzed the potential risks associated with the disposal and beneficial use of FBCBs. The purpose of the risk analysis was to evaluate FBCBs relative to Bevill Amendment risk assessment study requirements. Because of limited resources, we did not perform a quantitative risk assessment, but identified previous studies of similar materials to compare risks of those materials to FBCBs. To evaluate risks associated with FBCB land disposal, we reviewed previous studies of LVCC, a material very similar to FBCBs. Risks quantified in assessments previously performed for these materials were used to extrapolate to FBCB risks. To evaluate risks from land application of FBCBs, we reviewed the risk assessment of sewage sludge developed in support of the Part 503 Rule and studies of other similar materials to evaluate the potential risks from FBCBs. In the case of FBCB use in mine reclamation, no quantitative risk assessment studies of similar materials were available. Therefore, recently published studies of the effects of these materials were relied upon to evaluate potential FBCB risks associated with this use.

We compared risks associated with disposal of FBCBs with assessed risks of LVCC. Comparisons of the generation process, and chemical and physical characteristics of LVCC demonstrated that the materials are generally similar in physical characteristics and chemical composition, with the exception of the higher lime content of FBCBs. Although LVCC by-product generation is significantly greater annually than FBCBs, disposal practices are generally similar. FBCB disposal units tend, however, to be newer and with more extensive environmental controls. Using similar methods to those used to assess LVCC by-product risks, FBCB risks were estimated to be below levels of concern by all pathways evaluated.

We evaluated risks associated with agricultural land application of FBCBs against risk studies for sewage sludge, coal ash, and FGD wastes. Comparison of CIBO Survey sample results with Part 503 Rule limits demonstrated that a large majority of CIBO samples fall below Part 503 ceiling application limits setting maximum allowable concentrations of pollutants above which application is prohibited. Almost all FBCB samples also fall below cumulative loading limits when expected application rates are used to calculate high-end annual and lifetime loadings. This means that the expected maximum application regimen for FBCBs (5 tons/acre, 10 times, 3 years between applications) would result in pollutant loadings below levels of concern with respect to ecological and human health risks for most constituents.

Risks associated with FBCB use in mine reclamation were evaluated by reviewing available studies of FBCBs and similar materials. Based on the limited review of coal ash, FGD, and FBCB studies used in coal mine reclamation, we conclude the FBCBs is demonstrated to be effective in neutralizing mine spoil acidity and acid mine drainage, and in promoting revegetation of mine reclamation sites. Although the data regarding leaching of trace elements is limited, the study results suggest that no significant increase in trace metal concentrations can be detected above background levels when FBCBs are used. Ohio State's work also indicates that in addition to pH improvements, the use of FBCBs may reduce concentrations of certain phytotoxic elements in the spoils. Thus, from these limited studies we conclude that there are significant benefits to FBCB use in mine reclamation with little evidence of significant risk.

CHAPTER EIGHT

EXISTING REGULATORY CONTROLS ON FOSSIL FUEL COMBUSTION BYPRODUCTS

8.0 Introduction

The previous chapters of this report have provided detailed information on the generation, characteristics, management, and use of combustion byproducts from fossil fuel combustion. This chapter discusses at or on a general level the various federal and state laws and regulations that govern fossil fuel power plants with details on the laws and regulations that affect fossil fuel combustion byproducts. The existing regulatory structure has developed from a number of individual initiatives that were designed to address a particular environmental concern, in many cases without consideration of cross-media environmental impacts. In some instances, various environmental initiatives have had the unintended effect of restricting recycling or beneficial use of materials, thereby increasing the volume of materials being disposed. Under many federal environmental laws, implementation of specific environmental programs is carried out by the states. State level implementation of federal environmental laws typically requires adherence to minimum established standards, with many states imposing additional, more stringent requirements.

8.1 Methods and Limitations of the Analysis

The material in this chapter was developed by reviewing pre-existing EPA Reports to Congress and reports prepared by the American Coal Ash Association. To gather the most up-to-date information on state disposal regulations for fossil fuel combustion byproducts, a survey of the states was conducted by the CIBO Special Project. This survey of state disposal regulations was developed in consultation with the EPA to ensure that the information collected would be complete and useful to the EPA.

The information in this report was collected from numerous sources through May, 1997. Although the report seeks to accurately describe the information gathered the federal and state programs described herein are continuously changing. Therefore, the program extant in any particular state may differ from the description provided in this report. In addition, a portion of our analysis is based solely upon written survey responses. The CIBO Special Project has made no attempt to independently verify or clarify the information provided by state government respondents.

8.2 Federal Regulations Affecting Combustion By-products Content, Volume, and Management

The disposal and beneficial use of combustion by-products from a utility or non-utility combustion system are subject to several types of federal regulations. In this section, we discuss the effects that the Clean Air Act and its amendments ("CAA"), the Clean Water Act ("CWA"), the Safe Drinking Water Act ("SDWA"), the Resource Conservation and Recovery Act ("RCRA"), and the Comprehensive Environmental Response, Compensation and Liability Act ("CERCLA") have on combustion systems' generation of by-products, ash disposal, and beneficial use. These are not the only pieces of legislation or laws applicable to the operation of fossil fuel fired generating units, but they represent the statutes that have had the most significant impacts on the generation, reuse, and disposal of combustion by-products.

Other regulations range from the material inventory and reporting requirements under the Emergency Planning and Community Right to Know Act (EPCRA) to employee safety and health requirements under Occupational Safety and Health Administration regulations. In many cases, the various regulations intersect or overlap, often resulting in trade-offs with certain limitations on one criterion creating excesses with respect to another. These trade-offs are evident where a recognized increase in, for example, water pollution is found acceptable in order to make a different, albeit beneficial, reduction in air pollution.

8.2.1 Clean Air Act

Most notable among the federal regulations affecting by-products disposal are the regulations that apply to the generation and composition of combustion by-products in large volumes, i.e., the high volume wastes. The CAA and its amendments have significantly altered the generation of combustion by-products by imposing requirements to minimize the emissions of particulate matter, sulfur dioxide, and other pollutants from the stacks of utility and non-utility boilers. To protect public health and the environment, the federal CAA required the Environmental Protection Agency to establish National Air Ambient Quality Standards ("NAAQS") limits on the maximum ground level concentrations of six criteria pollutants. These include:

sulfur dioxide (SO_2)
particulate matter (PM)
carbon monoxide (CO)
ozone (O_3)
nitrogen oxides (NOx)
lead (Pb)

The general result of more restrictive emission standards has been, and will continue to be, an increase in the volume of combustion byproducts and a change in their composition. For example, as particulate matter standards have become more restrictive, emissions controls have, of necessity, become more efficient in terms of the size and volume of pollutant captured. The standard for particulate matter was changed in 1987 from one measuring total suspended particulates (TSP) to one measuring particulate matter ten microns in diameter or smaller (PM_{10}). This has recently been superseded by a new standard addressing particles that are 2.5 microns in diameter or smaller (Part II 62 FR 38652, July 18, 1997). The potential result is for a future increase in the volume of solid by-products from controlled particle sources because smaller and smaller airborne particles must now be captured and disposed of or utilized.

Similarly, the limit for ozone has been reduced to a more stringent limit (0.12 to 0.08 ppm) and the averaging time has been extended to eight hours from one hour. This will potentially increase the number of non-attainment areas and, thereby, impose more restrictions on combustion operations through an increase in NO_x controls, which in turn will affect the composition of ash by-products.

As a precursor to ozone formation, NOx emissions and controls will and are being similarly affected from other quarters. The CAA created the Ozone Transport Commission (OTC) to develop a plan to control NOx emissions in the Northeast Ozone Transport Region and, thereby, help meet the NAAQS for ozone. The Acid Rain Program established under Title IV of the CAA is the primary regulatory vehicle for the control and reduction of SO_2, and, with other provisions of the CAA, NO_x emissions.

While there can be no doubt of the environmental and health benefits of these requirements, the implementation of ever tightening restrictions on particulate emissions, NOx, and SO_2 has caused, and will continue to cause, an increasing volume and/or changing composition of by-products to be generated on a unit of output basis. A brief explanation follows.

As indicated above, the CAA has resulted in regulations restricting the emission of sulfur and nitrogen oxides. Each of these restrictions affects the generation and content of by-products generated by fossil fuel combustion. To control the emissions of acid gases, principally sulfur dioxide, several choices are available. In the case of conventional combustion technology, "end-of-pipe" scrubbing systems can be used, creating flue gas desulfurization residue. If FBC is used, a calcium-rich sorbent material, such as limestone, is normally injected directly into the combustion chamber. During the combustion process, SO_2 is generated and the calcium reacts with the SO_2 to form calcium sulfate. The calcium sulfate by-products, the unreacted sorbent material and any solid impurities in the sorbent material are entrained in the combustion byproduct along with the fuel ash. The composition and volume of the ash from an FBC boiler is, therefore, different from that of the ash from a conventional combustion boiler, because it contains both fuel ash and FGD material. It is, however, generally similar to the combustion byproduct produced from a conventional boiler using a dry FGD technology because both contain fuel ash, FGD material, and unreacted sorbent.

Add-on controls required to limit emissions of nitrogen oxides (NOx) also affect by-product composition. FBC is inherently a low temperature combustion technology. Therefore, the generation of thermal NOx is significantly lower than in conventional pulverized coal combustion processes. Since FBC technology is a relatively new technology, many FBC boilers have additional requirements for NOx controls due to EPA's New Source Review ("NSR") rules. NSR imposes permitting requirements on new sources based on the level of attainment of the NAAQS in the source location. For areas that are in attainment of the NAAQS, a new source would have to meet Best Available Control Technology ("BACT") standards. BACT standards take into account not only the environmental impact, but also the economic and energy costs to achieve reduced emissions, and are therefore somewhat less restrictive.

In areas that are in non-attainment, the more restrictive "Lowest Achievable Emission Rate" ("LAER") standard is imposed. This is the greatest emission control achieved in practice without regards to cost. Obviously, the imposition of LAER would potentially have the greatest impact on the quality and quantity of the products of combustion, as more controls would be necessary.
Typically, a selective non-catalytic reduction ("SNCR") process is used to demonstrate compliance with BACT requirements for NOx reduction. Most SNCR processes require injection of ammonia or urea compounds into the hot flue gas to combine with and remove the NOx. Some of the ammonia also combines with SO_2 remaining in the flue gas and creates ammonium bisulfites. Because the SO_2 in the flue gas is partially removed during combustion, a significantly lower volume of

ammonia bisulfites is formed in an FBC boiler with SNCR than in a pulverized coal unit with SNCR or selective catalytic reduction ("SCR"). Some of the ammonia or urea remains unreacted and is absorbed by the fly ash. Therefore, the fly ash will contain small quantities of ammonia or urea that vary with the changing operating conditions required to comply with permitted emission levels for NOx. More stringent NOx emissions require higher rates of ammonia injection and result in higher amounts of unreacted ammonia remaining in the ash.

State Implementation Plans

In most cases, EPA has delegated responsibility for implementation and enforcement of environmental regulations. While there can be and is a great deal of variation in the interpretation of the regulation and how it is imposed, the state's requirements must be no less stringent than the federal law.

The state implementation plan ("SIP") under Section 110 of the Clean Air Act is the primary regulatory mechanism by which emission controls are imposed by the states on stationary sources in order to meet NAAQS. EPA's approval of a state plan makes its provisions enforceable by the federal government, the state, and by citizen suit. All the states have SIPs, but the 1990 Amendments to the Clean Air Act require many changes in current SIPs, as delineated below.

In particular, Section 110(a)(2) of the Clean Air Act has been amended to require that an acceptable SIP contain detailed provisions addressing the following topics:

> Emission limitations and control measures.
>
> Monitoring requirements.
>
> Review of new and modified sources for compliance with New Source Performance Standards (NSPS), Prevention of Significant Deterioration (PSD), and nonattainment.
>
> A demonstration of adequate legal authority to operate and enforce the program.
>
> Emergency authority similar to that granted EPA under Section 303 of the Clean Air Act.
>
> A permit program.

New Source Performance Standards ("NSPS")

In 1979, EPA established NSPS for Electric Utility Steam Generating Units of greater than 250 million Btu/hour heat input (73 MW) in 40 CFR 60 Subpart Da. For these plants, EPA established performance standards that reflect the emission limitations achievable through application of the best available pollution control technology. NSP standards are also provided in Subpart Db for non-utility steam generating units burning coal or oil and greater than 29 MW. Small industrial and commercial units of between 2.9 and 29 MW are covered under Subpart Dc. The performance standards consider other environmental (e.g., increased water pollution in exchange for reduced air pollution) and energy impacts. Emissions for these facilities are monitored continuously and excess emissions are reported quarterly to both state agencies and to the EPA.

Prevention of Significant Deterioration ("PSD")

The goal of the PSD program is to avoid deterioration of air quality in attainment areas by maintaining pollutant emissions levels such that ambient air quality is allowed to increase by a small increment above a baseline. Section 165 of the CAA requires a PSD permit prior to construction or modification of any source in an attainment area. To obtain a PSD permit, a source must demonstrate that it will use Best Available Control Technology to reduce emissions for each pollutant subject to regulations under the CAA. In the late 1980's, EPA established a policy of evaluating BACT on a "top down" basis starting with the highest level of control; the evaluation took into account the economic cost, environmental impact, and energy aspects. BACT limitations must be at least as stringent as those emission levels required by applicable NSPS.

Hazardous Air Pollutants

Section 112(b)(l) of the CAA establishes a program to regulate emissions of 189 toxic air pollutants through technology-based standards. National Emission Standards for Hazardous Air Pollutants ("NESHAP") apply to facilities that emit or have the potential to emit ten (10) tons or more of any single hazardous air pollutant in a year. A facility that emits or has the potential to emit more than 25 tons per year of any combination of hazardous air pollutants also is subject to NESHAP. The impact of NESHAP on combustion byproducts is more difficult to determine, but probably has more to do with composition than volume of product.

8.2.2 Clean Water Act ("CWA")

The CWA and its amendments control discharges of waste streams into jurisdictional waters of the United States. The principal mechanism of control is the National Pollution Discharge Elimination System ("NPDES") permit program. Virtually any activity that will result in a discharge of process wastewater or storm water from an industrial site requires issuance of an NPDES permit. An NPDES permit establishes specific effluent limitations and conditions regarding any discharges to surface waters. Therefore, when facilities are permitted for disposal of waste, including by-products from combustion, consideration must be given to controlling the water discharge from the facility. Typical permit conditions require the facility operator to test and characterize the waste to determine if the runoff or discharge will contribute to the pollution of nearby rivers or streams. Extraction Procedure (EP) or Toxic Characteristic Leachate Procedure (TCLP) testing of a facility's waste stream is usually required so that the facility can ensure compliance with its permit conditions. Wastes that do not meet characteristics required by the facility's permit are rejected and disposed off-site, usually in specially designed and permitted facilities.

Under Section 402(b) of the CWA, responsibility for administration of the NPDES program can be approved for individual states. To obtain program approval, a state must have a statutory program for regulating discharges to surface waters. The CWA also requires that states establish water quality standards for all surface waters. The standards are subject to EPA approval.

The impact of the CWA on combustion byproducts is presently indirect, as it has to do more with releases from storage and ultimate disposal of FFCBs than generation or prescribed management practices. Nonetheless, CWA regulations' effects will be greater as beneficial uses of combustion byproducts become more common.

8.2.3 Safe Drinking Water Act ("SDWA")

The Safe Drinking Water Act also includes provisions that indirectly affect the handling and disposal of FBC by-products. The SDWA sets maximum contaminant levels ("MCL") for water that is used as a source of drinking water. Therefore, controls to prevent contamination of both surface water and ground water are necessary. Several trace constituents in fossil fuels, such as metals, are concentrated in the ash during combustion. Disposal or beneficial use of fossil fuel combustion byproducts may cause contaminant releases to surface or ground water, which are subject to MCLs established by the SDWA. Secondary drinking water standards for color, odor, and taste also have been established and also must be met.

8.2.4 Resource Conservation and Recovery Act ("RCRA")

The use or disposal of fossil fuel combustion by-products is potentially affected by RCRA. RCRA, as amended, is the primary federal statute governing the management of solid and hazardous waste. The principle objectives of RCRA are to:

- Promote the protection of human health and the environment from potential adverse effects of improper solid and hazardous waste management.
- Conserve material and energy resources through source reduction and waste recycling.
- Reduce or eliminate the generation of hazardous waste as expeditiously as possible.
- Improve solid waste management practices.

Special requirements for hazardous wastes are found in Subtitle C of RCRA. Subtitle C provides a statutory framework for tracking all hazardous and toxic wastes from "cradle to grave," that is, from their generation to their final disposal, destruction, or recycling. Hazardous waste can be generally defined as, according to Federal Law (40 CFR 261), a solid waste, or combination of solid wastes, which, because of its quantity, concentration, or physical, chemical, or infectious characteristics, may (1) cause, or significantly contribute to, an increase in serious irreversible, or incapacitating reversible illness; or (2) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, disposed of, or otherwise managed.[170]

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[170] The preceding discussion of RCRA was adapted from Report to Congress Cement Kiln Dust, Methods and Findings, EPA530-R-94-01, U. S. Environmental Protection Agency, Washington, D. C., December 1995, p. 7.20.

Subtitle D provides the framework for a state-based program for the management of non-hazardous solid wastes.

RCRA as originally enacted did not distinguish the regulatory treatment for the large volume of wastes that are typically associated with the combustion of solid fossil fuels (e.g., coal). To address this issue for coal, as well as other similar issues in other industries, the Solid Waste Disposal Act Amendments of 1980 (P.L. 96-482) contained the "Bevill Amendment" which is more fully discussed in Section 1.3 of this report. RCRA was further amended by the Hazardous and Solid Waste Amendments of 1984 (P.L. 98-3221) to give the U. S. Environmental Protection Agency flexibility in the promulgation of regulation under Subtitle C that considered the unique characteristics of some large-volume wastes, including fossil fuel combustion wastes, in the event that EPA concluded that hazardous waste regulations were warranted for these materials.

8.2.5 Comprehensive Environmental Response, Compensation, and Liability Act

While U.S. national policy is to reduce the volume of material being disposed of, there are other statutes that potentially discourage recycling or beneficial use of fossil fuel combustion byproducts. A prominent example is the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (P. L. 96-510) ("CERCLA" or Superfund). CERCLA authorizes the federal government to respond to the release or threatened release of hazardous substances, pollutants, or contaminants into the environment and establishes a fund to finance the government's response activities. The federal government may conduct a clean-up of the site, and sue potentially responsible parties (PRPs) to recover the cost of clean-up. Alternatively, the federal government may order the PRPs to conduct the clean-up action themselves. The PRPs can include a facility owner, operator, generator or transporter of the hazardous substance. Fossil fuel combustion byproducts are not specifically listed as a CERCLA hazardous substance, although some combustion byproducts may contain small amounts of constituents such as arsenic, cadmium, chromium and selenium that are CERCLA hazardous substances. This in turn may lead to the perception on the part of potential users of these materials that such use might confer potential liability under CERCLA for future environmental contamination.

8.3 State Regulation of Disposal and Beneficial Use of Fossil Fuel Combustion By-products

Disposal

The Bevill Amendment to RCRA provides a temporary exclusion of fossil fuel combustion by-products (wastes) from regulation under Federal hazardous waste regulations (RCRA Subtitle C). With the Bevill Amendment exclusion, fossil fuel combustion by-products effectively become non-hazardous solid wastes that are regulated under the states' implementation of RCRA Subtitle D.

The 1988 Report to Congress contained an analysis of state regulation of the disposal of coal combustion wastes. This analysis was based on a report prepared by the Utilities Solid Waste Activities Group in 1983 and updated by EPA in 1986 and 1987. The EPA conducted a further update of the disposal regulations in preparing its 1993 regulatory determination:

> The RTC included information on coal-fired electric utility waste regulations in all 50 States. In updating this information, EPA conducted a review of States that were selected according to the high levels of ash generated in those States. This approach resulted in a study universe of 17 States that generate approximately 70 percent of all coal ash in the United States.
>
> The data shows that States have generally implemented more stringent regulations for FFC [fossil fuel combustion] wastes since 1983 (when the State regulation review was conducted for the RTC [Report to Congress]). Under developing State industrial solid waste management programs, coal-fired utilities are more frequently being required to meet waste testing standards, and waste management units often must comply with design and operating requirements (e.g., liners and groundwater monitoring standards).[171]

As noted above, the state industrial solid waste management programs are continuing to develop. Therefore, to provide the most current information on state-level regulation of fossil fuel combustion wastes the Special Project conducted a survey of state disposal regulations. In developing the survey document, the Special Project reviewed the previous analyses of state disposal regulations and consulted with EPA to ensure that the information collected would be complete and useful to the EPA. The survey document is included as Appendix H. The survey document was distributed to pertinent regulatory agency personnel in all 50 States, five (5) Territories, and the District of Columbia, based on a mailing list of State Solid Waste Directors provided by the Association of State and Territorial Solid Waste Management Officials. Thirty States have returned the survey; these states account for approximately 69.4 percent of total coal consumption in 1995.

Exhibit 8-1 provides a summary of the state disposal regulations, as reported in our survey, that are applicable to fossil fuel combustion byproducts disposed of in landfills. Exhibit 8-2 provides a similar summary of the applicable regulations, as reported in our survey, for disposal in surface impoundments.

A review of the individual state solid waste regulations applicable to landfill disposal yields the following findings:

- Twenty-six of 30 states have enacted regulations that require permits for on-site disposal facilities. Three of 30 states require permits for off-site disposal facilities and 25 of 30 states require permits for both on- and off-site disposal facilities. One state, Utah, does not require a solid waste permit but may require a permit from the Division of Oil, Gas and Mining under some circumstances. In 1993, EPA found that 16 of 17 states surveyed required off-site FFCB management units to have some type of operating permit; accordingly, our findings are consistent with EPA's previous findings.[172]

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[171] 58 *Fed. Reg*. 42476, August 9, 1993.

[172] *Op. cit.*

- Twenty-nine of 30 states impose siting restrictions on FFCB landfills either by regulatory requirements or through a case-by-case investigation. One state, California, may impose siting restrictions as a local land use decision and not as an aspect of its solid waste regulations.

