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PROBLEMS ASSOCIATED WITH SOLID WASTES  
FROM ENERGY SYSTEMS

by

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## EXECUTIVE SUMMARY

Over six billion tons of solid waste are annually produced in the United States. At least 40 million tons of these wastes contain toxic chemicals, many of which are man-made organic compounds that may possess mutagenic, carcinogenic, teratogenic or acutely toxic properties. Unfortunately, certain technological and scientific breakthroughs have had the adverse impact of increasing the presence of these toxic chemicals in our environment by many orders of magnitude. Prior practices for disposing of wastes containing these chemicals demonstrated that little consideration had been given to the possibility of future generations coming into contact with these toxic species.

The most frequently cited examples of inadequate waste management are those of chemical industries; however, the energy development sector may also have problems with toxic waste disposal, if precautions are not taken. Under the Fuel Use Act, passed in November 1978, emphasis is placed on increased use of conventional coal combustion in place of oil and gas. Efforts are also underway to develop and improve technologies that produce liquid and gaseous products from coal and liquids from oil shale. These coal use initiatives run counter to many environmental initiatives and, except for their possible impact on air quality, these energy developments will most affect environmental initiatives on solid waste generation. Present federal initiatives call for approximately two billion tons of coal to be mined by 2000.

The amount of coal cleaning wastes, fly ash, and scrubber sludge to be disposed of from conventional combustion, already estimated at 66 million tons per year, will escalate dramatically to more than 200 million tons per year. Of perhaps greater importance, however, is that 600 million tons of coal per year will be converted to synfuels by 2000. It is estimated that up to 50 million tons of solid waste will be generated from these conversion processes. Although much of the waste streams from these processes will contain ash and scrubber sludge, new types of wastes will also be produced. In particular, the reducing nature of the conversion processes will produce considerable amounts of coal char, tars, and oils. These wastes could contain considerable amounts of organic chemicals that are toxic or carcinogenic. In addition to coal, oil shale development will produce 180 million tons per year of solid wastes by 1995. Continuing problems will also exist in disposing of nuclear fuel cycle wastes and drilling brines and muds from domestic oil and gas production.

In this study, we review waste streams from many energy-related technologies including coal, oil shale, tar sands, geothermal, oil and gas extraction, and nuclear power generation, with an emphasis on waste streams from coal and oil shale technologies. A number of waste streams are listed in Table 1, in which we attempt to rank these streams on the basis of harmful effects on health and the environment. Given the limited data available, these comparisons must be considered somewhat subjective.

### Regulatory Uncertainties

Although "hazardous" criteria may be relaxed under the current Resource Conservation and Recovery Act (RCRA) regulations, it appears that the EPA



Table 1 Summary of Energy Wastes and Relative Hazard Potential

Technology and Waste Stream	Characteristic or Chemical of Concern	Potential Hazard Ranking <sup>a</sup>
Conventional Coal Boiler		
Ash	Various trace elements	2
Lime/limestone scrubber sludge	Various trace elements	2
AFBC		
Ash	Various trace elements	2
Spent bed material	pH, total dissolved solids (TDS), sulfates	1
Coal Gasification		
Coal cleaning	pH, trace organics and inorganics	3
Gasifier ash/char	Fused aromatics, trace elements	3
Boiler ash	Various elements	2
Boiler FGD sludge	Various elements	2
Spent catalysts	Nickel (Ni), Cobalt (Co), Arsenic (As), Cadmium (Cd), Polycyclic organic matter	3
Acid gas clean up and pollution control wastes	Phenolics, aromatics, various elements	3
Tar and oil sludges	Heterocyclics, polynuclear aromatics (PNA), other organics	3
Biosludges	Heterocyclics, PNA, other organics	3
Coal Liquefaction		
Coal cleaning	pH, trace organics and inorganics	3
Liquefaction waste (chars, ash, filter cake)	Fused aromatics, trace elements	2
Boiler ash	Various elements	3
Spent catalysts	Ni, Co, As, Cd, POM	3
Acid gas clean up and pollution control wastes	Phenolics, aromatics	3
Tar and oil sludges	Heterocyclics, PNA, other organics	3
Biosludges	Heterocyclics, PNA, other organics	3
Oil Shale		
Raw shale dust	Respirable particulates	2
Spent shale	Trace organics, PNA, trace inorganics	3
Shale oil coke	As, Selenium (Se), PNA, other organics	3
API separator sludge	Phenolics, trace elements	3
Nonshale wastes	Heterocyclics, other organics, variety of trace inorganics	3
Geothermal	As, Lead (Pb), Potassium (K), Fluorine (F), TDS	2
Tar Sands	Similar to oil shale	3
Nuclear		
Low-level wastes	Low radioactivity	2
High-level wastes	High radioactivity	3
Oil Exploration		
Drilling muds	Bactericides, metals, organics	2
Drilling brines	TDS	1