- Twenty-four of the states responding require the use of liners, leachate control, and ground water monitoring in FFCB landfills through either regulatory requirements or a case-by-case investigation. Texas' regulations do not explicitly require these contaminant release/detection controls, however, these measures are recommended for on-site disposal facilities and are generally required by permit conditions for off-site disposal facilities. California's solid waste regulations do not address liner, leachate control, or ground water monitoring requirements because these are considered water quality issues under the jurisdiction of the Regional Water Quality Control Boards. In 1993 EPA found that 12 of 17 states had mandatory liner and ground water monitoring requirements while three states had discretionary authority;[173] our findings would therefore indicate that the use of these environmental protection measures by state governments is increasing. Indeed, our study shows that 12 states have a mandatory groundwater monitoring requirement while 13 states have discretionary authority based on a case-by-case investigation.

- Twenty-four of 30 states require testing of the FFCB prior to disposal by either regulatory requirement or a case-by-case requirement. Washington requires testing to demonstrate that the waste is non-hazardous and Texas requires testing for off-site disposal. Twenty-six of 27 states require reporting of the test results by either regulatory requirement or on a case-by-case basis.

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[173] *Op. cit.*

EXHIBIT 8-1
STATE REGULATIONS FOR DISPOSAL OF FFCBs IN A LANDFILL

State	Permit Requirements	Siting Restrictions	Liner Required	Leachate Control Required	Groundwater Monitoring Required	Testing Prior to Disposal	Reporting of Test Results to State	Regulations Require Control of Fugitive Dust
AZ	On & Off Site	Yes	Case by case	Case by case	Case by case	Yes	Yes	Yes
CA	On & Off Site	No, CA1	CA2	CA2	CA2	Yes	Yes	Yes
CO	On & Off Site	Case by case	Case by case	Case by case	Case by case	Yes	Yes	Yes
CT	On & Off Site	Yes	No	No	Yes	Yes	Yes	Yes
DE	On & Off Site	Yes	Yes	Yes	Yes	Yes	Yes	Yes
FL	On & Off Site	Yes	Case by case	Case by case	Yes	Case by case	Yes	Yes
GA	On & Off Site	Yes	No	No	Case by case	No	Case by case	Case by case
HI	On & Off Site	Yes	Yes	Case by case	Case by case	Case by case	Yes	Yes
IL	Off Site	Case by case	Yes	Yes	Yes	Yes	Case by case	Yes
IA	On & Off Site	Yes	Yes	Yes	Yes	Yes	Yes	Yes
KY	On & Off Site	Yes	Case by case	Case by case	Yes	Yes	Yes	Yes
MD	On & Off Site	Yes	Yes	Case by case	Case by case	No	Case by case	Yes
MI	On & Off Site	Yes	Case by case	Yes	Yes	Yes	Case by case	Yes
MN	On & Off Site	Yes	Case by case	Case by case	No response	Yes	Yes	Yes
NE	On & Off Site	Yes	Case by case	Case by case	Case by case	Yes	Yes	No response
NV	On & Off Site	Case by case	Case by case	Case by case	Case by case	Yes	Yes	Yes
NH	On & Off Site	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ND	On & Off Site	Yes	Yes	Case by case	Yes	Yes	Yes	Yes
OH	On & Off Site	Yes	Case by case	Case by case	Case by case	Yes	Yes	Yes
PA	On & Off Site	Yes	Case by case	Case by case	Yes	Yes	Yes	Yes

EXHIBIT 8-1 (continued)
STATE REGULATIONS FOR DISPOSAL OF FFCBs IN A LANDFILL

State	Permit Requirements	Siting Restrictions	Liner Required	Leachate Control Required	Groundwater Monitoring Required	Testing Prior to Disposal	Reporting of Test Results to State	Regulations Require Control of Fugitive Dust
SC	On & Off Site	Case by case	Case by case	Case by case	Case by case	Yes	Yes	Yes
SD	On & Off Site	Yes	Case by case	Case by case	Case by case	Case by case	Case by case	Case by case
TN	On & Off Site	Yes	Case by case	Case by case	Case by case	TN1	TN1	Case by case
TX	Off Site	No	TX1	TX2	TX3	TX4	Case by case	TX5
UT	UT1	No	No	No	Case by case	No	No response	Yes
VT	On & Off Site	Yes	Case by case	Case by case	Case by case	Case by case	No response	Case by case
VA	Off Site	Yes & CBC	No response	No, CBC	No, CBC	No	No	Yes
WA	On & Off Site	Yes	Yes, WA1	Yes	Yes	No, WA2	Case by case	No
WV	On Site, WV1	Yes	Yes	Yes	Yes	Yes	Yes	Case by case
WY	On & Off site	Yes	Case by case	Case by case	Case by case	Yes	Yes	Yes

CONTROLS
Yes: The disposal standard is imposed by State regulations.
No: The disposal standard is not imposed by State regulations.
Case by case (CBC): The State regulations require a case-by-case investigation to determine if the disposal standard will be imposed.

EXHIBIT 8-1 (continued)
STATE REGULATIONS FOR DISPOSAL OF FFCBs IN A LANDFILL

State	Permit Requirements	Siting Restrictions	Liner Required	Leachate Control Required	Groundwater Monitoring Required	Testing Prior to Disposal	Reporting of Test Results to State	Regulations Require Control of Fugitive Dust

NOTES
CA1 The State's regulations do not impose a siting restriction, treated as a local land use decision.
CA2 Covered by the Regional Water Quality Board located in each region of the state.
TN1 No response provided.
TX1 A liner is not specifically required by the State's regulations, recommended for on-site disposal facilities and generally required by permit for off-site disposal.
TX2 The State's regulations do not require leachate collection, recommended for on-site disposal and would be required by permit for off-site disposal.
TX3 The State's regulations do not require ground water monitoring, recommended for on-site disposal and would be required by permit for off-site disposal.
TX4 Required by permit for off-site disposal.
TX5 The State's regulations have a general prohibition on creating a nuisance.
UT1 The State's regulations do not require a permit for disposal or coal ash, a ground water discharge permit or a permit from the Division of Oil, Gas & Mining may be required in some circumstances.
WA1 In areas with greater than 12-inches of precipitation annually.
WA2 Testing is required to demonstrate the waste is non-hazardous.
WV1 No response provided regarding off site permit requirements.

EXHIBIT 8-2
STATE REGULATIONS FOR DISPOSAL OF FFCBs IN AN IMPOUNDMENT

State	Permit Requirement	Siting Restrictions	Liner Required	Leachate Collection Required	Groundwater Monitoring Required	Testing Prior to Disposal	Reporting of Test Results to State
AZ	On & Off Site	Yes	Case by case	Case by case	Case by case	Yes	Yes
CA	Not applicable	CA1	CA2	CA2	CA2	Yes	Not applicable
CO	On & Off Site	Case by case	Case by case	Case by case	Case by case	Yes	Yes
CT	On & Off Site	Yes	No	No	Yes	Yes	Case by case
DE	On & Off Site	Yes	Yes	Yes	Yes	Yes	Yes
FL	On & Off Site	Yes	Case by case	Case by case	Yes	Case by case	Yes
GA	On & Off Site	Case by case	Case by case	No	No	No	Case by case
HI	On & Off Site	Yes	Yes	Case by case	Case by case	Case by case	Yes
IL	On & Off Site	Case by case	Case by case	Case by case	Case by case	Case by case	Case by case
IA	On & Off Site	No	Yes	No	No	No	Yes
KY	On & Off Site	Case by case	Case by case	Case by case	Case by case	Yes	Yes
MD	On & Off Site	Case by case	Case by case	Case by case	Case by case	No	Case by case
MI	On & Off Site	Yes	Case by case	Case by case	Yes	Yes	Case by case
MN	On & Off Site	Yes	Case by case	Case by case	No response	Case by case	Yes
NE	No response	No response	No response	No response	No response	No response	No response
NV	On & Off Site	Case by case	Case by case	Case by case	Case by case	Yes	Yes
NH	On & Off Site	Yes	Yes	Yes	Yes	Yes	Yes
ND	On & Off Site	Yes	Yes	Case by case	Yes	Yes	Yes
OH	On & Off Site	Case by case	Case by case	Case by case	Case by case	Case by case	Case by case

EXHIBIT 8-2 (continued)
STATE REGULATIONS FOR DISPOSAL OF FFCBs IN AN IMPOUNDMENT

State	Permit Requirement	Siting Restrictions	Liner Required	Leachate Collection Required	Groundwater Monitoring Required	Testing Prior to Disposal	Reporting of Test Results to State
PA	On & Off Site	Yes	Case by case	Case by case	Yes	Yes	Yes
SC	On & Off Site	Case by case	Case by case	Case by case	Yes	Case by case	Yes
SD	On & Off Site	No response	Case by case	Case by case	Case by case	Case by case	Case by case
TN	On & Off Site	Case by case	Case by case	TN1	TN1	TN1	TN1
TX	Off Site	No	TX1	TX2	TX2	TX3	Case by case
UT	UT1	No	No	No	Case by case	No	No response
VT	On & Off Site	Yes	Case by case	Case by case	Case by case	Case by case	No response
VA	VA1	Case by case	No, CBC	No, CBC	No, CBC	No response	No response
WA	On & Off Site	Yes	Yes	Yes, WA1	Yes	No, WA2	Case by case
WV	On, WV1	Yes	Yes	No response	Yes	Yes	Yes
WY	On & Off Site	No	Case by case	Case by case	Case by case	Case by case	Yes

CONTROLS

Yes: The disposal standard is imposed by State regulations.

No: The disposal standard is not imposed by State regulations.

Case by case (CBC): The State regulations require a case-by-case investigation to determine if the disposal standard will be imposed.

EXHIBIT 8-2 (continued)
STATE REGULATIONS FOR DISPOSAL OF FFCBs IN AN IMPOUNDMENT

State	Permit Requirement	Siting Restrictions	Liner Required	Leachate Collection Required	Groundwater Monitoring Required	Testing Prior to Disposal	Reporting of Test Results to State

Notes

CA1 The State's regulations do not impose a siting restriction, treated as a local land use decision.

CA2 Covered by the Regional Water Quality Board located in each region of the state.

TN1 No response provided for these questions. Comment attached to survey indicated an impoundment would be regulated as a Class II (industrial) landfill.

TX1 A liner is not specifically required by the State's regulations, recommended for on-site disposal facilities and generally required by permit for off-site disposal.

TX2 The State's regulations do not require leachate collection, recommended for on-site disposal and would be required by permit for off-site disposal.

TX3 Required by permit for off-site disposal.

UT1 The State's regulations do not require a permit for disposal or coal ash, a ground water discharge permit or a permit from the Division of Oil, Gas & Mining may be required in some circumstances.

WA1 For impoundments with a capacity greater than two (2) million gallons.

WA2 Testing required to demonstrate that the waste is non-hazardous.

WV1 No response provided regarding off site permit requirements.

- Finally, 27 of 29 states responding to this question require control of fugitive dust at landfill operations by either regulatory requirement or case-by-case determinations. Texas regulations do not specify fugitive dust control. The regulations, however, do contain a general prohibition on creating a nuisance.

Similar findings were found for FFCB disposal in impoundments. Our survey of 39 FBC power plants found only four facilities that reported disposal by impoundment, indicating that the use of this disposal method is uncommon for FBC units.

Appendix I contains full summary tables of the results of the Survey of State Disposal Regulations. Review of this full summary shows that the states' programs are continuing to increase the regulatory controls on the disposal of FFCBs since the 1988 RTC and the 1993 regulatory determination.

Beneficial Use

The Pollution Prevention Act's order of preference for environmental management techniques are to reduce; reuse or recycle; treat; and dispose. The disposal option requirements have been analyzed above, however, each of the states has adopted regulations that affect the reuse or recycling (also sometimes referred to as beneficial use) of fossil fuel combustion by-products. The most complete information available on the state-level regulation of beneficial use is contained in The American Coal Ash Association report entitled *State Solid Waste Regulations Governing the Use of Coal Combustion Byproducts (CCBs).* The following information is extracted from the American Coal Ash Association report and the full text of the report is included as Appendix J.

> For consistency, this report [the ACAA report] utilizes the term CCBs [coal combustion byproducts]. The term is intended to generically refer to fly ash, bottom ash, boiler slag, and FGD material. The reader must recognize that each state has different approaches to classification of CCBs and that these respective classifications may limit or expand allowable uses of CCBs. For example, in Pennsylvania CCBs are referred to as "coal ash" which is defined to include only fly ash, bottom ash and boiler slag. Conversely, some states include within the definition of CCBs, wastes which have been combusted with other materials, such as petroleum coke, tire derived fuel and/or wood. In some cases these distinctions are noted herein [referring to the ACAA report]. However, the reader should not assume that use of the term CCB infers that all types of CCBs are included within the scope of a particular state's regulations.
>
> Most states currently do not have specific regulations addressing the use of CCBs and requests for CCB uses are handled on a case-by-case basis or under generic state recycling laws or regulations. Many states have adopted "generic" laws and regulations which authorize use and recycling of hazardous and/or solid wastes in certain applications. Some of these generic use laws are described in Section 3 [of the ACAA report]. States without formal CCB use regulations or guidelines often encourage the use of coal fly ash use in cement and concrete applications and products. Additionally, state highway departments are required by the Federal Highway Administration (FHWA) to have specifications conforming to federal

> procurement guidelines for cement and concrete containing coal fly ash for federally funded projects.
>
> Some states have adopted laws and regulations or issued policies and/or guidance regarding CCB use. The CCB uses authorized within these states vary widely. Some states authorize liberal use of CCBs, while others authorize CCB use only in limited applications. In addition, the level of regulatory control and oversight varies significantly. CCB uses presenting the greatest concern to state regulators are those which involve land application such as the use of CCBs in agricultural applications, structural fills, mine applications and embankments. Some states consider these applications to be waste disposal and not use or recycling.
>
> In summary, laws, regulations, policies, and/or guidance authorizing at least limited CCB uses have been adopted in the following states: Alabama, Arkansas, California, Georgia, Illinois, Indiana, Iowa, Kentucky, Maryland, Massachusetts, Michigan, Nebraska, New Jersey, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, South Carolina, Tennessee, Texas, Vermont, Virginia, West Virginia, and Wisconsin. [Exhibit 8-3] summarizes uses of CCBs that are "authorized" (●) or "allowed" (❑) on a state-by-state basis as presented in the remainder of this report [the ACAA report].[174]

In addition to the "authorized" or "allowed" beneficial use of coal (fossil fuel) combustion byproducts shown in Exhibit 8-3, several states have implemented regulations that will allow for a case-by-case review of a potential use of a "waste" material in a beneficial manner or have established a tiered level of regulatory oversight for use. In some instances these case-by-case analyses result in the issuance of an enforceable permit or "beneficial use determination" (BUD). The case-by-case analyses generally look to the characteristics of the waste, how the material will be used and what controls are in place to prevent endangering human health or the environment. The tiered level approach used in other states uses similar controls. Four examples of state regulatory programs (New York, Pennsylvania, Ohio and California) for beneficial use of FFCBs are described below to illustrate the approaches being used by the states to regulate the beneficial use of FFCBs. These four states have been selected for detailed review because the available information on these programs is the most in-depth. While the four state programs described herein may not necessarily be representative, as advanced programs, they do reflect prominent emerging trends in state-level residual material management.

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[174] American Coal Ash Association, *State Solid Waste Regulations Governing the Use of Coal Combustion Byproducts (CCBs),* Alexandria, VA, June 1996, p. 6.

EXHIBIT 8-3
USES OF CCBS BY STATE

	AL	AK	AZ	AR	CA	CO	CT	DE	FL	GA	HI	ID	IL	IN	IA	KS	KY	LA	ME	MD	MA	MI	MN	MS	MO
Cement/Concrete Products	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	●	❑	●	❑	●	❑	❑	❑	❑	●	❑	❑	❑
Flowable Fill													●	●							●	●			
Structural Fills		❑											●	●			●			●	●	●			
Road Base/Subbase													●	●	●		●				●	●			
Mineral Filler in Asphalt															●							●			
Snow and Ice Control													●	●			●								
Roofing Shingles													●				●								
Blasting Grit																	●								
Grouting						❑																●			
Mining Applications													●	●			●								
Wallboard										❑					●										
Waste Stabilization																									
Plastics/Paints/Metals													●		●		●								
Mineral Recovery													●	●	●										
Soil Amendment	●												●							●					
Ingredient in Product				●	●					●				●			●				●				
Aggregate																					●	●			
Ice Control (Rivers)																									
Landfill Cover		❑																			●				
Walking/Driving Surface																									
Concrete Block																					●				
Bricks/Ceramics/Insulation																									
Artificial Reefs																									

❑ : Allowed
● : Authorized

EXHIBIT 8-3 (continued)
USES OF CCBS BY STATE

	MT	NE	NV	NH	NJ	NM	NY	NC	ND	OH	OK	OR	PA	RI	SC	SD	TN	TX	UT	VT	VA	WA	WV	WI	WY
Cement/Concrete Products	❑	●	❑	❑	❑	❑	●	●	❑	●	❑	❑	●	❑	●	❑	❑	●	❑	❑	❑	❑	●	●	❑
Flowable Fill		●					●	●		●								●					●	●	
Structural Fills		●					●	●		●			●		●		●				●				
Road Base/Subbase		●						●		●			●				●	●			●		●	●	
Mineral Filler in Asphalt		●					●			●								●						●	
Snow and Ice Control							●	●		●			●								●		●	●	
Roofing Shingles							●	●		●					●			●					●		
Blasting Grit		●						●		●					●			●					●		
Grouting										●								●							
Mining Applications					●				●	●	●		●								●				
Wallboard							●											●							
Waste Stabilization		●								●								●					●		
Plastics/Paints/Metals								●		●								●					●		
Mineral Recovery								●		●			●								●		●		
Soil Amendment								●		●			●								●				
Ingredient in Product							●	●		●			●		●			●		●			●		
Aggregate		●				●	●	●		●			●		●		●	●					●		
Ice Control		●																							
Landfill Cover																							●		
Walking/Driving Surface										●								●			●				
Concrete Block										●								●					●		
Bricks/Ceramics/Insulation							●			●								●							
Artificial Reefs																		●							

❑ : Allowed
● : Authorized

Source: ACAA, 1996. Op. cit.

State of New York

The regulations of the State of New York have both a listing of authorized beneficial uses of coal combustion byproducts and a case-specific beneficial use determination procedure to allow for other uses of solid wastes. The authorized uses of CCBs include:

> (14) coal combustion bottom ash placed in commerce to serve as a component in the manufacture of roofing shingles or asphalt products; or as a traction agent on roadways, parking lots and other driving surfaces;
>
> (15) coal combustion fly ash or gas scrubbing by-products placed in commerce to serve as an ingredient to produce light weight block, light weight aggregate, low strength backfill material, manufactured gypsum or manufactured calcium chloride; and
>
> (16) coal combustion fly ash or coal combustion bottom ash placed in commerce to serve as a cement or aggregate substitute in concrete or concrete products; as raw feed in the manufacture of cement; or placed in commerce to serve as structural fill within building foundations when placed above the seasonal high groundwater table.[175]

The New York regulations also require reporting of the quantities of coal combustion byproducts generated and the quantity of CCBs placed in commerce in the above approved uses.[176]

The granting of a case-specific beneficial use is a rigorous process that considers the protection of human health and the environment as well as demonstrating that the use of a solid waste comprises an effective substitute for a commercial product. Continuing the example of the State of New York the following regulations would be applied to a BUD:

> (d) Case-specific beneficial use determinations.
>
> (1) The generator or proposed user of a solid waste may petition the department, in writing, for a determination that the solid waste under review in the petition may be beneficially used in a manufacturing process to make a product or as an effective substitute for a commercial product. Unless otherwise directed by the department, the evaluator may not consider any such petition unless it provides the following.
>
>> (i) a description of the solid waste under review and its proposed use;
>>
>> (ii) chemical and physical characteristics of the solid waste under review and of each type of proposed product;

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[175] 6 NYCRR Part 360, §§ 360-1.15(b)(14-16), October 9, 1993.

[176] 6 NYCRR Part 360, §3601.15(c), October 9, 1993.

(iii) a demonstration that there is a known or reasonably probable market for the intended use of the solid waste under review and of all proposed products by providing one or more of the following:

> (a) a contract to purchase the proposed product or to have the solid waste under review used in the manner proposed;
>
> (b) a description of how the proposed product will be used;
>
> (c) a demonstration that the proposed product complies with industry standards and specifications for that product; or
>
> (d) other documentation that a market for the proposed product or use exists; and

(iv) a demonstration that the management of the solid waste under review will not adversely affect human health and safety, the environment and natural resources by providing:

> (a) a solid waste control plan that describes the following:
>
> > (1) the source of the solid waste under review, including contractual arrangements with the supplier;
> >
> > (2) procedures for periodic testing of the solid waste under review and the proposed product to ensure that the proposed product's composition has not changed significantly;
> >
> > (3) the disposition of any solid waste which may result from the manufacture of the product into which the solid waste under review is intended to be incorporated;
> >
> > (4) a description of the type of storage (e.g., tank or pile) and the maximum anticipated inventory of the solid waste under review (not to exceed 90 days) before being used;
> >
> > (5) procedures for run-on and run-off control of the storage areas for the solid waste under review; and
> >
> > (6) a program and implementation schedule of best management practices designed to minimize uncontrolled dispersion of the solid waste under review before and during all aspects of its storage as inventory and/or during beneficial use; and

(b) a contingency plan that contains the information and is prepared in accordance with subdivision 360-1.9(h) of this Part.

(2) The department will determine in writing, on a case-by-case basis, whether the proposal constitutes a beneficial use based on a showing that all of the following criteria have been met:

> (i) the essential nature of the proposed use of the material constitutes a reuse rather than disposal;
>
> (ii) the proposal is consistent with the solid waste management policy contained in section 27-0106 of the ECL;
>
> (iii) the material under review must be intended to function or serve as an effective substitute for an analogous raw material or fuel;
>
> (iv) for a material which is proposed for incorporation into a manufacturing process, the material must not be required to be decontaminated or otherwise specially handled or processed before such incorporation, in order to minimize loss of material or to provide adequate protection, as needed, of public health, safety or welfare, the environment or natural resources;
>
> (v) whether a market is existing or is reasonably certain to be developed for the proposed use of the material under review or the product into which the solid waste under review is proposed to be incorporated; and
>
> (vi) other criteria as the department shall determine in its discretion to be appropriate.

(3) The department will either approve the petition, disapprove it, or allow the proposed use of the solid waste under review subject to such conditions as the department may impose. When granting a beneficial use determination, the department shall determine, on a case-by-case basis, the precise point at which the solid waste under review ceases to be solid waste. Unless otherwise determined for the particular solid waste under review, that point occurs when it is used in a manufacturing process to make a product or used as an effective substitute for a commercial product or used as fuel for energy recovery. As part of its petition, the petitioner may request that such point occur elsewhere. In such a request, the petitioner must include a demonstration that there is little potential for improper disposal of the material or little potential for the handling, transportation, or storage of the solid waste under review to have an adverse impact upon the public health, safety or welfare, the environment, or natural resources.

(4) The department may revoke any determination made under this subdivision if it finds that one or more of the matters serving as the basis for the department's determination was incorrect or is no longer valid or the department finds that there has been a violation of any condition that the department attached to such determination.[177]

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[177] 6 NYCRR Part 360, §3601.15(d), October 9, 1993.

One project in New York State, the Fort Drum Hot Water Cogeneration project (a coal fired FBC project) has petitioned and secured a New York State BUD for the use of coal combustion byproducts. As part of the approval, the State of New York found that the FBC material was an effective substitute for either lime or limestone that was being used for pH correction in agriculture and that a market for the FBC material either existed or could be created. The BUD issued for this application contained requirements for record keeping, testing, and reporting on the characteristics of the FBC material and imposed limitations on the quantities applied. Appendix K contains a copy of the New York State BUD and subsequent amendments for this project.

Commonwealth of Pennsylvania

In Pennsylvania, coal ash is regulated under the Solid Waste Management Ac t (35 P.S. §§ 6018.101-6018.1003) (the "Act") and the Residual Waste Management regulations promulgated thereunder These regulations are administered by two Pennsylvania Department of Environmental Protection ("PADEP") administrative bureaus. In 1986 the Act was amended to authorize the beneficial use of coal ash. Beneficial use of coal ash was implemented through PADEP guidelines until the Residual Waste Management regulations, 25 PA Code Chapter 287, were amended in July 1992 to include the beneficial use of coal ash in Sections 287.661 through 287.666 inclusive. The Residual Waste Management regulations were further amended in January, 1997 for the beneficial use of coal ash in mining applications (§§ 287.663 and 287.664). Appendix L contains a copy of the Pennsylvania Bulletin of January 25, 1997 with the amended regulations.

The Pennsylvania regulations permit the use of coal ash, which is defined as "[f]ly ash, bottom ash or boiler slag resulting from the combustion of coal, that is or has been beneficially used, reused or reclaimed for a commercial, industrial or governmental purpose..."[178] in several approved uses (with certain restrictions). Among the approved listings are:

> Structural fill (§287.661)
> Soil substitute or soil additive (§287.662)
> Manufacture of concrete (§287.665 [(b)(1)])
> Extraction of metals or compounds (§287.665 [(b)(2)])
> Use as a stabilized product (§287.665 [(b)(3)])
> Bottom ash or boiler slag as an antiskid material, or road surface preparation material (§287.665 [(b)(4)])
> Raw material for a product with commercial value, including the use of bottom ash as construction aggregate (§287.665 [(b)(5)])
> Mine subsidence control, mine fire control and mine sealing (§287.665 [(b)(6)])
> Use as a drainage material or pipe bedding (§287.665[(b)(7)])

The above listing of beneficial uses is administered by the PADEP Bureau of Land Recycling and Waste Management.

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[178] 25 Pa. Code, Chp. 287, §287.1.

Sections 287.663 and 287.664 are administered by the Bureau of Mining and Reclamation and pertain to the use of coal ash at surface mining sites. The January, 1997 amendments to these sections changed the requirements concerning groundwater monitoring, reporting to PADEP, coal ash beneficial uses in mining applications, and the amount of coal ash that could be used at active coal mine and abandoned mine sites. These amendments required the Bureau of Mining and Reclamation to develop certification guidelines and technical guidance for the beneficial use of coal ash in mining applications. Certification guidelines allow generators of coal ash to obtain certification for their coal ash by meeting the chemical and physical characteristics that are appropriate for the different beneficial uses. The technical guidance deals with the review and approval of the beneficial uses of coal ash at active coal mine sites and at abandoned mine sites.

Certification for Beneficial Use of Coal Ash for Use in Mining Applications

Certification of coal ash for beneficial use in mining applications entails an applicant providing documentation on how the coal ash is generated as well as providing details on the methods used to obtain the sample, and the analytical results. The analysis required is based on EPA's *Test Methods for Evaluating Solid Waste*, SW-846. The chemical constituents that must be determined are: pH, aluminum, arsenic, antimony, barium, boron, cadmium, chromium, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, and zinc. A Synthetic Precipitation Leaching Procedure (SPLP) test (EPA SW-846 Method 1312), must be performed for the following constituents: pH (initial and final), total organic halides, aluminum, arsenic, antimony, barium, boron, cadmium, chromium, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, zinc, sulfate, chloride, and sodium.

All coal ash constituents must have concentrations equal to or less than the maximum acceptable leachate limits for contaminants. These limits are based on the minimum requirements for an acceptable waste at a Class III residual waste landfill (Pa. Code, Chp. 288, §288.623). The PADEP may grant a contingent certification if the coal ash exceeds the maximum acceptable leachate concentration for aluminum, iron, manganese, sulfate, or zinc. This contingent approval would be granted for use at a specific mine site on a case-by-case basis.

In addition to the general certification requirements, there are additional requirements for certification for specific uses. For coal ash placement, the pH must be in the range of 7.0 to 12.5 at the generator's site. For use as a soil additive instead of lime or for use of coal ash in alkaline addition, the calcium carbonate equivalence must be no less than 10 percent by dry weight. For use as a low permeability material, the ash must be able to meet a hydraulic conductivity (permeability) of 1×10^{-6} cm/sec or less. Each of these beneficial uses is explained below.

After the PADEP certifies the coal ash for beneficial use, it is re-evaluated every six months thereafter, or whenever there is a significant operational change in the combustion unit. The PADEP may use its discretion to obtain and analyze coal ash samples at the generation site or at the mine site, to determine if the coal ash meets the certification guidelines for its beneficial use.

The full text of the draft *Technical Guidance documents for Certification Guidelines for Beneficial Use of Coal Ash* dated February 26, 1997 is included in Appendix M.

Beneficial Use Approval

In addition to the certification of the coal ash, the PADEP requires beneficial use approval prior to placement. In the case of coal ash placement, groundwater monitoring prior to approval and during operations is required. Groundwater monitoring also may be required for alkaline addition and low permeability use applications.

Monitoring points may be wells, springs, seeps, mine discharges, and/or abandoned mine shafts. Monitoring points must be approved by the PADEP. The number of monitoring points must be sufficient to determine the impact of coal ash placement. Up gradient monitoring points are not required unless there is a concern about pollution which is unrelated to the mine site. Six background samples for each monitoring point taken monthly, or at six week intervals, are required to determine background water quality unless justification is provided for fewer samples.

The required monitoring data includes the following parameters: static water elevation (for monitoring wells); flow (for discharges); pH (field and laboratory); specific conductance, alkalinity, and acidity; and iron, manganese, sulfate, total dissolved solids, total suspended solids, aluminum, arsenic, cadmium, calcium, chromium, chloride, copper, lead, magnesium, mercury, nickel, potassium, selenium, sodium, and zinc concentrations. All sample collection and analysis activities must follow EPA SW-846 methods.

Once coal ash placement(or other beneficial uses where groundwater monitoring is required) begins, groundwater monitoring is performed quarterly for the following parameters: static water elevation (for monitoring wells) flow (for discharges), pH (field and laboratory), specific conductance, alkalinity, acidity, iron, manganese, sulfate, total dissolved solids and total suspended solids. Groundwater monitoring is performed annually for aluminum, arsenic, cadmium, calcium, chromium, chloride, copper, lead, magnesium, mercury, nickel, potassium, selenium, sodium, and zinc.

The PADEP also imposes other requirements in the approval process, including submittal of documents describing the entire proposed project, landowner approval, and bonding. These requirements are consistent with the application and approval process for other mining applications by the PADEP in which coal ash is not being used beneficially.

The full text of the Draft *Technical Guidance for the Beneficial Uses of Coal Ash* is provided as Appendix N.

Mining Applications Where Beneficial Use of Coal Ash Is Permitted

Coal ash placement involves the mixing of coal ash with mine spoil or placing it in horizontal layers for use as backfill. Its purpose is to improve groundwater quality or prevent groundwater degradation.

Coal ash use as a soil substitute or a soil additive at coal mine sites involves applying the material at a rate that improves the productivity and properties of the soil and does not cause a public health, safety, or environmental pollution problem. The Technical Guidance document requires a coal ash and soil/mine spoil mixture to have a pH that is normally between 6.5 and 8.0. If coal ash is used as a soil substitute, the volume of coal ash must be in an appropriate ratio with other material to create a final vegetation supporting layer. The soil or mine spoil must be sampled and analyzed for contaminants before any coal ash is used. Maximum contaminant loading rates for arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc are established.

Coal ash can be used as an alkaline material to neutralize mine spoil acidity. The manner of placement and the volume of coal ash used at various locations is determined by the amount of neutralization required. The groundwater monitoring is usually more extensive for alkaline addition than coal ash placement because the success of alkaline addition has to be evaluated.

In a low permeability application, the coal ash is used in backfilled mine spoil to prevent or reduce surface water infiltration. This type of use is an integral part of the pollution prevention plan for the mining operation. The groundwater monitoring requirements are similar to those for coal ash placement.

For additional details on the PADEP Bureau of Mining and Reclamation’s program on the beneficial use of coal ash in mining applications, see Appendix O, which contains a draft letter report from PADEP dated September 24, 1997.

State of Ohio

The State of Ohio's Environmental Protection Agency has adopted a policy for the "Beneficial Use of Nontoxic Bottom Ash, Fly Ash and Spent Foundry Sand, and Other Exempt Wastes."[179] This policy specifies testing requirements to determine if the material is "nontoxic," and creates tiered regulatory oversight requirements depending on the results of the tests performed on the material being considered for beneficial use. In this tiered approach, beneficial use of a waste covered by the policy does not require a permit from the Ohio EPA, except under certain specified conditions, so long as the application complies with the provisions of the policy.[180] The policy does, however, require a plan approval (permit) for land applications in which the material is being used for nutrient benefits, soil conditioning, or agronomic liming.[181]

The Ohio definition of nontoxic as used in the policy is as follows:

> "Nontoxic Bottom Ash, Fly Ash and Spent Foundry Sand" means bottom ash and fly ash generated by fuel burning operations which burn as fuel primarily coal, and spent foundry sand generated from foundry operations, where the leachate (from either an acid or deionized water extraction of the material, as determined in accordance with the testing procedures described in this policy) does not exceed thirty times the levels

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[179] Ohio Environmental Protection Agency, Policy Number DSW 0400.007, November 7, 1994.

[180] *Ibid*. p. 2.

[181] *Ibid*.

> specified in O. A. C. Rule 3745-81-11(B) for any parameter listed in the following table.
>
> | Parameter | 3745-81-11(B) Ohio Primary Maximum Contaminant Levels (Drinking Water Standards, or DWS) (mg/L) | Nontoxic Criteria = 30x Standard (mg/L) |
> |---|---|---|
> | Arsenic | 0.05 | 1.5 |
> | Barium | 2.00 | 60.0 |
> | Cadmium | 0.0005 | 0.15 |
> | Chromium | 0.1 | 3.0 |
> | Lead | 0.05** | 1.5 |
> | Mercury | 0.002 | 0.06 |
> | Selenium | 0.05 | * |
>
> * For a bottom ash, fly ash or spent foundry sand to be considered nontoxic, the selenium concentration in the leachate may not exceed 1 mg/L.
> ** This is an action level, not a primary maximum contaminant level. For purpose of this policy, this number will be referenced as a drinking water standard (DWS).
>
> The term "nontoxic" is used only to refer directly to these three wastes (when the leachate meets this criterion).[182]

The testing, using either an acid or deionized water extraction, must be performed in accordance with specified sampling methods and use either the Toxicity Characteristic Leaching Procedure (TCLP, USEPA Method 1311) or deionized water solution specified in ASTM D3987-85. Discretion is provided in selecting the leaching method to be used such that it best represents the end use of the waste. Whichever method is selected, it must be used in all subsequent tests of the material. At least three tests of the material being considered for beneficial use are required.[183] The policy specifies that additional testing, annually at a minimum, must be performed to be able to continue beneficial use; if the production process or raw materials used in the production process change, however, an analysis must be conducted and submitted to the Ohio EPA. The routine annual testing results may not be required to be sent to the Ohio EPA, although the generator must retain the test results for at least five years and provide Ohio EPA access to the results. If any subsequent testing shows that a parameter exceeds the nontoxic criteria it must be reported immediately to the Ohio EPA.[184]

The policy document defines beneficial use as follows:

> "Beneficial Use" means the environmentally sound and technically feasible use of waste materials as products or raw materials in lieu of a competing product or raw material in accordance with the conditions outlined in this policy or in accordance with conditions specified by the Ohio EPA. Beneficial use is not disposal and does

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[182] *Ibid*. pp. 3&4.

[183] *Ibid*. pp. 4&5.

[184] *Ibid*. p. 6.

> not normally require a permit to use the material from the Ohio Environmental Protection Agency...The term does not include valley fills (filling low areas of land for any purpose, e.g. flood control, unplanned but potential future development, aesthetic reasons, etc., other than what is defined by this policy as a beneficial use), or the use of waste covered by this policy to fill open pits from coal or industrial mineral mining.[185]

The Ohio policy has established four (4) categories, or tiers, of regulatory oversight, as follows:

> "Category 1" means beneficial uses, indicated with an "x" in the table on Page 7 of 13, that do not require Ohio EPA review or notification. "General Requirements" apply.
>
> "Category 2" means beneficial uses, indicated with an "o" in the table on Page 7 of 13, that do not require prior Ohio EPA review, where "Isolation Distances," "Other Criteria," and "Annual Report" apply. Examples: certain volumes of waste as structural fill; pipe bedding; roads/parking lots, and borrow pits.
>
> "Category 3" means beneficial uses, indicated with an "xx" in the table on Page 7 of 13, of certain volumes of waste as structural fill, where "Isolation Distances," "Other Criteria," and a "30-day Prior Notification to Ohio EPA" apply.
>
> "Category 4" means beneficial uses not categorized or listed in this policy, where a 60-day prior notification of Ohio EPA is required. Ohio EPA consent is required to proceed.[186]

The table referenced in the above definitions is reproduced herein as Exhibit 8- 5.

The "General Requirements" applicable to all beneficial use projects are as follows:

> 1. The use shall not create a nuisance condition. The waste may not be used in a manner that is likely to cause an adverse impact to public health or the environment.
>
> 2. Storage piles at the site or facility where the material will be used or stored prior to use shall not create a nuisance. Erosion control practices shall be used for the pile. Runoff should be eliminated or handled appropriately. Runoff at the generator must be handled pursuant to a general or individual NPDES permit.

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[185] *Ibid*. p. 3.

[186] *Ibid*. p. 4.

3. Waste may not be beneficially used, without a permit, in projects which would include placing the waste in a stream bed, wetland, leach field or well. However, manufactured products (e.g., concrete) may be used for engineered construction projects (e.g., bridge building), where the product might be placed in a stream.[187]

The " Annual Report" requirements are as follows:

> For Category 2, each applying facility shall submit an annual report to the appropriate (generator's) Ohio EPA district office. A copy shall be sent to the Ohio EPA Central Office, Permits Section. The annual report shall be submitted by April 1 and shall include a summary of each beneficial use project completed during the previous calendar year. Each project summary shall include, at a minimum:
>
> a. a description of the nature, purpose, and location of the project;
> b. type of waste and estimated volume of waste used; and
> c. the leachate test results.[188]

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[187] *Ibid*. pp. 9&10.

[188] *Ibid*. p. 10.

EXHIBIT 8-5
OHIO BENEFICIAL USE POLICY

Source: Ohio Environmental Protection Agency, Policy Number DSW 0400.007, November 7, 1994.

The "Isolation Distances" requirements are as follows:

> Unless otherwise approved by the Ohio EPA, for Category 1 (only as noted in the Table on Page 7), and all uses in Categories 2 and 3, wastes may not be placed within:
>
> 1. 100 feet of any intermittent or perennial streams, unless the waste is otherwise protected by a properly engineered diversion or structure.
>
> 2. 300 feet of any drinking water well, including a well used for livestock watering;
>
> 3. a regulatory floodplain unless a properly engineered dike, levee or other structure that can protect the structural fill from a 100 year flood.
>
> 4. 5 feet above the aquifer system used as the primary source of water to wells within 2500 feet of the beneficial use site;
>
> 5. 100 feet of any wetland.[189]

The "Other Criteria," applicable to all uses in category 2 and 3 are as follows:

1. Surface runoff from the fill area is minimized during filling and construction activity. Erosion and sediment control measures are implemented in accordance with sound engineering practices. Run-on from adjacent areas must be diverted around the site.

2. Structural fill shall be covered with a minimum of 12 inches of compacted soil or an unspecified thickness of asphalt or concrete.[190]

The "30-Day Notification," applicable to all category 3 uses are as follows:

> At least 30 calendar days before initiating the proposed project, the person proposing such use shall submit a written notice to the Ohio EPA Division of Surface Water. Ohio EPA Division of Surface Water shall notify, in a timely manner, the applicant if there appear to be any problems with or deficiencies of the beneficial use request. Consent of the Ohio EPA Division of Surface Water is not required; however, Ohio EPA Division of Surface Water may request more information or, if environmental problems seem likely, require that an alternative use be found.

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[189] *Ibid*.

[190] *Ibid*.

> The notice shall contain, at a minimum:
>
> 1. A description of the nature, purpose, and location of the project, including a topographic map showing limits of waste placement, the project area, including any wells, springs, streams, and a wetland determination within 1,000 feet, and any available soil maps of the project area.
>
> 2. The estimated beginning and ending dates for the project.
>
> 3. Construction plans for the structural fill, including a stability analysis when necessary, prepared by a registered (in Ohio) professional engineer in accordance with sound engineering practice and signed and sealed by the engineer.
>
> 4. An estimate of the volume of nontoxic bottom ash, fly ash, or spent foundry sand to be used for the project.
>
> 5. A leaching analysis for the material to be used in the project, in accordance with the testing procedures described in this policy.
>
> If the TCLP test indicates that a nontoxic bottom ash or foundry sand leachate consistently meets Ohio's Primary Maximum Contaminant Levels for public water systems, then no notice is required. Project summaries shall be submitted annually as described in the previous section.[191]

The "Category 4" requirements are as follows:

> Except for those uses that are defined in this policy, no person shall manage a nontoxic bottom ash, fly ash, or spent foundry sand, or other exempt waste (including residual wastes) for any beneficial use unless such person has first requested and received written approval from the Ohio EPA Division of Surface Water, or other appropriate division(s) of the Agency.
>
> A request for approval of beneficial use under this policy shall be on forms provided by the Ohio EPA Division of Surface Water (Attachment 1), shall be complete, received at least 60 days prior to the proposed use, and shall:
>
> 1. Chemically and physically characterize the material and identify the quantity, quality, and source of material to be used.
>
> 2. Describe the proposed method of application and demonstrate the beneficial use of the material.

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[191] *Ibid*. pp. 9&10.

3. Demonstrate that the intended use will not adversely affect public health or the environment.

4. If the Ohio EPA Division of Surface Water consents to a beneficial use request the Ohio EPA may:

    a. Limit the type, source, or amount of material to be used.

    b. Limit the term of the approval.

    c. Require the submission of an annual analysis or other appropriate information to ensure that the quality of the material to be beneficially used remains consistent with that stated in the approval.

    d. Include any other conditions the Ohio EPA Division of Surface Water believes appropriate.

5. The Ohio EPA Division of Surface Water, after considering the potential for water pollution, shall notify the applicant of the final determination on each beneficial use request in a timely manner.

6. The Ohio EPA may require discontinuation of a beneficial use if it is found that the beneficial use is being conducted in a manner inconsistent with the original request, or whenever the beneficial use is adversely affecting public health or the environment.

The Ohio policy is designed to provide increased regulatory oversight as the quantity and quality of the FFCB varies. For instance, if the leaching tests show that the leachate meets the Drinking Water Standards (DWS) only those projects with over 30,000 tons of FFCBs used in a properly engineered structural fill would require a "30-Day Prior Notification" to the Ohio EPA and maintaining "Isolation Distances" and "Other Requirements" specified in the policy. In the case of the FFCB leachate being in the range of 5x to 20x DWS the same regulatory oversight is required for between 600 and 30,000 tons. In the case where the FFCB's leachate is more than 20x but less than 30x DWS full Category 4 review is required. In this instance, the regulatory oversight extends beyond the requirements shown above in the following areas:

<u>Receiver Notification</u>

For generator give-away/sell programs, each receiver shall be informed of the nature of the waste and that the waste may contaminate water if water is in prolonged

> contact with the waste. This notification shall be in the form of an information sheet or label.[192]
>
> Requests for Information
>
> The Ohio EPA may at any reasonable time request all relevant documents and other relevant information necessary to demonstrate hat an ongoing or proposed beneficial use of waste is being, or will be, conducted in a manner that is consistent with this policy.
>
> Failure to have documentation of compliance with this policy available after initiation of a claimed beneficial use may be cause for Ohio EPA to require discontinuation of the use.[193]

The above two provisions provide additional warning to the public about the improper use of FFCBs and provide the Ohio EPA with enforcement powers if the policy is not be followed. Lastly, the Ohio EPA has flexibility in its policy to deviate from the standards "[i]f an applicant can affirmatively demonstrate to the Ohio EPA Division of Surface Water that the nontoxic bottom ash, fly ash, or spent foundry sand or other exempt waste (including residual wastes) will not adversely impact the public health or the environment..."[194]

State of California

The State of California is another example of a state with a tiered regulatory program. The California Integrated Waste Management Board ("CIWMB") is responsible for determining the correct level of regulatory oversight for solid wastes generated and managed in the state. Under the CIWMB process five tiers of regulatory oversight have been established and all solid wastes are being evaluated for placement within the tiers. The five tiers are as follows:

> Excluded Tier
> Enforcement Agency Notification Tier
> Standardized Tier
> Regulation Tier
> Full Permit Tier

with, as the titles imply, an increasing level of regulatory oversight.

Until the State of California began its process of categorizing wastes to various levels of regulatory oversight the only option available to CIWMB was

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[192] *Ibid*. p. 11.

[193] *Ibid*. p. 12.

[194] *Ibid*. p. 11.

> ...a full solid waste facilities permit regardless of the operation's impact on public health, safety and the environment. Applying this "one-size-fits-all" permit to a wide range of solid waste operations has resulted in confusion among the regulated community and enforcement agencies, creating uneven application of statutory and regulatory requirements throughout the state. In some cases a solid waste facilities permit has been issued, in others it has not. To remedy the problems associated with a "one-size-fits-all" permit system, the Board adopted regulations which establish a new flexible regulatory tier structure. These regulations did not place any solid waste operations into a tier; instead, placement into the regulatory tiers is to be undertaken though separate rulemakings for different types of operations.
>
> To ensure that placement of different types of operations or facilities into the regulatory tiers is treated consistently statewide and addresses the diversity of operations that fall under CIWMB jurisdiction, a public advisory body was convened to assist in the development of a general methodology. At its March 29, 1995 general business meeting, the CIWMB approved a process for determining CIWMB authority for types of operations and a general methodology for determining placement of those operations where the CIWMB has authority. The methodology uses environmental indicators and their associated mitigation measures to help determine placement within the regulatory tiers, and addresses existing levels of regulatory oversight by other agencies to reduce overlap and duplication...[195]

To determine what regulatory tier was appropriate for "nonhazardous ash operations" the CIWMB conducted public workshops beginning in March 1996 to solicit input from all stakeholders. As a result of the several public workshops, and written and oral comments from stakeholders, a draft set of regulations was prepared and publicly noticed in the fall of 1996. In December 1996, a workgroup meeting was held with industry representatives, local enforcement agencies, and other interested parties to determine threshold levels between beneficial reuse and disposal.

California's definition of nonhazardous ash is: "...the nonhazardous residue from the combustion of any nonhazardous solid or liquid materials pursuant to the California Code of Regulations, Title 22 or which may be managed as a nonhazardous waste as approved by the Department of Toxic Substances Control."[196]

The regulations for nonhazardous ash operations being developed in 1996 by the CIWMB included regulations for the land application of nonhazardous ash. The draft regulations proposed to use EPA's 40 CFR Part 503 clean sludge metal loading limits.[197] During the public review process, the 503 limits for molybdenum and selenium were questioned as being appropriate due to soil conditions found in a limited region in California. As a result of this questioning, a "peer review" of both the 503

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[195] California Integrated Waste Management Board, Board Meeting, May 28, 1997, Agenda Item 42, pp. 318&319.

[196] *Ibid.*, p. 326.

[197] Tables 1-4, 40 CFR §503.13.

limits and proposed more restrictive limits was conducted. While the peer review was being completed, the CIWMB planned to continue to use the EPA 503 levels in its regulations.

In January 1997, the California Department of Food and Agriculture ("CDFA") requested that the CIWMB remove the land application of nonhazardous ash operations from the regulatory tiers since CDFA held primary responsibility for the protection of the public due to agricultural operations, such as fertilizer regulation. Subsequently, the staffs of CDFA and CIWMB discussed the existing regulatory and proposed regulatory programs for overlaps, concerns regarding health and safety, and any gaps existing with the science. As a result of these staff discussions, and correspondence between the CDFA and CIWMB it was concluded by the CIWMB that the existing regulatory program of the CDFA would adequately address the use of nonhazardous ash in agriculture.

At the May 28, 1997 CIWMB Board Meeting regulations were adopted that placed certain nonhazardous ash use operations outside of the regulatory tier framework. Among the activities placed outside the regulatory tier was land application of nonhazardous ash. Exhibit 8-6 is a copy of the placement of various nonhazardous ash activities in the regulatory tiers as a result of the May 28, 1997 CIWMB Board Meeting. A full copy of the text of the regulations adopted at the May 28, 1997 Board Meeting is contained in Appendix P.

EXHIBIT 8-6

NONHAZARDOUS ASH OPERATIONS AND FACILITIES PLACEMENT INTO THE REGULATORY TIERS

Not Subject to Article 5.6	Excluded Tier	Enforcement Agency Notification Tier	Standardized Tier
Manufacturing	Transfer/Processing Specified in Section 17377.1	Transfer/Processing Operations	Disposal/Monofill
Uses Specified in Section 17376(b)(5)	Weathertight Storage		
Stockpiling as Specified in Section 17376(b)(2)			
Daily Cover			

There are no operations or facilities placed within the Registration and Full Permit tiers within this Article.

Associated with the regulations adopted at the May 28, 1997 CIWMB Board Meeting the CIWMB has developed a "Standardized Nonhazardous Ash Solid Waste Facility Permit" application form for use in securing the necessary permits for some operations. The CIWMB staff is also developing a "Local Enforcement Agency Advisory" providing guidance for handling agricultural land application of nonhazardous ash.

This example of how California is regulating nonhazardous ash is illustrative of the level of science and regulatory oversight that is being applied by the various states to the management of FFCBs.

Federal Initiatives

In addition to the state regulations governing the beneficial use of FFCBs the federal government has undertaken actions to encourage the use of these materials. For example:

> The federal government has promoted CCB reuse through a variety of initiatives. In 1983, EPA promulgated the first federal procurement guideline that required agencies using federal funds to implement a preference program favoring the purchase of cement and concrete containing fly ash. 40 C. F. R. Part 249. The EPA endorses the use of pozzolans, such as coal ash, as the preferred method for stabilizing certain metal bearing wastes. 52 *Federal Register* 29992.[198]
>
> Most recently, Executive Order No. 12973, *Federal Acquisition, Recycling and Waste Prevention*, 58 *Federal Register* 54911 (October 22, 1993), directs federal agencies to develop affirmative procurement programs for environmentally preferable products and requires EPA to issue guidance on principles agencies should use in making determinations for the preference and purchase of environmentally preferable products. EPA has in response proposed a Comprehensive Procurement Guideline (CPG) designating items that can be made with recovered materials, including fly ash. 59 *Federal Register* 18852 (April 20, 1994).[199]

8.4 Summary and Conclusions

From the foregoing, it is clear that a number of federal and state statutes and enabling regulations serve to stimulate the beneficial use of fossil fuel combustion by-products, and to control the manner in which they are managed.

Federal programs designed to limit contaminant releases into environmental media (principally air and water) have led to a direct increase in the quantities of solid pollution control residues that are generated and need to be managed. Recently enacted regulations to further limit small particles and ground-level ozone will likely increase FFCB (and other air pollution control residue) generation further. Additional federal imperatives to prevent pollution have limited implications for fossil fuel

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[198] *Op. cit.* p. 3.

[199] *Ibid*.

use, in that generation of ash is an inevitable consequence of energy recovery through combustion. At the same time, however, numerous opportunities exist for the recovery and reuse (the next preferred alternative) of these materials. Federal water pollution control requirements would seem to adequately address both point and non-point (stormwater) discharges of FFCBs and their constituents to surface water bodies.

State-level regulations are emerging that appear to address the most common concerns that appear in the management of solid residual materials. The CIBO Special Project has conducted a detailed survey on state waste disposal regulations, and has documented that virtually all of the state programs responding have a regulatory structure in place to control environmental and human health risks associated with improper land disposal of solid wastes. Common elements include permitting, use of liners, leachate collection, ground water monitoring, fugitive dust suppression, and other contaminant release mechanisms. These elements are either imposed uniformly, or in many cases, are considered on a case-by-case (site-specific) basis. In addition, a number of significant state programs have emerged that address the use of residual materials (including FFCBs) in productive applications (e.g., agriculture, structural fill, waste stabilization). Many of these programs require material testing, submittal of a detailed use plan, and other information from the prospective user, so as to ensure that the use is appropriate and adequately protective of human health and the environment.

The CIBO Special Project believes that this network of federal and state regulatory controls provides adequate assurance that FFCBs will be used and disposed in an acceptable and environmentally sound manner, and that further controls under RCRA would be both unnecessary and redundant.

CHAPTER NINE

ALTERNATIVE DISPOSAL PRACTICES AND COSTS

9.0 Introduction

This chapter describes the types of FBCB disposal practices that could potentially be mandated by EPA, should the Agency decide that current practices are inadequate, and presents a preliminary analysis of facility-level costs that such mandates would impose upon the owners and operators of FBC units. Section 9.1 provides a brief description of the general elements of engineered units that are designed for the permanent, environmentally sound disposal of solid materials in land-based units (landfills). Section 9.2 delineates the basic elements of the landfill design and operating standards that have been promulgated by EPA for the management of municipal solid waste (MSW) and for RCRA hazardous wastes and how these requirements might be applied to FBCBs. EPA's standards for MSW and hazardous waste management are codified at 40 CFR Part 258 and Part 264, respectively. Section 9.3 presents our analysis of the costs of imposing either of these two sets of regulatory requirements on the management of FBCBs. Finally, the associated economic impacts from these prospective regulatory controls are examined in Section 9.4.

9.1 Alternative Land Disposal Practices

As described above in Chapter 5, FBCBs that are not sent to productive use applications are generally disposed in on-site disposal units. Most of these units have been constructed specifically for this purpose, and may have a variety of features that serve to limit constituent migration from the disposed material into the environment. Most of these units have been designed, constructed, and operated in accordance with state-level requirements and have been permitted under state law. In general, however, these requirements and the associated practices that have been applied to FBCB disposal are not as comprehensive as those mandated by federal hazardous waste landfill standards. While several units incorporate the use of synthetic and/or recompacted clay liners and many more have other contaminant release controls, most units in current use do not include the full array of engineered controls and operating practices that may be employed to limit or prevent contaminant migration.

The remainder of this section discusses, in general terms, additional design and operating practices that may be used at engineered landfills. The specifics of landfill design actually vary widely from site to site depending on numerous factors such as the intrinsic hazardous nature of the waste; the requirements imposed by various federal, state, and local regulations; the climate and hydrogeology of the site; the resource value of the underlying ground water; the proximity of nearby populations and endangered species; and the location of the site relative to sensitive environments such as floodplains, seismic impact zones, and wetlands.

Engineered landfills often are designed with run-on control systems. Run-on from adjacent property can increase the amount of water percolating into the landfill and contribute to leachate formation; leachate is liquid that has percolated through the wastes and extracted dissolved or suspended materials. Run-on can be controlled through construction of diversion ditches, trench drains, and other devices. Typically, run-on control systems are designed to prevent flow onto the active portion of the landfill during the peak discharge from a 25-year storm. Well-designed landfills also have run-off control systems to prevent surface run-off from the site from entering nearby areas and streams. Run-off control systems are typically designed to collect and control the water volume resulting from a 24-hour, 25-year storm.

Engineered landfills also may be equipped with components that contain and remove leachate. Liner systems are frequently installed prior to placement of wastes in landfills to prevent leachate from entering ground water. Liner systems are constructed with low-permeability soils and/or synthetic materials that are sloped to divert the leachate to underdrain pipes, which collect the leachate for treatment; these are known as leachate collection systems (LCS). Liner configurations frequently used include a single layer of compacted clay; a flexible membrane liner (FML) made of high density polyethylene (HDPE) or other material underlying a LCS; a "composite" liner system consisting of a LCS and FML overlying a two- to three-foot layer of compacted clay; and a "triple" liner system consisting of two FMLs with LCSs above and between them, overlying a layer of compacted clay. Well-designed LCSs maintain less than a 30-cm depth of leachate over the liner. All components of the liner and LCS must be constructed of materials that have appropriate chemical properties and sufficient strength and thickness to prevent failure due to pressure gradients, physical contact with the waste and leachate, and other stresses.

Landfills equipped with leachate collection systems must also have mechanisms in place for leachate treatment and disposal. Frequently, collected leachate is recirculated back into the landfill. Alternatively, leachate may be treated on site and then discharged to a surface water body. A third alternative is to discharge the leachate to a municipal wastewater treatment plant with or without prior treatment, depending on the characteristics of the leachate and the requirements of the sewage treatment plant. Many different types of biological and physical/chemical treatment technologies are available for treating leachate prior to discharge to surface water or a wastewater treatment plant. Discharges of collected leachate and run-off to surface water must be performed in accordance with National Pollutant Discharge Elimination System (NPDES) requirements established pursuant to Section 402 of the Clean Water Act.

Ground-water monitoring is frequently conducted to detect leachate releases from landfills and evaluate the degree and significance of resultant ground-water contamination. Effective monitoring well systems must comprise a sufficient number of appropriately located wells able to yield ground-water samples that represent the quality of background ground water and the quality of ground water downgradient of the fill area. The number, spacing, and depths of monitoring wells are based on site-specific characteristics. Samples are collected periodically and analyzed for hazardous constituents or for parameters that indicate that a release has occurred. Statistical analysis of the samples is performed to help determine whether a release has occurred and the nature and extent of the contamination. Operators of some landfills also conduct monitoring of surface water, soils, and air.

If contamination is significant, corrective action is taken to clean up the environment to the extent feasible. Many different types of ground-water corrective action technologies are available, including source controls to minimize further releases (e.g., excavation of the waste, placing a low-permeability cap over the fill area); ground-water recovery wells that remove ground water from the subsurface and treat it to reduce contaminant levels; and slurry walls, which restrict ground-water flow and thereby minimize further spread of the contamination. The technical feasibility, costs, and effectiveness of these technologies vary widely from site to site.

Closure and post-closure care are important components of environmentally protective landfill management. When a landfill (or a portion of the landfill) is filled to capacity, a final cover is installed to minimize infiltration and erosion. The cover may consist simply of vegetated top soil. More sophisticated covers also contain a liner made of polyvinyl chloride (PVC) or other synthetic material underlying a drainage collection system; "composite" cover systems also include a two-foot clay layer. The cover should be designed with a permeability less than or equal to the permeability of the bottom liner system or natural subsoils to prevent ponding at the bottom of the landfill. After the landfill is closed, post-closure care is conducted for many years. Post-closure care activities typically include maintenance of the integrity of the landfill cover, operation of the LCS, and monitoring of ground water.

A wide variety of additional design and operating features are practiced at landfills, including access controls (e.g., installation of fences to prevent public exposure to hazards), the use of daily cover (covering each day's fill with soil, tarps, or other similar materials to prevent dust from blowing), and others. The degree of latitude that a landfill owner or operator may exercise in selecting among the environmental controls discussed above depends largely on the regulatory status of the landfill. Without federal or state requirements, the need for these controls depends on the characteristics of the waste and the environmental and exposure characteristics of the waste disposal site.

9.2 Potential Regulatory Alternatives

In EPA's three-step decision-making process, costs and economic impacts of regulatory alternatives are evaluated only if new RCRA regulatory controls might be warranted. Based upon the information provided in the preceding chapters, the CIBO Special Project believes that there is no factual basis that would lead to such a determination. Nonetheless, to present a complete analysis and more fully inform EPA's decision making, we have performed a simulation of likely regulatory impacts. Moreover, Section 8002(n)(5) of RCRA requires EPA to analyze "alternatives to current disposal methods" for materials generated from the combustion of coal and other fossil fuels, while Section 8002(n)(6) requires the Agency to analyze "the costs of such alternatives" and Section 8002(n)(7) directs EPA to address "the impact of those alternatives on the use of coal and other natural resources."

This section describes two alternative disposal practices for FBCBs that could be imposed by EPA should the Agency withdraw these materials from the Bevill Exclusion. The prospective costs and economic impacts associated with imposing these alternatives are examined in Sections 9.3 and 9.4, respectively. This analysis draws on the information presented above and in preceding chapters addressing current management practices and potential management alternatives. The approaches and analytical methods used in preparing the material that follows are patterned closely upon previous EPA studies of special wastes. Accordingly, the predicted cost and economic impacts described below should be fully consistent with those developed in support of previous regulatory determinations and be of direct relevance to the Agency's decision making process.

The waste management practices discussed in this report reflect the range of practices that are currently employed to manage FBC FBCB as well as alternative management techniques that could be imposed by EPA through a withdrawal of special waste status. These practices fall into two basic categories: (1) current practices; and (2) alternative land disposal practices.

9.2.1 Current Practices

The major current practices that are applied to FBCB from FBC fall into two basic categories, which are discussed below: 1) off-site beneficial use; and 2) on-site land disposal. Both of these approaches to FBCB management confer economic benefit to or impose costs on the facility owners or operators that employ them. Our evaluation of alternative FBCB management methods and their costs builds upon an understanding of the current, or baseline, practices for FBCB management that are described in this section.

Off-Site Beneficial Use

As discussed above, FBCBs may be used for a number of off-site beneficial purposes, including stabilizing wastes, liming farmland, neutralizing waste acids, and most importantly, reclaiming mined lands. Currently, productive use applications account for nearly 75 percent of the FBCB generated by FBC units, according to 1996 CIBO Special Project Survey data. The vast majority of the more than three million tons per year of FBCB generated and used by this group of facilities in recent time has gone to reclaim previously mined lands. In fact, a number of FBC installations that have been developed during the past 20 years have explicitly been planned so as to make use of the combustion FBCB to recontour mined areas and neutralize acid drainage and run-off from historical coal mining activities. While these productive applications do not, in many cases, generate additional revenues for the plant operator, they do provide environmental benefits and may reduce or eliminate operating costs that would otherwise be incurred by other reuse or disposal methods.

For purposes of analysis, we have assumed that the activities needed to prepare and use FBCBs to reclaim mined land impose a total cost on the operator that is equivalent to the cost of placing the material in unlined on-site disposal units (i.e., $4/short ton as described below). Our estimate reflects anticipated capital charges (e.g., for mobile heavy equipment) as well as operating and maintenance (O&M) costs, such as vehicle maintenance, fuel, operator labor, supervision, etc.

Current Land Disposal Practices

Approximately one-half of the respondents to the 1996 Survey report disposing some or all of their FBC FBCB, almost all of it in on-site units. In total, quantities disposed account for about 26 percent of the reported quantities generated. Facilities relying on on-site disposal typically employ FBCB monofills for this purpose, though some operators (particularly those in industrial settings) co-dispose their FBCB with other waste streams generated on- or off-site. For simplicity, we have employed a uniform assumption of a $4/short ton disposal cost for managing combustion FBCB in on-site disposal units. This cost estimate is based upon previous EPA work on an analogous high-volume solid waste (cement kiln dust), and is highly consistent with the reported on-site FBCB management costs provided by respondents to the 1996 Survey.

9.2.2 Alternative Practices

In the event of a change in the RCRA regulatory status of FBCB from FBC, it is likely that changes in existing management practices would be required at most plants to attain regulatory compliance. These modifications would likely be driven by specific regulatory requirements, which cannot be precisely defined at this time. The CIBO Special Project has prepared an analysis of the costs of two general approaches to more stringent regulation of the land disposal of FBC FBCB, which are described in this section. The regulatory framework for one of these approaches is Subtitle C of RCRA, which provides for a comprehensive system for the management of hazardous wastes. The framework for the other approach is Subtitle D of RCRA, which provides for a controls over municipal (non-hazardous) solid waste. In the analysis that follows, we have simulated the effects of imposing each of these two regulatory approaches on FBCB that is currently disposed, and also have performed an analysis of the cost impacts of requiring all FBC FBCB to disposed in conformance to these requirements (i.e., on the effects of a beneficial use ban coupled with more stringent land disposal requirements).

Subtitle C Standards

EPA regulations promulgated pursuant to RCRA Subtitle C define stringent "cradle to grave" management practices that must be applied to hazardous wastes generated and managed in the United States. Under these regulations, only carefully defined approaches to hazardous waste management are permissible, and all of these approaches are adapted to the conditions found at individual hazardous waste management sites through permits. As an inorganic solid material, only a very few options are available for the permanent disposal of fossil fuel combustion byproduct as a hazardous waste. FBCBs could be managed for short periods of time in waste piles, but long term disposal would require the use of a landfill meeting EPA-specified minimum technology standards. Accordingly, we have identified and categorized all requirements under Subtitle C that might have cost implications for the management of FBCBs in a hazardous waste landfill, including requirements related to notification, permitting, technical standards for land disposal, monitoring, closure, post-closure care, and financial responsibility. Corrective action for continuing releases due to past practices and Land Disposal Restrictions program requirements have not been included in our analysis because it is very difficult at this time to predict how these requirements might be applied by EPA to the material of interest in this study and accordingly, to estimate the associated costs. The same concern applies to the flexibility provided to EPA by RCRA §3004(x).

Subtitle D Standards

EPA has promulgated standards addressing the land disposal of municipal solid waste at 40 CFR Part 258. These regulations, while not directly germane to the management of a non-organic industrial material such as FBCB, nonetheless provide a reasonable starting point for formulating a plausible framework for a federal program addressing solid, non-hazardous wastes. The general features of EPA's program for MSW management comprise a composite (compacted clay covered by synthetic) liner, leachate collection system, run-on and run-off controls, ground water monitoring, closure, and post-closure care. The principle differences between this Subtitle D design and Subtitle C hazardous waste landfill standards have mainly to do with liner configurations, certain permitting requirements, and other design features, as well as with the absence of major Subtitle C program elements such as land disposal restrictions and corrective action requirements. Our analysis has employed a simulation of an FBCB monofill that has been designed in conformance with the Part 258 standards; hence, certain controls that apply to MSW (e.g., daily cover) have been omitted.

9.3 Costs of Regulatory Alternatives

This section consists of two sub-sections. The first describes the approach and methods used to develop the cost and impact estimates. The second presents and discusses the costs of managing FBCBs under two different sets of disposal practices.

9.3.1 Approach and Methods

This section describes how the CIBO Special Project conducted its cost analysis. A short section on the conceptual framework used for the analysis is followed by a description of the methodology used to estimate facility costs and a discussion of data sources and limitations.

In our basic analytical framework, the costs imposed by an alternative management practice are incremental and measured as the difference in cost between the current management practice (referred to hereafter as the "baseline") and the (generally different) alternative practice. This approach is fully consistent with that employed in previous RCRA Section 8002 studies.

Approach to Estimating Costs and Impacts of FBCB Management Alternatives

The CIBO Special Project's basic approach to analyzing the costs of FBCB management alternatives in this report is to estimate the financial costs of each of the two alternatives as they would be experienced by the sample of facilities using FBC technology to combust coal and/or other fossil fuels that responded to the 1996 Survey on FBCB generation and management. We developed predicted impacts by applying cost-estimating functions to the quantities of FBCB disposed and otherwise managed at the facilities in this sample (approximately 40 percent of the population of interest). This approach may be contrasted with an exhaustive analysis of the costs at every facility in the country, for which sufficient data were unavailable, and a model facility approach, which may have lacked realism for specific facilities. A disadvantage of the approach used is that in order to extrapolate the results of the cost analysis at specific facilities to estimates of nationwide costs, one must assume that the sample is representative of the industry as a whole. As described above, we believe that the respondent group represents all geographic regions in which FBC technology is applied to fossil fuels, as well as the full range of facility sizes and other characteristics that might influence the selection of appropriate FBCB management options and their costs.

Methods for Estimating Facility Costs

To calculate the costs of managing FBCBs in various ways for the plants in our sample, we applied cost-estimating functions, based on an engineering analysis of each alternative and its component operations and activities. These functions were developed to express FBCB management costs as a function of waste generation rate, and have been drawn from recent EPA work on the costs of disposing of materials analogous to FBCBs (e.g., cement kiln dust, mineral processing wastes).

In our cost estimating analysis, the first step was to estimate the costs of waste management activities and their distribution over time. The second step was to discount all future costs to the present and then calculate the equivalent annualized compliance cost or benefit. The annualized compliance cost is the average annual cost, over the assumed operating life of the facility that has the same total present value as the sum of the actual expenses incurred at their actual times. This method offers the distinct advantage of allowing comparisons among alternative technologies whose costs and benefits may be incurred at different times.

Cost estimating functions were developed from an engineering analysis of each set of disposal practices and were generally based on empirical data. The sum of the costs of each element equals the total facility cost for a particular FBCB disposal strategy. In all cases, our cost estimating procedures consider both initial capital investment costs and annual operating and maintenance (O&M) costs (e.g., materials, labor, and utilities). Detailed results are expressed as annualized total costs, total and annualized capital costs, and unit costs (e.g., cost per unit of waste or product). These detailed results are provided in Appendix Q to this document. For clarity, this chapter includes only the annualized total costs and unit costs.

Beyond the typical cost categories (capital and O&M) that apply to all capital investments, two additional categories of costs may apply to material disposal under RCRA regulations. In one category are the capital costs for disposal facility closure and annual costs of post-closure care and maintenance, which are simply capital and O&M costs that are incurred in the future, beginning at facility closure. In the other category are the costs associated with potential corrective actions for solid waste management units that release hazardous constituents to the environment. The CIBO Special Project has not included the costs of corrective action in this impact analysis due to the wide range of uncertainty associated with predicting the magnitude, distribution, and timing of these potential costs.

Costing Functions and Their Application

The preliminary regulatory cost estimates presented in this chapter were calculated using recent data drawn from the 1996 Survey and some cost curves. Quantities of FBCBs reporting to disposal were developed in the following way. The reported quantities of FBCB generated and disposed in 1993, 1994, and 1995 were averaged to yield average FBCB quantities generated and disposed at each facility. For facilities with data reflecting only one or two years, averages were calculated using only reported non-zero quantities. That is, we did not include zero values in calculations of average quantities generated and disposed. As stated above, we have developed cost estimates based upon recent and current disposal practices in the primary analysis of impact, and also have simulated the operational and cost impacts of a ban on productive or beneficial uses of FBCB. Obviously, in the latter scenario, the quantities of FBCB disposed, and the number of facilities affected both increase substantially, as do total and facility average cost impacts.

Baseline costs were calculated assuming a $4/short ton on-site disposal cost. This cost estimate is drawn from recent EPA work on an analogous high volume waste (CKD) and is consistent with the facility-level data provided by 1996 Survey respondents. In addition, because use of FBCB in mine reclamation is one of the predominant uses of FBCB which is not included in the disposal category, and because the cost of disposing on-site is similar to the cost of using FBCB in mine reclamation, the $4/ton disposal cost was applied to the FBCB quantities examined in both sets of regulatory scenarios.

Subtitle C disposal costs were calculated using a set of landfill equations incorporating the initial capital, annual capital, annual O & M costs, closure, post closure care, and cover replacement costs associated with designing, constructing, operating, closing, and maintaining a Subtitle C landfill. To reflect facility-level scale economies, we evaluated the point at which off-site waste disposal would be a more economical option than constructing and operating a unit on site. Drawing upon recent work and available data, we employed an off-site Subtitle C disposal cost of $113/short ton. The break-even point between on- and off-site disposal was 21,243 tons/yr. That is, at disposal rates greater than this value, we assumed that the material would be managed on site, and at rates below this level, it would be sent off-site to a commercial landfill.

Subtitle D disposal costs were calculated by adapting a costing model developed by ICF Kaiser for EPA to simulate the costs of applying new landfill standards to cement kiln dust (CKD). In this exercise, we took the results of an application simulating Part 258 controls on CKD disposal over a range of waste disposal rates, and fit a curve through the data representing total annualized costs as a function of waste disposal rate. The resulting equation served as the costing function for the present analysis. As in the evaluation of Subtitle C costs, we evaluated the point at which off-site waste disposal would be a more economical option than constructing and operating a unit on site. Drawing upon recent work and available data, we employed an off-site Subtitle D disposal cost of $45.48/ton. The break-even point between on- and off-site disposal was 6,656 tons/yr.

Cost Accounting Assumptions

Costs of regulations can be viewed in two contexts: economic and financial. The two perspectives consider regulatory costs in two very different ways for different purposes. The economic context considers impacts on resource allocation for the economy as a whole, while the financial context evaluates private sector effects on facilities, firms, and other discrete entities. For this report, the CIBO Special Project has focused on the financial context (i.e., impacts on facilities and industries), in keeping with the statutory directives articulated at RCRA §8002(n) and past EPA practice, by evaluating the costs of alternative management practices and their anticipated effects on several of the affected industries.

Consequently, in conducting this analysis, we have employed data and cost accounting assumptions that reflect the viewpoint of boiler operators. For example, we have employed a discount rate (7 percent) that, in theory, approximates the likely cost of obtaining financing for regulatory compliance-related expenditures, rather than a "social" discount rate, or cost to society. This discount rate is based on current guidance issued by the Office of Management and Budget[200] for analyses of regulatory impact, and is consistent with recent analyses of proposed rules issued by EPA's Office of Solid Waste. Similarly, costs and benefits have been calculated on a before-tax basis, to provide a consistent basis from which to evaluate the ability of affected operators to pass through regulatory compliance costs to downstream customers and/or upstream suppliers.

9.3.2 Costing Results

In this sub-section, we first describe the results obtained from simulating the application of Subtitle C and Subtitle D landfill standards to the facilities disposing FBCBs in land-based units. We then present the prospective cost impacts of requiring disposal of all FBCBs in accordance with Subtitle C and Subtitle D standards.

<u>Quantities Currently Disposed - Subtitle C Cost Study</u>

Facility-level cost impacts assuming Subtitle C landfill disposal are presented in Exhibit 9-1. Annualized costs for 12 of the 19 facilities that currently dispose FBCBs exceed $1 million, and for these 12 facilities, range from about $1.9 million to more than $13 million over and above baseline waste management costs. As a group, the 19 facilities have a projected weighted average incremental cost of about $8.7 million per facility per year. That is, post-compliance weighted average management costs are about $9.6 million, as compared with baseline costs of about $900,000. This represents a ten-fold increase in FBCB disposal costs. The remaining seven facilities dispose of substantially smaller quantities of combustion FBCB, and their projected incremental costs range from about $100,000 (at two facilities) to almost $1 million per year. Unit costs for Subtitle C compliance range from $31/ton to the off-site (incremental) commercial disposal cost of $109/ton. The weighted average incremental management cost of $49/ton is more than ten times the current (baseline) material management cost of $4/ton.

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[200] OMB, 1992. Circular A-94.

EXHIBIT 9-1

REPORTED QUANTITIES DISPOSED - SUBTITLE C COMPLIANCE COST STUDY

Facility ID	SIC	Average Disposed (tons)	Baseline Cost ($ 000)	Subtitle C Cost ($ 000)	Incremental Cost ($ 000)	Incremental Cost/ton[*] ($)
Plant #08	2075	122,449	490	7,000	6,510	53
Plant #12	2075	431,502	1,700	15,000	13,300	31
Plant #13	2075	6,423	26	720	694	108
Plant #30	2075	1,000	4	110	106	106
Plant #20	2621	64,500	260	4,800	4,540	70
Plant #35	2621	94,033	380	6,000	5,620	60
Plant #07	4910	6,467	26	730	704	109
Plant #39	4910	45,473	180	3,900	3,720	82
Plant #06	4911	168,046	670	8,500	7,830	47
Plant #29	4911	46,172	180	3,900	3,720	81
Plant #36	4911	17,513	70	2,000	1,930	110
Plant #38	4911	255,189	1,000	11,000	10,000	39
Plant #42	4911	87,045	350	5,700	5,350	61
Plant #01	4931	26,840	110	2,900	2,790	104
Plant #23	4931	188,421	750	9,100	8,350	44
Plant #37	4931	2,185	9	250	241	110
Plant #14	8221	8,867	35	1,000	965	109
Plant #22	8221	936	4	110	106	114
Plant #43	9199	4,800	19	540	521	109
Total		1,577,860	6,262	83,260	76,998	
Average		83,045	330	4,382	4,053	81
Wt. Avg.			892	9,596	8,705	49
Maximum		431,502	1,700	15,000	13,300	114

[*] Note: Rounding errors in calculating the unit cost produce an increment that, in a few cases, exceeds the expected maximum of $41, i.e., $45.-$4.

Quantities Currently Disposed - Subtitle D Cost Study

Estimated costs of FBCB management under Subtitle D landfill standards are presented in Exhibit 9-2. Projected incremental FBCB management costs range from about $40,000 to $6.6 million, with a weighted average value of nearly $3.7 million annually, for the 19 FBCB-disposing facilities within the survey population. Regulatory compliance costs exceed $1 million annually at eight of these facilities. Due to scale economies, we project that six of the facility operators would choose to send their FBCB to an off-site disposal unit, at an annual cost of between $39,000 and $264,000. On a unit cost basis, incremental costs range between $15 and $42/ton, with

EXHIBIT 9-2

REPORTED QUANTITIES DISPOSED - SUBTITLE D COMPLIANCE COST STUDY

Public ID	SIC	Average Disposed (tons)	Baseline Cost ($ 000)	Subtitle D Cost ($ 000)	Incremental Cost ($ 000)	Incremental Cost/ton ($)
Plant #08	2075	122,449	490	2,700	2,210	18
Plant #12	2075	431,502	1,700	8,300	6,600	15
Plant #13	2075	6,423	26	290	264	41
Plant #30	2075	1,000	4	45	41	41
Plant #20	2621	64,500	260	1,500	1,240	19
Plant #35	2621	94,033	380	2,100	1,720	18
Plant #07	4910	6,467	26	290	264	41
Plant #39	4910	45,473	180	1,100	920	20
Plant #06	4911	168,046	670	3,600	2,930	17
Plant #29	4911	46,172	180	1,100	920	20
Plant #36	4911	17,513	70	530	460	26
Plant #38	4911	255,189	1,000	5,200	4,200	16
Plant #42	4911	87,045	350	2,000	1,650	19
Plant #01	4931	26,840	110	730	620	23
Plant #23	4931	188,421	750	4,000	3,250	17
Plant #37	4931	2,185	9	99	90	41
Plant #14	8221	8,867	35	350	315	36
Plant #22	8221	936	4	43	39	42
Plant #43	9199	4,800	19	220	201	42
Total		1,577,860	6,262	34,197	27,935	
Average		83,045	330	1,800	1,470	27
Wt. Avg.			892	4,566	3,674	18
Maximum		431,502	1,700	8,300	6,600	42

[*] Note: Rounding errors in calculating the unit cost produce an increment that, in a few cases, exceeds the expected maximum of $41, i.e., $45.-$4.

a weighted average value of $18/ton, more than 4 times the current material management cost of $4/ton.

Restrictions on Productive Use of FBCBs

As discussed above, the majority of the FBCB generated by fluidized bed combustion of fossil fuels is put to productive use, principally to reclaim previously mined lands. Most of these uses involve placement of FBCB onto the land surface, or in the case of agricultural uses, active integration of the FBCB into the soil itself. If EPA were to assert jurisdiction over these uses and to prohibit or limit them in the future, the FBCB previously applied to productive uses would then need to be disposed in an environmentally sound manner, i.e., according to the regulatory controls in effect at that time.

The following cost results parallel those presented above, and reflect the assumption that all FBCB currently being disposed plus all FBCB currently being put to productive use would need to be disposed in conformance with either Subtitle C landfill standards or Subtitle D standards.

Total Quantities - Subtitle C Cost Study

Projected costs of imposing full Subtitle C standards on the entire quantity of FBCBs generated within the group of facilities responding to the 1996 Survey are presented in Exhibit 9-3. It can be readily observed that prohibiting productive use applications would double the number of affected facilities from 19 to 39, and nearly triple total incremental management costs for this group from $77 million to $237 million annually. At the facility level, 33 of the 39 facilities in the data set would be projected to experience cost increases in excess of $1 million annually, and ten of these would have predicted incremental costs of more than $10 million per year. Incremental unit costs range from $28 to $114 per ton, with a weighted average value of $40 per ton, or ten times current FBCB management costs.

Total Quantities - Subtitle D Cost Study

Cost results from our analysis of requiring Subtitle D disposal of all FBC FBCB generated by the facilities reflected in the 1996 Survey are presented in Exhibit 9-4. Total projected impacts are about $97 million annually across the 39 facilities, ranging from a low of $39,000 to a maximum of $7.4 million per year. Weighted average incremental costs are about $4.7 million per facility under this analytical scenario. Twenty one facilities are projected to experience incremental costs of more than $1 million annually. Incremental unit costs vary between $15 and $42 per ton, with a weighted average value of $17 per ton over and above baseline costs, or a multiple of about four.

To determine whether the projected costs associated with prospective RCRA regulatory controls over FBCB management might fall disproportionately upon certain segments of the FBC population and to support the evaluation of economic impact presented below, we present in Exhibit 9-5 a table summarizing the foregoing cost impact results by SIC code.

Because the magnitude of the projected cost impacts is directly proportional to facility size (capacity) and throughput of fuels and sorbents, the smaller facilities (such as in SIC codes 8221-Universities, and 9199-municipal governments) have as a group much smaller estimated cost impacts, relative to the industrial and power-generating facilities. Weighted average and even maximum facility-level impacts are below $1 million per year, except under the scenario in which all FBCB would need to be managed in accordance with Subtitle C controls. It also may be observed that impacts of any potential FBCB utilization restrictions would fall most heavily on facilities in SIC Code 4911 (electric power generation). The number of affected facilities would increase from five (those currently disposing FBCBs) to 18, while total sector-wide annual

EXHIBIT 9-3
TOTAL REPORTED FBCB QUANTITIES - SUBTITLE C COMPLIANCE COST STUDY

Facility ID	SIC	Average Generated (tons)	Baseline Cost ($ 000)	Subtitle C Cost ($ 000)	Incremental Cost ($ 000)	Incremental Cost/ton ($)
Plant #08	2075	133,194	530	7,300	6,770	51
Plant #12	2075	455,553	1,800	15,000	13,200	29
Plant #13	2075	6,423	26	720	694	108
Plant #28	2075	2,080	8	230	222	107
Plant #30	2075	3,742	15	420	405	108
Plant #20	2621	64,500	260	4,800	4,540	70
Plant #35	2621	94,033	380	6,000	5,620	60
Plant #07	4910	6,600	26	740	714	108
Plant #39	4910	45,473	180	3,900	3,720	82
Plant #06	4911	388,872	1,600	14,000	12,400	32
Plant #09	4911	163,558	650	8,300	7,650	47
Plant #10	4911	10,605	42	1,200	1,158	109
Plant #11	4911	298,255	1,200	12,000	10,800	36
Plant #15	4911	275,745	1,100	11,000	9,900	36
Plant #16	4911	488,866	2,000	16,000	14,000	29
Plant #19	4911	253,611	1,000	11,000	10,000	39
Plant #24	4911	273,850	1,100	11,000	9,900	36
Plant #25	4911	41,712	170	3,700	3,530	85
Plant #26	4911	304,717	1,200	12,000	10,800	35
Plant #29	4911	46,172	180	3,900	3,720	81
Plant #31	4911	306,375	1,200	12,000	10,800	35
Plant #32	4911	147,000	590	7,800	7,210	49
Plant #33	4911	502,254	2,000	16,000	14,000	28
Plant #36	4911	32,000	130	3,200	3,070	96
Plant #38	4911	255,189	1,000	11,000	10,000	39
Plant #40	4911	156,859	630	8,100	7,470	48
Plant #42	4911	235,873	940	10,000	9,060	38
Plant #01	4931	137,296	550	7,500	6,950	51
Plant #02	4931	29,303	120	3,000	2,880	98
Plant #03	4931	25,603	100	2,800	2,700	105
Plant #04	4931	29,955	120	3,000	2,880	96
Plant #17	4931	40,666	160	3,600	3,440	85
Plant #18	4931	349,161	1,400	13,000	11,600	33
Plant #23	4931	188,421	750	9,100	8,350	44
Plant #37	4931	23,000	92	2,600	2,508	109
Plant #14	8221	8,867	35	1,000	965	109
Plant #22	8221	936	4	110	106	114
Plant #41	8221	22,060	88	2,500	2,412	109
Plant #43	9199	9,800	39	1,100	1,061	108
Total		5,858,177	23,415	260,620	237,205	
Average		150,210	600	6,683	6,082	69
Wt. Avg.			1,198	11,458	10,259	40
Maximum		502,254	2,000	16,000	14,000	114

EXHIBIT 9-4
TOTAL REPORTED FBCB QUANTITIES - SUBTITLE D COMPLIANCE COST STUDY

Facility ID	SIC	Average Generated (tons)	Baseline Cost ($ 000)	Subtitle D Cost ($ 000)	Incremental Cost ($ 000)	Incremental Cost/ton ($)
Plant #08	2075	133,194	530	2,900	2,370	18
Plant #12	2075	455,553	1,800	8,700	6,900	15
Plant #13	2075	6,423	26	290	264	41
Plant #28	2075	2,080	8	95	87	42
Plant #30	2075	3,742	15	170	155	41
Plant #20	2621	64,500	260	1,500	1,240	19
Plant #35	2621	94,033	380	2,100	1,720	18
Plant #07	4910	6,600	26	300	274	42
Plant #39	4910	45,473	180	1,100	920	20
Plant #06	4911	388,872	1,600	7,600	6,000	15
Plant #09	4911	163,558	650	3,500	2,850	17
Plant #10	4911	10,605	42	390	348	33
Plant #11	4911	298,255	1,200	6,000	4,800	16
Plant #15	4911	275,745	1,100	5,600	4,500	16
Plant #16	4911	488,866	2,000	9,200	7,200	15
Plant #19	4911	253,611	1,000	5,200	4,200	17
Plant #24	4911	273,850	1,100	5,600	4,500	16
Plant #25	4911	41,712	170	1,000	830	20
Plant #26	4911	304,717	1,200	6,100	4,900	16
Plant #29	4911	46,172	180	1,100	920	20
Plant #31	4911	306,375	1,200	6,200	5,000	16
Plant #32	4911	147,000	590	3,200	2,610	18
Plant #33	4911	502,254	2,000	9,400	7,400	15
Plant #36	4911	32,000	130	840	710	22
Plant #38	4911	255,189	1,000	5,200	4,200	16
Plant #40	4911	156,859	630	3,400	2,770	18
Plant #42	4911	235,873	940	4,900	3,960	17
Plant #01	4931	137,296	550	3,000	2,450	18
Plant #02	4931	29,303	120	780	660	23
Plant #03	4931	25,603	100	700	600	23
Plant #04	4931	29,955	120	800	680	23
Plant #17	4931	40,666	160	1,000	840	21
Plant #18	4931	349,161	1,400	6,900	5,500	16
Plant #23	4931	188,421	750	4,000	3,250	17
Plant #37	4931	23,000	92	650	558	24
Plant #14	8221	8,867	35	350	315	36
Plant #22	8221	936	4	43	39	42
Plant #41	8221	22,060	88	630	542	25
Plant #43	9199	9,800	39	370	331	34
Total		5,858,177	23,415	120,808	97,393	
Average		150,210	600	3,098	2,497	23
Wt. Avg.			1,198	5,926	4,727	17
Maximum		502,254	2,000	9,400	7,400	42

EXHIBIT 9-5

PROSPECTIVE COST IMPACTS OF RCRA CONTROLS BY SECTOR

		Incremental Cost - Quantities Disposed				Incremental Cost - Quantities Disposed Plus Quantities Used			
		Subtitle C		Subtitle D		Subtitle C		Subtitle D	
		Total ($000)	Cost/ton ($)	Total ($000)	Cost/ton ($)	Total ($000)	Cost/ton ($)	Total ($000)	Cost/ton ($)
2075	Total	20,610	-	9,115	-	21,291	-	9,776	-
	# Facil.	4	-	4	-	5	-	5	-
	Min	106	31	41	15	222	29	87	15
	Avg	5,153	75	2,279	29	4,258	81	1,955	31
	Wt. Avg	11,651	37	5,558	16	11,517	35	5,760	16
	Max	13,300	108	6,600	41	13,200	108	6,900	42
2621	Total	10,160	-	2,960	-	10,160	-	2,960	-
	# Facil.	2	-	2	-	2	-	2	-
	Min	4,540	60	1,240	18	4,540	60	1,240	18
	Avg	5,080	65	1,480	19	5,080	65	1,480	19
	Wt. Avg	5,181	64	1,525	19	5,181	64	1,525	19
	Max	5,620	70	1,720	19	5,620	70	1,720	19
4910	Total	4,424	-	1,184	-	4,434	-	1,194	-
	# Facil.	2	-	2	-	2	-	2	-
	Min	704	82	264	20	714	82	274	20
	Avg	2,212	95	592	31	2,217	95	597	31
	Wt. Avg	3,344	85	838	23	3,339	85	838	23
	Max	3,720	109	920	41	3,720	108	920	42
4911	Total	28,830	-	10,160	-	155,468	-	67,698	-
	# Facil.	5	-	5	-	18	-	18	-
	Min	1,930	39	460	16	1,158	28	348	15
	Avg	5,766	68	2,032	20	8,637	50	3,761	18
	Wt. Avg	7,908	50	3,063	18	10,785	37	5,012	16
	Max	10,000	110	4,200	26	14,000	109	7,400	33
4931	Total	11,381	-	3,960	-	41,308	-	14,538	-
	# Facil.	3	-	3	-	8	-	8	-
	Min	241	44	90	17	2,508	33	558	16
	Avg	3,794	86	1,320	27	5,164	78	1,817	21
	Wt. Avg	7,582	52	2,894	18	8,520	50	3,608	18
	Max	8,350	110	3,250	41	11,600	109	5,500	24
8221	Total	1,071	-	354	-	3,483	-	896	-
	# Facil.	2	-	2	-	3	-	3	-
	Min	106	109	39	36	106	109	39	25
	Avg	536	111	177	39	1,161	111	299	34
	Wt. Avg	883	109	289	36	1,942	109	464	28
	Max	965	114	315	42	2,412	114	542	42
9199	Total	521	-	201	-	1,061	-	331	-
	# Facil.	1	-	1	-	1	-	1	-
	Min	521	109	201	42	1,061	108	331	34
	Avg	521	109	201	42	1,061	108	331	34
	Wt. Avg	521	109	201	42	1,061	108	331	34
	Max	521	109	201	42	1,061	108	331	34

compliance costs would rise from about $29 million to $155 million assuming Subtitle C disposal, and from $10 million to about $68 million under a Subtitle D scenario.

9.4 Economic Impacts of Prospective RCRA Controls

To evaluate the ultimate financial impacts of prospective RCRA regulatory controls, the CIBO Special Project has prepared two case study illustrations of the ways in which increased FBCB management costs would be reflected in the financial performance of the business enterprise. These case studies reflect two of the major types of facilities represented in the FBC population, an independent power project and an FBC installation at an industrial facility. We have chosen this approach as opposed to a facility-specific evaluation of the population because of time and data limitations. The case study facilities have, however, been developed so as to be generally representative of the members of the larger group.

We employed a proprietary project screening model developed by Foster Wheeler Power Systems, Inc. to develop capital and operating costs for the two hypothetical projects. The model produces operating *pro forma* statements using typical debt structures for each type of project to allow calculation of return on investment and other financial variables. The two types of projects selected to be modeled have the following general design characteristics: the first is an 80 MW waste coal-fired IPP and the second is a 150,000 lb/hr steam boiler at an industrial facility using a medium sulfur coal.

To calculate the financial data necessary to assess the impacts of changes in FBCB management conditions, we developed a *pro forma* and back-calculated electricity or steam prices to satisfy specified financial criteria. Once the steam or electricity prices were determined, we recalculated the *pro forma* using the new FBCB disposal costs.

Independent Power Production Project:

This 80 MW IPP project was assumed to have one source of income, electricity sales to a utility under a PPA, that did not allow increased regulation-imposed costs to be included in the rates. This size of a project would have a capital cost of approximately $173,247,000. Major material flows are as follows: fuel - 61.5 tph (tons per hour); limestone - 3.1 tph; and FBCB - 30.9 tph. We have assumed a 20 percent equity investment, with 80 percent of the debt being tax exempt and 20 percent of the debt being taxable. We also assumed a 20 year project life with 15 year amortization of the debt. The imposition of full Subtitle D or C disposal unit standards and the resulting dramatically increased costs in combination with the fixed revenue source for this project would, according to the simulation, result in insufficient cash flow to meet debt service obligations. In other words, the project would become financially non-viable and would close. To more precisely define the point at which increased byproduct management costs would threaten the financial viability of the case study facility, we conducted a sensitivity analysis to determine the maximum disposal cost the project could tolerate while meeting debt service obligations. Analytical assumptions and output from the simulation are presented below in Exhibit 9-6.

EXHIBIT 9-6

IMPACT OF INCREASED FBCB MANAGEMENT COSTS ON A MODEL IPP PROJECT

	Maximum Disposal	
Description	Base Case (000 $)	Cost Case (000 $)
Revenues	35,758	35,758
Expenses		
Fixed O & M	6,962	6,962
Utilities & Chemicals	1,439	1,439
Fuel	7,606	7,606
Limestone	462	462
Ash Disposal	1,016	4,821
Debt Service	14,468	14,468
Taxes	934	0
Total Expenses	32,887	35,758
Fee & Return on Investment	2,871	0
Approximate ash disposal cost		$20.24

The total FFBC management cost at which the model plant becomes non-viable occurs at $20.24 per ton, which is significantly less than the unit cost estimated for all of the individual commercial power-generating FBC plants (i.e., those in SIC Codes 4910, 4911, and 4931) under Subtitle C controls, and significantly less than facility-specific estimated costs at most of these plants assuming a Subtitle D regulatory scenario (see Exhibit 9-5).

Industrial Steam Production

In this case study example, we assumed a 150,000 lb/hr industrial steam generator functioning as a "profit center" and analyzed it as a stand alone operation. This size corresponds to material flows of the following : fuel - 7.2 tph; limestone - 1.3 tph; and FBCB - 2.3 tph; obviously, this a much smaller scale operation than the previously described IPP. All simulations of this case assume a 20 percent equity investment and that all of the debt is taxable. We again assumed a 20 year project life with a 15 year amortization of the debt. In the case of the IPP project described above, imposition of full subtitle C disposal costs caused the project to be non-economic, suggesting facility closure. In this case study, the power house would be operating within a larger commercial entity, making ultimate economic impact more difficult to predict. Accordingly, we simply provide below the estimated financial performance (expressed as return on investment) associated with the steam generator in the baseline and after imposition of either Subtitle C or D FBCB management controls. Results are presented in Exhibit 9-7.

EXHIBIT 9-7

IMPACT OF INCREASED FBCB MANAGEMENT COSTS ON A MODEL INDUSTRIAL STEAM GENERATOR

Description	Base Case (000 $)	Subtitle D (000 $)	Subtitle C (000 $)
Revenue	10,882	10,882	10,882
Expenses			
Fixed O & M	2,765	2,765	2,765
Utilities & Chemicals	1,116	1,116	1,116
Fuel	1,469	1,469	1,469
Limestone	212	212	212
Ash Disposal	75	855	2,413
Debt Service	3,889	3,889	3,889
Taxes	354	63	0
Total Expenses	9,880	10,369	11,864
Fee & Return on Investment	1,002	513	(982)
Percent Return on Investment	18.6	11.9	0

This simulation suggests that Subtitle D standards would reduce the margin of the model powerhouse by 50 percent and its return on investment by approximately one-third, and that Subtitle C controls would, as in the prior case, render the project financially non-viable.

CHAPTER TEN

STUDY FINDINGS AND REGULATORY IMPLICATIONS

10.0 Introduction

This chapter provides a summary of the information presented in prior chapters of this Report, articulates the findings of the study relative to the Bevill Amendment study factors, and presents the recommendations of the CIBO Special Project regarding EPA's forthcoming regulatory determination for fossil fuel combustion by-products.

10.1 Study Findings

Results of the CIBO Special Project's analysis of the eight Congressionally-mandated study factors (see Chapter 1) are presented as follows: sources and volumes of material (Study Factor 1) in Section 10.1.1; present disposal and utilization practices (Study Factor 2), and the current and potential utilization of such materials (Study Factor 8) in Section 10.1.2; potential danger to human health and the environment (Study Factor 3) in Sections 10.1.3; documented cases of danger to human health and the environment from surface run-off or leachate (Study Factor 4) in Section 10.1.4; and alternatives to current disposal methods (Study Factor 5), and costs and impacts of alternative FBC byproduct management scenarios (Study Factors 6 and 7) in Section 10.1.5.

In addition, we have summarized and compared data pertaining to these study factors as they apply to FBCBs and analogous CCBs that are generated by non-FBC units and previously studied utility boilers. This comparison is presented in Appendix C.

10.1.1 Sources and Volumes of Waste (Study Factor 1)

In 1995, the operators of non-utility fluidized bed combustion boilers using fossil fuels in the United States comprised 84 facilities operating 123 boilers in 31 states. Pennsylvania has the largest number of facilities using fossil fuels in FBC units (and the largest number of units in service), followed by California, Illinois, and Iowa, all of which are home to at least five facilities and/or ten FBC boilers. The vast majority of the units in this population are of the circulating fluid bed (CFB) type, and most burn coal or waste coal as their primary fuel. Other fossil fuels used in FBC units include petroleum coke, fuel oil, natural gas, propane, and refinery process gases. The FBC units addressed in this study range in size from very small (1 MWe) to relatively large (320 MWe), though in general these units are dwarfed in scale by typical utility power plants.

Based on an analysis of new data collected in support of this Report, the Special Project has documented that fossil fuel-fired FBC units generate substantial quantities of solid combustion byproducts, both as a consequence of the types of solid fuels that they burn and as a result of their innovative use of sorbents (limestone) in the boiler assembly itself to remove sulfur oxides from exhaust gases. As a result, FBCBs exhibit characteristics of both coal combustion ash and flue gas desulfurization wastes generated by conventional coal-fired technologies. The Special Project received detailed survey responses from the operators of 39 facilities, 38 of which have been used to estimate FBCB generation rates and perform the analyses presented in this report. Based upon these data, the Special Project estimates that approximately 9.4 million short tons of FBCBs are generated annually by the 84 facilities in the population.

FBCB generation varies widely across these facilities, and is principally a function of two major factors: the size (capacity) of the FBC unit, and the type(s) of fuel fed to the unit. Because FBC technology is very efficient (residual (non-combusted) carbon content of about 0.5-2 percent), the quantity of ash byproduct generated by any particular unit will closely track the percentage of non-combustible material in the fuel feedstock(s), and by the quantity of sorbent (limestone) required to provide acceptable SO_2 removal. Thus, for example, FBC units burning waste coal and/or fuel with a high sulfur content will, all else being equal, generate proportionally more FBCBs than units that burn higher quality fuel materials.

10.1.2 Current and Potential Byproduct Management Practices (Study Factors 2 and 8)

Year to year, approximately two-thirds or more of the FBCBs generated are used in productive applications, with the remainder being land disposed in landfills or impoundments. Approximately 80 percent of the FBC byproducts that are productively used (and 60 percent of the FBCBs generated) are sent to reclamation of coal mines and mined lands. Generally, this practice is employed under the terms of a facility-specific permits issued by appropriate state government agencies. Additional important productive applications include using FBCBs to stabilize various industrial and municipal wastes, as a component of structural or flowable fill material, and as a soil amendment, conditioner, or other agricultural supplement.

For that portion of FBCBs that are disposed, the general practice is to manage it in engineered landfills or surface impoundments, virtually all of which have been constructed and operated under state-issued permits. Almost all of these units have been placed into service since the advent of waste management controls under RCRA and analogous state statutes and regulations. The operators of most of these units employ a variety of contaminant release controls, including run-on and run-off controls, dust suppression, and use of some type of liner system, according to 1996 Survey results.

These management patterns are in sharp contrast to those typically applied to fossil fuel combustion byproducts generated by the electric utility industry. The utility industry in the aggregate disposes of two thirds to three quarters of its combustion byproducts, often to units originally constructed and placed into service decades before concerns about the potential environmental and human health impacts of industrial waste management became prevalent.

Federal statutes that potentially affect management of FBCBs include the Clean Air Act (CAA), Clean Water Act (CWA), the Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). Provisions of regulations developed under authority of the CAA and CWA impose regulatory controls on releases of FBCBs to the air (via stack or fugitive dust emissions) and water (from stormwater run-off and point source effluent discharges), respectively. Under both RCRA and CERCLA, the federal government can respond to situations where the release of FBCBs or their constituents present an imminent and substantial danger to human health and the environment. FBCBs that are not placed into productive use also are subject to regulation under Subtitle D of RCRA. The CIBO Special Project believes that this network of federal and state regulatory controls provides adequate assurance that FFCBs will be used and disposed in an acceptable and environmentally sound manner, and that further controls under RCRA would be both unnecessary and redundant.

To fill an important gap in EPA's knowledge of current state level regulatory control over solid waste disposal, the Special Project conducted a detailed survey of regulatory controls addressing land management of coal combustion ash in landfills and surface impoundments. The Special Project received responses from representatives of 30 states that collectively account for almost 70 percent of national coal consumption. Based on this survey, the Special Project has found that many states (including the vast majority of jurisdictions in which fluidized bed fossil fuel combustion occurs) have existing programs that regulate disposal of FBCBs and other similar materials in landfills and surface impoundments, generally through permits and case-by-case determinations as to the specific constituent release controls (e.g., liners, leachate collection systems, operating practices) that will be required of the FBCB disposal unit operator.

In addition, the Special Project has collected detailed information on the provisions of several state-level programs that regulate the use of FBCBs in various productive applications. While not comprehensive, the results of this exercise suggest that such uses tend to be controlled by state governments in such a way that the potential for related adverse impacts to human health or the environment is minimized.

10.1.3 Waste Characteristics and Potential Risks to Human Health and the Environment (Study Factor 3)

To analyze the potential for adverse impacts to human health and the environment arising from the disposal and use of FBCBs, the Special Project conducted a risk screening exercise, performed a side-by-side comparison of FBCBs with analogous, previously studied coal combustion byproducts, and reviewed the literature for studies in which FBCB-related impacts had been examined by others.
In terms of intrinsic hazard, the data suggest that FBCBs are relatively benign, consisting mainly of calcium, sulfur, silicon, iron, and aluminum oxides, and trace concentrations of other metallic and non-metallic constituents. When mixed with water, FBCBs produce solutions having a highly alkaline pH. Total composition and leach test results suggest a low level of intrinsic hazard. FBCBs very rarely exhibit the RCRA hazardous waste characteristic of toxicity, as determined by the TCLP test. Our screening-level risk analysis produced results that parallel those of previous studies of CCBs. That is, given the highly conservative risk screening criteria and assumptions applied to perform the screening, several metallic constituents were identified that required further analysis before we could conclude that FBCBs would not pose risks under realistic management and environmental conditions. Accordingly, these constituents were evaluated further in a comparison with other quantitative assessments of risks posed by similar materials, i.e., utility CCBs. Results of these assessments indicated that FBCBs pose no higher or more extensive risks than these other materials, which had previously been found by EPA to not warrant additional federal regulatory controls.

Finally, our review of a number of studies conducted or supported by various government agencies and academic institutions yielded no information that suggests that when properly applied at reasonable rates, FBCBs can be used in a variety of ways (e.g., mined land reclamation, agriculture) with no adverse effects on human health or the environment. Indeed, in the case of mined land reclamation, application of FBCBs has been shown to impart benefits to the surrounding environment through mitigation of acid mine drainage and improvement of the native soils, such that after mixing with FBCBs, they can support vegetation.

10.1.4 Documented Evidence of Damage (Study Factor 4)

As described in Chapter 6, the Special Project conducted several related activities to determine whether and to what extent human health impacts or environmental degradation has been caused by management of FBCBs. Our review of judicial proceedings yielded no evidence of such impacts. Information submitted in response to the 1996 Survey highlighted eight instances in which pertinent environmental quality standards had been exceeded at or adjacent to a member of the study population. In most of these eight cases, it is clear that these exceedances existed prior to placement of FBCBs at the site. In the remaining few instances, the evidence is less clear, but seems to indicate that FBCBs and their management played little or no role in causing the reported environmental contamination. Finally, the Special Project solicited environmental performance information from the State of Pennsylvania relative to the widespread use of FBCBs in mine reclamation in this state. While there have been a number of cited permit violations at several FBC facilities at which FBCBs have been land applied, most of these incidents have been related to administrative or housekeeping requirements, and in no instance has actual environmental contamination or damage from FBCB placement been alleged by the Pennsylvania Department of Environmental Protection.

Thus, based upon the Special Project's information collection and analysis activities as described in Chapter 6 of this Report, the Special Project is not aware of any cases conforming to EPA's established "tests of proof" of environmental or human health impacts associated with the disposal or productive use of FBCBs.

10.1.5 Potential Costs and Impacts of Alternative Federal Regulation (Study Factors 5, 6, and 7)

For purposes of analysis, the Special Project developed two alternative management scenarios for FBCBs that address the likely outcome of a prospective loss of the Special Waste status of these materials. One reflects most of the major elements of hazardous waste regulation under Subtitle C of RCRA, and the other simulates application of the solid waste disposal regimen that applies to municipal solid waste (MSW) landfills under RCRA Subtitle D.

Were the operators of FBC units required to manage their combustion byproducts as RCRA hazardous wastes, FBCB management costs would increase dramatically, to the point at which the economic viability of the facilities would be threatened. Predicted impacts would be particularly acute in the independent power sector; as highlighted in Appendix B, substantial operating cost increases cannot be sustained by a typical IPP, meaning that imposition of Subtitle C FBCB management costs would almost certainly lead to facility closure. The viability of industrial facilities under stringent new waste management controls is more variable. Industrial users of FBC technology would likely shift to new sources of electricity and/or steam rather than absorb significant new FBCB management costs. Imposition of new landfill design and operating standards under RCRA Subtitle D also would impart significant challenges to the owners and operators of FBC units at most facilities.

10.2 Recommendations

This section presents the CIBO Special Project's views on two important aspects of the decision to be made by EPA relative to the Special Waste status of FBCBs: the decision making rationale to be employed by the Agency, and the specific regulatory options that EPA will consider.

10.2.1 Decision Making Rationale

In EPA's two most recent regulatory determinations for Bevill wastes (applied to cement kiln dust and utility fossil fuel combustion wastes, respectively), the Agency has employed a three step decision making process to sequentially evaluate the most critical Bevill study factors in a consistent and logical manner. The Special Project endorses this general approach, and provides below its interpretation of the salient facts as viewed through the lens of the Agency's established decision making rationale.

Step 1: Does management of FBCBs pose human health and environmental problems? Might current practices cause problems in the future?

Upon reviewing the results of a search for documented cases of damage to human health and the environment, performing screening-level and comparative risk assessments, and evaluating the results of laboratory analyses of a large number of FBCB samples, the Special Project has concluded that risks associated with current methods of FBCB disposal and beneficial use are low. While there is always the potential, under certain circumstances, for virtually any material (including FBCBs) to pose a danger to human health and environment if mis-managed, there is no evidence that current management practices or discernible trends might lead to such impacts. Indeed, there are numerous examples of environmental improvements brought about by the judicious use of FBCBs, particularly in reclaiming mined lands, stabilizing waste materials, and improving fill or soil quality.

In the view of the Special Project, should EPA decide to follow its traditional three step decision making methodology in determining the Special Waste status of FBCBs, that evaluation should logically conclude at this juncture, given the absence of past or current impacts and low predicted risks; EPA should determine that there is <u>not</u> any justification for new regulatory controls.

Step 2: Is more stringent regulation necessary or desirable?

Taken as a whole, the information presented in this Report does not suggest that additional or more stringent regulation of FBCBs is either necessary or desirable. In the 17 years since enactment of the Bevill Amendment, state-level regulatory programs have evolved and matured in a number of significant respects. Extensive information developed and reported by the Special Project (see Chapter 8) leads to the conclusion that both disposal and productive use of FBCBs are already extensively (and often intensively) regulated. While these programs vary widely, most require permits and the submittal of material characterization and/or environmental performance data to a cognizant agency, as well as a case-by-case determination regarding the need for specific contaminant release controls. It is unclear that additional waste management controls at the federal level would impart significant improvements in protection of human health or the environment. Indeed, to the extent that such controls discouraged productive use of the material, they might actually lead to a decline in environmental quality in certain locations.

Step 3: What would be the operational and economic consequences of a decision to regulate FBCBs under Subtitle C?

As shown in Chapter 9, imposition of Subtitle C management controls on FBCBs would almost certainly lead to closure of all independent power producers that generate these materials. Similarly, impacts of mandating the MSW landfill "default" landfill design and operating standards would threaten the economic viability of many of these operations. Because operation of a FBC unit is not necessarily central to their core business, industrial operators would experience less severe impacts than the IPPs. Nonetheless, they would likely need to expend significant resources (human and financial) arranging for alternative sources of electricity and/or steam. There also could be significant economic impact in individual states, because Subtitle C controls would presumably preclude further FBCB use in mine reclamation, thereby eliminating a very low cost, effective means of remediating historical environmental damage.

10.2.2 Discussion of Regulatory Options

Under the authority of section 3001(b)(3)(C) of the Resource Conservation and Recovery Act (RCRA), as amended, EPA must formulate its findings regarding regulatory options. This section of the statute requires that, after completing the Report to Congress (RTC) mandated by section 8002(n) of RCRA, the EPA Administrator must determine whether Subtitle C regulation of any special waste (also referred to as Bevill waste) is warranted. In anticipation of this required action, the Special Project submits the following analysis of regulatory options available to the Administrator. Because the data collected by the Special Project seem to indicate that current management practices and state regulatory programs are sufficient to protect human health and the environment, the mentioning of various options in this section is not intended as an explicit or implicit endorsement of such options. Rather, it is intended to reflect EPA's past practice in reviewing candidate regulatory approaches.

Once again, the last RTC on a Bevill waste provides a rubric for discussion of options. In the RTC regarding cement kiln dust (see 59 Federal Register 709, January 6, 1994), and in the subsequent regulatory determination on February 7, 1995, the EPA referenced five regulatory options:

Option 1: Retain the CKD (Bevill) exemption.

Option 2: Retain the CKD (Bevill) exemption, but the Agency would enter into voluntary agreements with the industry whereby they would implement dust recycling technologies, reduce waste, and monitor and control CKD management and use.

Option 3: Remove the CKD (Bevill) exemption, but delay implementation for some period of time (e.g., two years) that would allow industry time to employ pollution prevention measures.

Option 4: Remove the CKD (Bevill) exemption, and implement the compliance measures within six months.

Option 5: Promulgate tailored regulatory standards for the management of CKD waste under Subtitle C of RCRA.

While it is not clear that EPA should parse its regulatory options for non-utility fossil fuel combustion byproducts (ash) in precisely the same way, the CKD report does provide a useful framework for analysis. Options 2 through 5 presuppose environmental impacts related to FBCB disposal that are not borne out in the data and analysis set forth elsewhere in this Report. In addition, Option 2 relies upon uncertain legislative authorization, as EPA discussions with the cement industry and the azo dye and pigment industry have indicated. Inasmuch as there has been no demonstrated environmental detriment and potential environmental benefits (i.e., waste coal site reclamation) associated with FBCB management, Options 2 and 3 would inappropriately impose economic hardship where it is not warranted. In any event, the use of Subtitle C authority referenced directly in Option 5 would not seem appropriate because FBCBs are high-volume, low-toxicity waste products that fail to meet the legal tests established under RCRA.

Option 1 offers the most appropriate regulatory result for non-utility FBCBs. In light of the information imparted by this Special Study, it would seem most appropriate to take the Option 1 approach of foregoing imposing additional regulation at the federal level, while retaining the regulatory flexibility of RCRA Subtitle D, allowing states to design programs appropriate to the needs and conditions of their areas.

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GLOSSARY

ASTM - The American Society for Testing and Materials, an organization that develops and maintains test methods and standards for use in commerce.

acid cleaning solution wastes - Water side cleaning wastes resulting from the removal of mineral scale and corrosion products from boilers.

acid mine drainage - Water draining from closed or abandoned mines that is highly acidic, often due to high concentrations of acidic sulfates.

acid neutralization - Reaction of an acid with a base to raise the pH of the acid, i.e., make it more neutral.

acidic soils - Soils exhibiting a pH of less than 7.

acidity - The amount of free carbon dioxide, mineral acids, and salts (especially sulfates of iron and aluminum) which hydrolyze to generate hydrogen ions in water,reported as milli-equivalents per liter of acid, or ppm acidity as calcium carbonate, or as pH, the measure of hydrogen ion concentration. Indicated by a pH of less than 7.

air pollution control devices - Devices used to limit particulate or gaseous emissions from boilers and other industrial or commercial operations to the atmosphere.

air split - The ratio between primary air and secondary air provided to the furnace of a boiler.

alkaline cleaning solution wastes - Water-side cleaning waste resulting primarily from the removal of oil, grease, or temporary coatings with some removal of flaky surface oxides and mill scale from boilers.

alkaline fly ash scrubber - A flue gas desulfurization system in which flue gas reacts with alkaline fly ash that is augmented with lime/limestone slurry.

alkaline materials - Water-soluble materials that yield a high concentration of hydroxyl (OH-) ions in solution, or otherwise produce a solution with a pH greater than 7 when dissolved.

alkaline passivating waste - Water-side cleaning waste resulting from the neutralization of acidity after acid cleaning of a boiler.

alkalinity - The amount of carbonates, bicarbonates, hydroxides, and silicates or phosphates in water, reported as grains per gallon, pH, or ppm of carbonate. Indicated by a pH of greater than 7.

anhydrite - Calcium sulfate ($CaSO_4$).

anion - A negatively charged ion.

anthracite - A high ASTM ranked coal with fixed carbon 92% or more and less than 98%, and volatile matter 8% or less and more than 2% on a dry, mineral-matter free basis.

aquifer - A water-bearing subsurface formation of permeable rock, sand, or gravel capable of yielding quantities of water to wells or springs. A useable aquifer is one that may be used for agricultural and industrial purposes as well as human consumption.

aragonite - An unconsolidated form of limestone formed by precipitation of calcium carbonate ($CaCO_3$) in water.

as fired fuel - The condition of the fuel as fed to the furnace in a boiler. The fuel requires no additional processing to allow it to be used in the furnace.

ash -The incombustible solid matter in fuel.

attenuation - A process that slows the migration of constituents through the ground.

avoided cost - The incremental cost to an electric utility for electric energy or capacity or both, which, but for the purchase from a qualifying facility, such utility would generate itself or purchase from another source. Under PURPA, a state's Public Utility Commission approves the avoided costs for each utility.

background concentrations - Ambient concentrations of naturally occurring or anthropogenic chemicals present in the environment not due to fossil fuel combustion byproduct management. These concentrations are used as baseline levels to compare with chemical concentrations measured in combustion byproducts.

backpass - Common name for the convection section of a boiler.

baghouse - An air pollution abatement device used to trap particulates by filtering gas streams through large fabric bags usually made of glass fibers. A baghouse will contain a large number of fabric filters.

base load - The term applied to that portion of a station or boiler load that is essentially constant for long periods of time.

bed ash - The bottom ash from a fluidized bed combustion boiler.

bed material - The granular particles that comprise the bed in a fluidized bed boiler.

beneficiation - The treating of a raw material so as to improve its properties. For fuel processing it may involve a flotation process for separating out high fuel value material from waste material. In the context of coal mining, the mining company may beneficiate coal by washing it in order to obtain and ship a better quality fuel.

beneficial use - A use which is of benefit as a substitute for natural or commercial products and does not contribute to adverse effects on health or environment.

Best Available Control Technology (BACT) - Air pollution controls that achieve the "maximum degree of [emission] reduction ... which the permitting authority, on a case-by-case basis taking into account energy, environmental, and economic impacts and other costs, determines is achievable for such facility...." To obtain a Prevention of Significant Deterioration (PSD) permit, a major source must demonstrate that it will use BACT to reduce emissions for each pollutant subject to regulation under the Clean Air Act (40 CFR Part 52.21).

best management practices - Procedures, methods, and devices, that improve or maintain the quality of environmental media.

Bevill Amendment - Section 3001(b)(3) of RCRA, which temporarily excludes fossil fuel combustion byproducts (and other specific waste categories) from regulation as a hazardous waste under Subtitle C of RCRA, pending study. While temporarily excluding fossil fuel combustion byproducts from regulation as a hazardous waste, the Bevill Amendment does not preclude fossil fuel combustion byproduct regulation under other provisions of federal or state law.

bioaccumulation - The net uptake of a chemical in the environment into biological tissues via all exposure pathways. It includes the accumulation that may occur by direct exposure to contaminated media (e.g., dermal absorption, ingestion) as well as exposure from food. This phenomenon can result in higher concentrations of substances in biological tissue than in surrounding environmental media.

bituminous coal - ASTM coal rank classification on a mineral-matter-free basis and with bed moisture only. Several subclasses have been established to more fully describe this type of coal.

boiler - A closed loop or vessel in which water is heated, steam is generated, steam is superheated, or any combination thereof, under pressure or vacuum by the application of heat.

boiler blowdown - Removal of a portion of boiler water for the purpose of reducing solid material concentrations or discharging sludge.

boiler cleaning waste - Waste resulting from the cleaning of fossil fuel fired boilers. Boiler cleaning wastes are either water-side or gas-side cleaning wastes.

boiler slag - Melted and fused particles of ash that collect on the bottom of the boiler.

boiler water - A term used to define a representative sample of the boiler circulating water. The sample is obtained after the generated steam has been separated and before the incoming feedwater or added chemical becomes mixed with it so that its composition is affected.

bone coal - A coal that has a very high ash content.

bottom ash - Large particles of solid combustion byproducts that settle on the bottom of the boiler. In the case of pulverized fuel and stoker fired boilers this will consist of fuel ash and char. In the case of fluidized bed combustion by common useage it will consist of fuel ash, char, unreacted limestone and anhydrite.

British thermal unit (BTU) - The mean British thermal unit is 1/180 of the heat required to raise the temperature of 1 pound of water from 32°F to 212°F at a constant atmospheric pressure. It is about equal to the quantity of heat required to raise 1 pound of water 1 degree F.

bulk constituents - For purpose of this report, constituents that exceed 0.05 percent by weight in fossil fuel combustion byproducts.

CERCLA - The Comprehensive Environmental Response, Compensation, and Liability Act, commonly referred to as Superfund.

calcareous materials - General term used for solid materials containing calcium carbonate, such as limestone and dolomite, and for materials that are regarded as basic or alkaline.

calcination - Heating an ore, mineral product, or intermediate product in a furnace or kiln to decompose carbonates or intermediate compounds to CO_2 and associated oxides.

calorific value - The heating value of a specific fuel, expressed in Btu/pound as fired.

cancer/noncancer risks - The incremental probability resulting from exposure to a hazardous substance of an individual or population experiencing cancer or adverse, noncancer effects.

cancer slope factor - An estimate of the probability of a response (e.g., cancer) per unit intake of a chemical over a lifetime.

capacity - The load for which a generating unit or other electrical apparatus is rated, either by the manufacturer or user.

capacity factor - A measure of the level of plant utilization. It is calculated as the total output over a period of time divided by the product of the rated capacity over the same time period.

carcinogenic - A substance that produces or incites cancer.

cation - A positively charged ion.

cell - A section of a landfill, or size of that section. Usually only a few cells of a landfill are open to accept waste at a time.

cement and concrete products - when used in this document, the quantity of combustion byproducts used in the manufacture of Portland cement, as a raw feed or in a blended cement; and combustion byproducts used as a mixture ingredient in the production of fresh concrete for a variety of uses.

chain grate stoker - A stoker which has a moving endless chain as a grate surface, onto which coal is fed directly from a hopper.

char - Unburned combustibles in solid form combined with a portion of fuel ash.

circuit - When used in the context of a boiler, a group of connected boiler components having the same medium, e.g., a steam circuit would have all of the steam-related piping and pressure parts.

clarification - The removal of particulate matter, chemical floc, and precipitates from suspension in a fluid through gravity settling.

clarifier - A tank in which solids are settled to the bottom and are subsequently separated from a fluid as a sludge.

clinker - A hard, compacted, congealed mass of fuel matter fused together in the furnace of a boiler.

closure and post-closure care plan - A written plan that identifies and describes the steps that will be carried out to close, dismantle, decommission, and/or reclaim a waste management unit.

co-combustion byproducts - Combustion byproducts derived from the burning of either (1) a mixture of fossil fuels, or (2) fossil fuels and other fuels.

cogeneration - The sequential production of useful thermal energy (heat or steam) and electricity for use in industrial or commercial, heating, or cooling purposes.

cogeneration facility - 1) When used in the context of economic regulation, a power plant and interconnecting transmission facilities that meets the operating and efficiency standards and ownership criteria as determined by the FERC; 2) a facility that is engaged in cogeneration.

coke - The solid, cellular, infusible material remaining after the carbonization of coal.

coke breeze - Coke whose particle size is unsuitable for charging a blast furnace.

co-managed wastes - Mixtures of one or more of the combustion wastes with one or more other wastes generated in conjunction with the combustion of fossil fuels that are necessarily associated with the production of energy.

combustibles - The heat-producing constituents of a fuel. These constituents can consist of carbon, hydrogen, sulfur, and many other elements and compounds.

combustion - The rapid chemical combination of oxygen with combustible elements of a fuel, resulting in the production of heat.

combustion chamber - Also known as the furnace. The gas-tight portion of a boiler in which combustion takes place.

combustion efficiency - The measure of the completeness of oxidation of all fuel compounds. It is the ratio of actual heat released by combustion to the maximum heat of combustion available.

complete combustion - The complete oxidation of all combustible constituents of a fuel.

composite sample - A sample composed of several sub-samples collected either over time or over a volume of material to be representative of the sampled material.

compression test - A method used to measure the amount of force that can be applied to an object of known area before failure.

constituent mobility - The tendency of a substance to move through the environment.

constituent persistence - The tendency of a substance to remain in the environment. Generally based on a substance's half-life in water, air, and soil. Substances with longer half-lives (i.e., more persistent) may present a greater hazard.

contaminant plume - A body of contaminated ground water spreading from a surface or subsurface source of contamination.

cooling tower blowdown - Water withdrawn from the cooling system in order to control the concentration of impurities in the cooling water.

condensate - Condensed water resulting from the removal of latent heat from steam.

convection - A transfer of heat taking place by a movement of the heated medium itself.

convection section, convection pass - A section of the steam generator (boiler) in the flue gas path where heat is exchanged by convection between flue gas and steam/water tubes or air heater.

corrosivity - One of the four characteristics of a hazardous waste as defined by EPA (see 40 CFR Part 261).

crusher - A machine that reduces the size of solid fuel particles to a desired maximum for firing in a boiler.

culm - The refuse (tailings) from anthracite production.

cyclone - In a circulating fluidized bed combustion system, a refractory-lined stationary centrifugal device installed vertically using gravitational acceleration to separate solids from combustion gases leaving the combustion chamber.

cyclone furnace - A specialty furnace for high intensity heat release. So named because of its swirling gas and fuel flows.

dimineralizer regeneration and rinse waste - A low volume wastewater generated from the treatment of water to be used at the plant. Generally, demineralized water is used as boiler feedwater.

disposal - The discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous waste into or on any land or water such that any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including ground waters.

dolomite - Loosely used term to describe any carbonate rock containing 20 percent or more magnesium carbonate ($MgCO_3$).

dry bottom furnace - A pulverized-fuel furnace in which bottom ash particles are deposited on the furnace bottom in a dry, non-adherent condition.

dry scrubber - An FGD system in which sulfur dioxide is collected by a solid medium; the final product is totally dry, typically a fine powder.

dry sorbent injection - An FGD system in which a powdered sorbent is injected into the flue gas before it enters the baghouse. Sulfur dioxide reacts with the reagent in the flue gas and on the surface of the filter in the baghouse.

dual alkali fly ash scrubber - A flue gas desulfurization system similar to the lime/limestone process, except that the primary reagent is a solution of sodium salts and lime.

effluent - A waste liquid in its natural state or partially or completely treated that discharges into the environment from a manufacturing or treatment process.

electrostatic precipitator - An air pollution control device that imparts an electrical charge to particles in a gas stream, causing them to collect on an electrode.

elutration - Selective removal of fine solids from a fluidized bed by entrainment in upward flowing gases.

energy - Usable power (as heat or electricity), or the resources for producing such power.

environmental media - One or more of the following: air, soils, ground water, or surface water.

evapotranspiration - The combined process of evaporation and transpiration.

excess air - The air that is supplied for combustion in excess of that theoretically required for complete combustion.

exempt wholesale generator (EWG) - a person or entity determined by the FERC to be in business of owning or operating all or part of a facility used to generate electric energy exclusively for sale at wholesale, including the interconnection transmission facilities. An EWG is exempt from all provisions of PUHCA and may not be considered an electric utility company under PUHCA, whether or not an affiliate, or an associate company of a holding company.

exposure pathway - The course a substance takes from the point where it is released into the environment (i.e., the source) to an exposed organism. Each exposure pathway includes a source or release from a source, an exposure point (a location of potential contact between an organism and a substance), and an exposure route (the way a substance comes in contact with an organism, such as ingestion, inhalation, and dermal contact).

exposure potential - The likelihood of individuals, resources, or populations being exposed to a contaminant.

Extraction Procedure - A laboratory method specified by EPA prior to September 25, 1990 that was intended to simulate the generation and release of leachate from an improperly disposed solid waste. This procedure was applied to solid wastes to determine whether they exhibit the hazardous waste characteristic of toxicity. See Toxic Characteristic Leaching Procedure.

fabric filter - An air pollution control device which removes particulate matter from gas streams by retaining the particles in a porous structure. They operate in a manner similar to a bag in a vacuum cleaner, trapping the larger particulate and passing the fine particulate and gases. Fabric filters are typically used in parallel or series to form a baghouse.

Federal Energy Regulatory Commission (FERC) - The administrative agency created under the Federal Power Act which regulates all electricity sales for resale in interstate commerce and wheeling agreements, and which determines whether or not a given project qualifies as a Qualifying Facility under PURPA.

Fines - Extremely small particles, in the context of solid fuels these particles are generally less than 50 microns (0.002 inches) in size.

fixed carbon - The carbonaceous residue less the ash remaining in the test container after the volatile matter has been driven off when making a proximate analysis for a solid fuel.

flowable fill - Use of combustion byproducts in a fluid mixture resembling a grout for backfill applications where bearing strengths as well as excavatability comparable to those of compacted soils are needed. The mixture may have a variety of proportions, with typical ingredients including water and fly ash, along with optional fillers such as bottom ash or sand and small additions of Portland cement.

flue gas - The gaseous products of combustion in the flue to the stack. The gaseous products may include carbon dioxide, carbon monoxide, oxides of nitrogen (NOx), oxides of sulfur (SOx), volatile and semi-volatile organic compounds, oxygen, and nitrogen.

flue gas desulfurization (FGD) - Removal of sulfur dioxide in the flue gas.

flue gas desulfurization (FGD) sludge - waste that is generated by a wet removal process of some of the sulfur compounds from the flue gas after combustion.

fluidized bed - A system where a bed of granulated particles are maintained in a mobile suspension by an upward flow of air or gas.

fluidized bed combustion - The process where a fuel is burned in a fluidized bed; both the fuel and the products of combustion are held in suspension by the upward flow of air.

fluidized bed combustion byproduct - The solid residue(s) from combustion of fossil fuels in fluidized bed boilers; the principal topic of this report.

fly ash - In the case of pulverized fuel and stoker feed combustion, suspended ash particles carried in the flue gas. For fluidized bed combustion it includes suspended ash particles, fine char, unreacted limestone, and anhydrite (calcium sulfate) carried in the flue gas.

forced draft fan - A fan that creates a draft with a pressure greater than ambient air pressure. An application for a forced draft fan is supplying, or pushing, air under pressure to the combustion chamber.

fossil fuel combustion byproducts - The solid byproducts from combustion of fossil fuels. In the case of pulverized fuel and stoker fired combustion these byproducts consist of fly ash, bottom ash, boiler slag, and FGD byproducts. In the case of fluidized bed combustion the byproducts consist of fly and bottom ash.

fugitive dust - Particles suspended in the air by either wind erosion or mechanical disturbances.

fuel - A substance containing combustibles used for generating heat.

fuel pile runoff - Unmanaged water that has come into contact with a plant's fuel pile.

furnace - the combustion chamber of a boiler.

fusion - The melting (i.e., making liquid or plastic) of a solid material.

gas-side cleaning waste - Waste produced during the removal of residues (usually fly ash and soot) from the gas-side of the boiler (air pre-heater, economizer, superheater, stack, and ancillary equipment).

gob - The refuse from bituminous coal production.

grab sample - A single sample of a material (e.g., soil, coal) that is collected at one time for laboratory analysis.

ground water -The water contained within the pore spaces of subsurface formations below the water table and within the zone of saturation.

ground water monitoring well - A well used to obtain ground-water samples for water-quality analysis.

hazardous waste - According to Federal Law (40 CFR 261) a solid waste, or combination of solid wastes, which, because of its quantity, concentration, or physical, chemical, or infectious characteristics, may (1) cause, or significantly contribute to, an increase in serious irreversible, or incapacitating reversible illness; or (2) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, disposed of, or otherwise managed.

hazardous waste stabilization - The use of a substance as a dewatering and solidifying agent prior to the land disposal of liquid or sludges containing hazardous wastes.

heavy metals - Metallic elements with high atomic weights, e.g., mercury, chromium, cadmium, arsenic, and lead. These metals can damage living organisms at low concentrations and tend to accumulate in the food chain.

high volume waste - The solid combustion byproducts of fossil fuels and FGD materials generated by a boiler. Recognized as high volume due to the quantity produced compared to other wastes associated with plant operations. In the case of pulverized fuel and stoker combustion these wastes consist of fly ash, bottom ash, boiler slag, and flue gas desulfurization wastes. In the case of fluidized bed combustion these waste consist of fly ash and bed ash.

hot cyclone - See cyclone

hydrated lime - Calcium hydroxide ($Ca(OH)_2$) formed by adding water to quick lime.

hydration - The formation of a compound by the combination of water with another substance.

hydraulic conductivity - The quantity of water that will flow through a unit cross-sectional area of a porous material per unit of time.

hydrologically down gradient - The direction towards which groundwater and surface water flow.

ignitability - One of the four characteristics of a hazardous waste as defined by EPA (See 40 CFR 261).

in-bed - Refers to the volume within the fluidized bed zone.

independent power producer (IPP) - A nontraditional utility, private investor, or entity who develops, owns, and/or operates electric power generating plants and sells the output at wholesale rates to a traditional electric utility. Although the term has never been “officially” defined in a statute, a QF may or may not be considered to be an IPP, depending on the context.

induced draft fan - Large fan used to draw combustion gases through the furnace, heat recovery, and air pollution control devices of a boiler.

infiltration - The flow of water downward from the land surface through the upper soil layers, which may eventually lead to groundwater resources.

injection well - A well into which fluids are injected.

inorganic constituents - Chemical substances derived from mineral sources that do not usually contain carbon.

kilowatt (kw) - One thousand watts. The watt is the basic unit of electric power, and it is the measure of the rate at which electrical energy is generated or used. It is analogous to horsepower or foot-pounds per minute of mechanical power.

kilowatt-hour - The measure of the quantity of electrical energy generated or consumed. One kilowatt-hour is the total energy developed by the power of one kilowatt supplied to or taken from an electric current steadily for one hour.

land disposal - The placement of wastes in a landfill, surface impoundment, waste pile, injection well, land treatment facility, salt dome formation, salt bed formation, or underground mine or cave.

landfill - A disposal facility or part of a facility where hazardous or non-hazardous waste is placed in or on land which is not a land treatment facility, a surface impoundment, or injection well.

land reclamation - Process of changing the landscape back to conditions similar to those present at a given location prior to a land alteration activity (e.g., quarrying, strip mining).

land treatment facility - A facility or part of a facility at which hazardous waste is applied onto or incorporated into the soil surface.

leachate - In the context of this report, 1) the liquid resulting from water percolating through, and dissolving materials in waste, and; 2) the liquid resulting from the use of a leaching solution on a waste in a laboratory test to characterize the hazard of the waste.

leachate collection, removal, and treatment systems - mitigative measures used to prevent the leachate from building up above the liner.

leachate extraction test - A laboratory procedure used to predict the type and concentration of constituents that will leach out of waste material.

lift - The depth of a single layer of material prior to compaction in a fill area or landfill.

lignite - A coal of lowest ASTM ranking with calorific value limits on a moist, mineral-matter-free basis of less than 8,300 BTU/lb.

lime - A calcined or burned form of limestone popularly know as quick lime and hydrated lime. "Lime" is used in some FGD systems.

limestone - Broad term used to describe carbonate rocks or fossils consisting primarily of calcium carbonate or combinations of calcium carbonate and magnesium carbonate with varying amounts of impurities. Generally found as a bedded sedimentary rock composed mainly of calcium carbonate, or a rock type composed of, in general, at least 80 percent of carbonates of calcium and magnesium.

lime/limestone FGD process - A form of wet flue gas desulfurization system in which flue gases pass through a fly ash collection device and into a contact chamber where they react with a solution of lime or crushed limestone to form a slurry which is dewatered and disposed.

liner - A mitigative measure used to prevent ground-water contamination in which synthetic, natural clay, or bentonite materials that are compatible with the wastes are used to seal the bottom and sides of surface impoundments and landfills.

low volume waste - Wastes generated during equipment operation and maintenance and water purification processes associated with the combustion of fossil fuels. Low volume wastes include boiler cleaning solutions, boiler blowdown, demineralizer regenerants and rinses, pyrites, and cooling tower blowdown.

Maximum Contaminant Levels (MCLs) - The maximum permissible level promulgated under the Safe Drinking Water Act for contaminants in water that is delivered to any user of a public water system. Primary MCLs are established in 40 CFR Part 141 to be protective of human health; secondary MCLs are established in 40 CFR Part 143 to protect the aesthetic quality of drinking water (e.g, taste, odor, color, and appearance).

maximum exposed individual (MEI) - The actual or hypothetical individual, who based on location, sensitivity, and exposure pattern, is subject to the highest concentration of a substance, and therefore has the highest reasonable risk. The MEI may vary by exposure pathway.

mechanical stoker - A device consisting of a mechanically operated fuel feeding mechanism and a grate, and is used for the purpose of feeding solid fuel into a furnace, and to distribute it over a grate, admitting air to the fuel for the purpose of combustion, and providing a means for removal or discharge of solid combustion byproducts.

megawatt (MW) - One million watts or one thousand kilowatts. See kilowatts.

megawatt-hour (Mwh) - A measure of the quantity of electrical energy generated or consumed. See kilowatt-hour.

middling stream - A coal mining byproduct. A middling stream may consist mainly of culm from an anthracite mine or gob from a bituminous mine.

mineral filler - In this report, the use of a fossil fuel combustion byproducts to 1) compensate for deficient fines in aggregate mixes, or to impart other physical characteristics to the aggregate mixture, or 2) substitute the use of fossil fuel combustion byproducts for other minerals or compounds in coatings, paints, plastics, or metals.

mineral-matter-free basis - Refers to a method of reporting coal (or other solid fuel) analysis (either proximate or ultimate) whereby the ash and other minerals which are in the original coal/fuel are eliminated and the other constituents are recalculated to total 100 percent.

mining applications - The use of fossil fuel combustion byproducts to 1) in surface mining for reclamation in a landfill-like application to restore surface mined areas to original or desirable contours, or to amend mine spoil materials and acid mine drainage, or 2) in underground mining use as a flowable fill to control surface subsidence conditions, control mine fires, or seal shafts.

moisture content - The amount of water in a substance, expressed as a percent.

monofill - A landfill that contains one type of waste, such as fossil fuel combustion byproducts.

NOx - A generic acronym to describe the various oxides of nitrogen formed during the combustion of fossil fuels.

natural circulation (boiler steam/water circuit) - The circulating flow path of water, water/steam, and steam in the steam/water circuit of a boiler resulting from the addition of heat through waterwall tubes and the formation of steam bubbles in the water solution, causing a difference in water densities between waterwalls and steam drum downcomers, sometimes called thermal-siphon circulation.

New Source Performance Standards (NSPS) - Federal air pollution control standards that must be achieved by newly operational or significantly modified industrial facilities. These standards include limits on particulate matter and other boiler emissions.

Nonattainment areas or status - Air quality control areas not in compliance with the National Ambient Air Quality Standards for a given pollutant.

nonrecourse financing - If a loan is with recourse, the lender has a general claim against the parent company if the collateral is insufficient to repay the debt. With nonrecourse, the only collateral for a loan is the assets of the project company. The parent company(s) is protected against a claim from the lenders should the project company not be able to repay the debt. The lenders look only to the assets of the project company for repayment of principal and interest. Used in project financing for QF and IPP projects.

non-utility generator (NUG) - Generally is synonymous with IPP, but it is more likely to include QFs within its scope. Non-utility generators include industrial and commercial operators who produce electricity in the conduct of their own business and sell excess electricity to utilities as well as cogenerators and small power producers (as defined under PURPA).

NPDES permits - EPA permits to discharge wastewaters from a point source into surface waterways, issued under the National Pollutant Discharge Elimination System (NPDES).

off-balance-sheet financing - Refers to financing that is not shown as a liability on a company's balance sheet; it often takes the form of a project-specific nonrecourse financing. For example, a project company will secure financing where the lender has no recourse to the project company's owner(s) or parent company. Since the owner(s) or parent company are not obligated to service the project company's debts or provide collateral for the project, the owner(s) or parent company will not reflect the project company's obligations on their financial statements.

off-site - geographically noncontiguous property, or contiguous property that is not owned by the same person or entity. The opposite of on-site.

on-site - the same or geographically contiguous property which may be divided by public or private right(s) of way, provided the entrance and exit between the properties is at or across roads or intersections, and access is by crossing as opposed to going along the right(s) of way. Noncontiguous properties owned by the same person or entity connected by a right of way which the person or entity controls and to which the public does not have access, is also considered on-site property.

organic constituents - In a mixture of elements and/or compounds, those compounds that are carbon based.

overburden - The earth covering or soil overlying a deposit of coal or other mineral.

PDWS - Primary Drinking Water Standards established by the Safe Drinking Water Act.

pH - a measure of the acidity or alkalinity of a material, liquid or solid. pH is represented on a scale of 0 to 14 with 7 being neutral state, 0 being the most acidic and 14 the most alkaline.

particle size distribution - The comparative amounts of particles of different sizes within a defined volume.

particulates - fine liquid or solid particles such as dust, smoke, mist, fumes, or smog, found in the air or emissions.

partnership - An association of two or more individuals or entities who engage in business for a profit. All partnerships are automatically general partnerships (in which each partner can be held completely liable for the debts and obligations of the entire partnership) unless certain legal requirements are met and adhered to in forming and managing a limited partnership.

perched aquifer - Unconfined ground water separated from an underlying main body of ground water by a low-permeability unsaturated zone.

permeability - 1) the ability of a geologic formation to transmit ground water or other fluids through pores or cracks, 2) the rate at which water will seep through waste material.

petroleum coke - solid carbonaceous residue remaining in oil refining stills after the distillation process.

plume - a body of a pollutant originating from a specific source and influenced by such factors as the local topography, ground water flow pattern, and character of the aquifer.

pneumatic conveyance - Transport of material (e.g., fossil fuel combustion byproducts) via forced air flow.

pond liquors - waste fluid extracted from a surface impoundment or landfill.

power purchase agreement - A contractual agreement between a project company and a utility that covers the purchase of electricity over the financial life of the project, and that specifies rates and conditions of purchase.

pozzolan - A material rich in silica or silica and aluminum that is chemically inert and possesses little or no value as a cement agent, but, when in a finely divided form and in the presence of water, will react with calcium hydroxide to form compounds possessing cement-like properties.

pozzolanic - Forming a strong, slow-hardening cement-like substance when mixed with lime or other hardening material.

precipitator - See electrostatic precipitator.

Prevention of Significant Deterioration - A key element of the Clean Air Act that establishes non-degradation of air sheds with acceptable air pollutant levels as the first priority of state-level air quality programs.

primary air - Air that is either (1) introduced with the fuel at the burners, or (2) air that provides the initial fluidizing air flow and air for combustion.

products of combustion - The gases, vapors, and solids resulting from the combustion of fuel.

products of incomplete combustion (PICs) - Compounds resulting from the incomplete thermal breakdown and oxidation of organic chemicals.

project company - Usually a partnership between subsidiaries of larger companies formed for a particular project. The project company will build, own, and (possibly) operate the project.

project financing - Financing that involves a specific economic unit (often known as a project) based primarily on the cash flows from that project and the collateral value of the project's assets (i.e., asset-based financing as opposed to balance-sheet financing). See also nonrecourse financing.

proximate analysis - An analysis of a solid fuel that identifies the fuel's moisture content, volatile matter, fixed carbon, and ash content expressed on a percent by weight basis. A proximate analysis also will include the heating value of the solid fuel being analyzed.

public utility commission - A state government organization having broad authority to regulate both the prices charged by and the financial performance of investor owned public utilities.

Public Utility Holding Company Act of 1935 (PUHCA) - Federal legislation administered by the Securities and Exchange Commission.

Public Utility Regulatory Policies Act of 1978 (PURPA) - Federal legislation (PL 95-617) that is designed to encourage conservation and efficient generation of electricity. Its Title II required the FERC to promulgate rules to encourage cogeneration and small power production. As part of the general framework, the FERC requires electric utilities to purchase power from qualifying facilities at an amount equal to the purchasing utility's avoided cost for the power sold by the QF. Under the FERC's PURPA regulations, QFs are totally exempt from PUHCA.

pulverizer - A machine that reduces the particle size of a solid fuel to a fineness suitable for burning in suspension.

pyrites - A compound of iron and sulfur naturally occurring in coal. In pulverized coal combustion, pyrites are separated from the coal during pulverizing and are not introduced to the furnace.

qualifying facility (QF) - A qualifying facility is defined in FERC's PURPA implementing regulations as either a qualifying cogeneration facility which produces both electricity and useful thermal energy (such as steam or heat) or a qualifying small power production facility which uses certain fuel types. A qualifying cogeneration facility can be of any size as long as the percentage of useful thermal energy produced is not less than five (5) percent of the total energy produced when measured by combining the heat energy of the electricity produced and the thermal energy produced. In addition, while able to burn any type of fuel, the efficiency of the cogeneration facility must be at least 41 percent, as measured by the ratio of BTUs of energy output to BTUs of energy input and meet the specified ownership criteria. A qualifying small power production facility is limited in size and must meet fuel use and ownership criteria specified in the implementing regulations. In order for a power facility to be considered a QF, a project developer or owner must file an application with the FERC. A utility, utility holding company or a subsidiary of any of the foregoing may not own more than 50 percent of a QF.

quick lime - Calcium oxide (CaO).

RCRA - Resource Conservation and Recovery Act, as amended (Pub. L. 94-580). The Federal statute that provides EPA with the authority to regulate the treatment, accumulation, storage, disposal, and reclamation of solid and hazardous wastes.

radiant heat - heat transmitted by radiation as contrasted with transmitted by convection (e.g., radiant heat from the sun).

radiation - The combined process of emission, transmission, and absorption of radiant energy.

radionuclides - Elements that emit alpha, beta, and/or gamma rays by the spontaneous disintegration of atomic nuclei.

rank - A method of classifying coal based on the degree of progressive alteration in the natural series from lignite B to meta-anthracite. The rank indicates a coal's geological history and broad characteristics. According to the ranking scale, the classification limits are on a mineral-matter-free basis. The American Society of Testing and Materials (ASTM) established the ranking scale.

RCRA Subtitle C Characteristics - criteria used to determine if an unlisted waste is a hazardous waste under Subtitle C of RCRA.

> corrosivity - a solid waste is considered corrosive if it is aqueous and has a pH less than or equal to 2 or greater than or equal to 12.5 or if it is a liquid and corrodes steel at a rate greater than 6.35 mm per year at a test temperature of 55°C.
>
> toxicity - a solid waste exhibits the characteristic of toxicity if, using the Toxic Characteristic Leaching Procedure, it yields a concentration of specified contaminants equal to or exceeding values tabulated in Table 1, 40 CFR 261.24.
>
> ignitability - a solid waste exhibits the characteristic of ignitability if it is a liquid with a flashpoint below 60°C or a non-liquid capable or causing fires at standard temperature and pressure.
>
> reactivity - a solid waste is considered reactive if it reacts violently, forms potentially explosive mixtures, or generates toxic fumes when mixed with water, or if it is normally unstable and undergoes violent change with out deteriorating.

reagent - A substance that takes part in one or more chemical reactions or biological processes.

recharge - The replenishment of ground water by infiltration of precipitation though the soil.

reference dose (RfD) - An estimate (with uncertainty spanning perhaps an order of magnitude or greater) of a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime.

refractory - A brick, tile, or concrete-like material for boilers that resists high temperature, corrosion, abrasion, pressure, and rapid temperature changes. Typically, refractory is used as an insulator or abrasion-resistant lining in a combustion chamber or cyclone.

rehydration - Reincorporation of water that has been removed from a substance.

representative sample - A sample of a universe or whole (e.g., waste pile, lagoon, ground water) that can be expected to exhibit the average properties of the universe or whole.

residual waste - Unused materials or byproducts of a process that have no immediate use.

risk assessment - A formalized methodology for analyzing the adverse effects resulting from releases of hazardous substances. Risk assessment generally includes the collection of data and background information, an exposure assessment, a hazard assessment, a dose-response evaluation, and risk characterization.

risk potential - As used in this report, the potential for fossil fuel combustion byproduct management to contribute to adverse effects via the ground water, surface water, and air pathways, based on a qualitative (i.e., non-modeling) analysis of factors that influence risk.

risk screening criteria - As used in this report, a set of chemical-specific benchmarks used to compare concentrations measured in fossil fuel combustion byproducts for the purpose of determining the intrinsic hazard of the materials. Concentrations in FFCBs that fell below these criteria were judged to pose a low or negligible risk that did not need further study. Concentrations above the criteria indicated that more detailed study was needed to determine the risks associated with certain FFCB constituents and exposure pathways.

road base - Aggregate beneath the wearing surface of a road that acts as a support or substrate.

SDWS - Secondary Drinking Water Standards established by the Safe Drinking Water Act.

SO_x - The acronym used to describe the various oxides of sulfur that are formed during the combustion of fossil fuels containing sulfur or sulfur compounds.

secondary air - Combustion air supplied to the upper portions of the combustion chamber, supplementing the primary air. It provides a staged combustion effect to ensure high combustion efficiencies and to minimize NO_x production.

seeps/seepage - Springs/leakage to underlying aquifers through stream beds or the emergence of ground water into a stream channel, but may also relate to flow between different aquifer units.

selective catalytic reduction (SCR) - A process whereby a pollutant, such as NO_x, passes through a ceramic bed of trace metallic elements and is converted into a nonpollutant such as N_2 gas. SCR is also commonly used to convert other emissions such as CO to CO_2 and SO_x to either elemental sulfur or a sulfate (a particulate which can then be captured in the particulate control device).

selective non-catalytic reduction (SNCR) - A process that primarily involves injecting ammonia or urea into the top of the hot cyclone under certain temperature, pressure, and residence time conditions for converting NO_x into N_2, O_2, and H_2O.

semi-volatile organic compounds - A class of organic compounds that have a moderate tendency to vaporize.

settling lagoon - A surface impoundment used to remove solids from a liquid by gravity settling.

sewage sludge stabilization - The use of a substance (e.g., FFCB) as a dewatering or solidifying agent for sewage sludges prior to disposal or beneficial use, such as for fertilizer or soil amendment.

shear strength - The resistance offered by a material subjected to a compressive stress created when two contiguous parts of the material are forced in opposite parallel directions.

sieve - A laboratory apparatus that sifts through screens particles of a substance to separate fine particles from he coarser particles to determine volumes by size and by weight.

sintering - Causing to become a coherent mass by heating without melting.

slag - Molten or fused solid matter.

sludge - Precipitated solid matter produced by industrial processes and typically mud-like in its consistency.

slurry - A mixture of finely divided insoluble matter in a fluid.

small power production facility - A type of FERC qualifying facility that is i) limited in size, ii) limited in fuel types used, and iii) meets FERC's ownership criteria.

snow and ice control - Use of bottom ash or other fossil fuel combustion byproduct as an alternative to sand for road de-icing operations and skid control.

soil amendment - Material added to soils to change their chemical characteristics to improve crop production. For example, FFCB is used to improve the quality of soil, including pH adjustment for agricultural purposes.

soil stabilizer - A material used to prevent soil from shifting, subsiding, drifting away as fugitive dust, or eroding.

solid waste - As defined by RCRA the term "solid waste" means any garbage, refuse, sludge from a water treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities, but does not include solid or dissolved material in domestic sewage, or solid or dissolved materials in irrigation return flows or industrial discharges which are point sources subject to permits under the Clean Water Act, or special nuclear or byproduct material as defined by the Atomic Energy Act of 1954.

soot - Unburned particles of carbon, produced by the incomplete combustion of hydrocarbons.

sorbent - A constituent in a fluidized bed that reacts with and captures a pollutant.

special wastes - 1) in the context of RCRA, four categories of wastes, including FFCB, for which EPA is required to defer most RCRA Subtitle C requirements until comprehensive studies are presented to the U. S. Congress, and the most appropriate regulatory approach is determined (RCRA Section 3001 (b) (3)); 2) solid wastes that state regulatory bodies have determined are difficult to handle, require special precautions because the properties or nature of the waste creates waste management problems in normal operations.

spray drying process - A flue gas desulfurization system in which a fine spray of alkaline solution is injected into the flue gas as it passes through a contact camber, where the reaction with the sulfur oxides occurs. The heat of the flue gas evaporates the water in the solution, leaving a dry powder, which is collected by a particulate collector.

stabilization - Making resistant to physical or chemical change by treatment.

stack - A chimney or smokestack, a vertical conduit used to discharge the gaseous products of combustion to the atmosphere.

staged combustion - Combustion that involves regulating the flow of air into the combustion chamber so that the fuel is burned in "stages" as it rises through the furnace area. The introduction of secondary air at various levels provides for staged combustion.

start-up - The act or an instance of setting in operation or motion.

start-up burners - During the start-up of a boiler, start-up burners will typically fire an auxiliary fuel such as natural gas. The purpose of the burners is to raise the temperature of the boiler to allow for solid fuel ignition. The start-up burners will generally continue operating until steady state continuous solid fuel firing has been achieved.

steady state - An adjective that implies that a system is in a stable dynamic state in which inputs balance outputs.

stoichiometric combustion - The complete oxidation of all combustible constituents of a fuel using the exact amount of air suggested by theory.

stoker - See mechanical stoker.

storage - The holding of waste for a temporary period, at the end of which the waste is recovered, treated, disposed of, or stored elsewhere.

structural fills - As used in this report, the use of fossil fuel combustion byproducts in an embankment application to improve the topography and/or provide foundation support for commercial, residential, or other construction.

subbase - In the context of roads, an underlying support placed below what is normally construed as the road base.

subbituminous - A coal of intermediate rank by ASTM definition between lignite and bituminous with calorific value limits on a moist, mineral-matter-free basis of 8,300 BTU/lb to 11,500 BTU/lb.

sub-stoichiometric combustion - Combustion with a deficiency of the theoretical amount of air needed to complete combustion.

sump effluents - Waste from sumps that collect liquid from floor and equipment drains.

surface impoundment - A unit that is a natural topographic depression, artificial excavation, or diked area formed primarily of earthen materials (though it may be lined with artificial materials), which is designed to hold an accumulation of liquid wastes or wastes containing free liquids.

surface water - Water that rests on the surface of the rocky curst of the earth.

Synthetic Precipitation Leaching Procedure (SPLP) - A laboratory analytical method (No. 1312, SW-846) that simulates land disposal of inorganic wastes in monofills, a situation that occurs in some FFCB management practices.

theoretical air (stoichiometric air) - The chemically correct amount of air required for complete combustion of a given quantity of a specific fuel.

ton - A weight equal to 2,000 pounds.

total dissolved solids (TDS) - A measure of the dissolved solids in wastewater, effluent, or water bodies. Dissolved solids are disintegrated organic and inorganic materials contained in water. Excessive amounts make water unfit to drink or use in industrial processes.

total suspended solids (TSS) - A measure of suspended solids in wastewater, effluent, or water bodies, determined by tests for “total suspended non-filterable solids.” Suspended solids are small, undissolved particles of solids which could be pollutants.

toxicity (1) - The degree of danger posed by a substance to animals or plant life, or (2) - One of the four characteristics of a hazardous waste as defined by EPA (see 40 CFR Part 261).

Toxicity Characteristic Leaching Procedure (TCLP) - A laboratory method (No. 1311, SW-846) that simulates the generation and release of leachate from an improperly disposed solid waste. This procedure is applied to solid wastes to determine whether they exhibit the hazardous waste characteristic of toxicity.

trace element - An element that appears in a naturally-occurring concentration of less than 1 percent.

traveling grate stoker - A stoker similar to a chain grate stoker except that the grate is separate from but is supported on and driven by chains.

treatment - Any method, technique, or process, including neutralization, designed to change the physical, chemical, or biological character or composition of a waste so as to neutralize it, recover it, make it safer to transport, store or dispose of, or amenable for recovery, storage, or volume reduction.

turbine (steam) - An enclosed rotary-type prime mover in which heat energy from steam is converted into mechanical energy by the force of a high velocity flow of steam directed against successive rows of radial blades fastened to a central shaft.

turbine-generator - A rotary-type unit consisting of a turbine and an electric generator.

ultimate analysis - A chemical analysis of a solid fuel that states the carbon, hydrogen, sulfur, nitrogen, chlorine, oxygen and ash content expressed on a percent by weight basis.

utility boiler - A boiler that produces steam primarily for the production of electricity in the utility industry.

vacuum - A pressure less than atmospheric.

volatile - substance that tends to vaporize at relatively low temperature.

volatile matter - Consist of those products given off by a material as a gas or vapor, determined by definite prescribed test methods.

volatile organic compounds - A class of organic compounds that have a high tendency to vaporize.

waste fuel - Any by-product fuel that is a waste from a manufacturing or industrial process. The issue of whether or not a product is a waste is determined by the FERC in granting QF status to a small power producer that desires to burn a waste material.

waste management units - Locations at which wastes are treated, stored, accumulated, recovered for reuse, and/or disposed. Waste management units include wastewater treatment plants, surface impoundments, waste piles, landfills, and quarries.

waste solidification and stabilization - use of fossil fuel combustion byproducts either alone or interblended with lime and/or Portland cement or other agents to encapsulate or immobilize municipal sludges, non-toxic and toxic materials, and non-hazardous and hazardous materials.

waste stabilization - Treatment with the following reagents (or waste reagents) or combination of reagents to reduce the leachability of hazardous metals or inorganics: (1) Portland Cement; or (2) lime/pozzolans. This does not preclude the addition of reagents (e.g., iron salts, silicates, and clays) designed to enhance the set/cure time and/or compressive strength (see 40 CFR 268.42).

water-side cleaning waste - Waste produced during the removal of scale and corrosion byproducts from the water side of the boiler (i.e., the piping systems containing the steam or hot water).

water table - The level below which the soil or rock is saturated with water. It is also the upper boundary of the saturated zone. At this level, the hydraulic pressure is equal to atmospheric pressure.

wellhead protection area - An area delineated around and up gradient of a drinking water well in which activities and substances that may result in contamination of a well are regulated.

wet bottom furnace - A pulverized fuel fired furnace in which the ash particles are deposited and retained on the floor thereof and molten ash is removed by tapping either contiguously or intermittently (also called a slag tap furnace).

wet scrubber - A device utilizing a liquid, designed to separate particulate matter or gaseous contaminants from a gas stream by one or more mechanisms such as absorption, condensation, diffusion, or inertial impaction.