<sup>a</sup>1:low -- concentrations of chemicals are known to be low, with few additional data necessary.

2:intermediate -- concentrations of chemicals approach criteria and/or additional data may illustrate that toxic levels of the chemicals are high.

3:high -- concentrations of chemicals exceed criteria and/or there is a high potential that additional data will illustrate severe problems associated with toxic constituents.

will have considerable latitude to define hazardous wastes, particularly under the "toxic" category.

The EPA has recently revised the rules and regulations under Subtitle C of the RCRA (Federal Register, May 19, 1980). One area where changes have affected the legal standing of solid wastes is in the definition of hazardous wastes. First, a pH range of 2.5-12.5 was defined as noncorrosive and acceptable, thus reducing the number of waste streams considered hazardous. Practically all waste streams from energy industries are thus removed, with two possible exceptions. Untreated coal refuse drainage can exhibit a pH range of 1.7 to 2.9, whereas untreated, spent residue from fluidized bed combustion can exhibit a pH greater than 12.5. Second, the concentrations for Extraction Procedure (EP) toxicity were increased to one hundred times those of the National Interim Primary Drinking Water Standards (NIPDWS), and, as a result, practically all waste streams for coal and oil shale do not meet hazardous criteria. It should be noted, however, that many coal technology wastes have not been analyzed according to EP toxicity protocols. The net effect of these changes has been to take large volumes of wastes and remove them from hazardous lists in these "interim final" rules. However, extracts from some coal cleaning wastes may contain 100 times the NIPDWS concentrations for chromium.

The EPA did put two new categories in place for defining solid waste: "acute hazard" and "toxic." Since a waste may be deemed "toxic" if any one of over 350 chemicals is present, the Administrator may designate it as hazardous. The regulations provide many nonquantitative qualifiers for "toxic." Thus, it appears that the EPA will have considerable latitude in defining hazardous wastes in this category. Needless to say, many of these 350 chemicals are present in coal and oil shale solid wastes. Spent catalysts, biosludges, acid gas treatment sludge, and tars and oily sludge may have problematic characteristics with regard to the toxic criteria. In addition to the heavy metals that they already contain, spent catalysts contain trace metals and highly polymeric organic materials derived from coal and oil shale. Biosludge, acid gas treatment sludge, tars, and oily sludge tend to concentrate certain trace elements and organics originating from coal and oil shale. Thus, it is in the "toxic" category that many energy wastes may be considered hazardous.

It is possible that many energy wastes will be classified as "hazardous." Energy waste streams, in general, are presently poorly characterized and may be regulated in the future on development of a legally defensible data base. The waste streams most likely to be affected include selected streams from coal liquefaction and gasification and coal cleaning waste streams. This conclusion is based on our review and analysis of the available data presented in the following text.

#### The Nature and Problems of Coal and Oil Shale Wastes

A typical coal gasification plant is expected to produce up to five million tons per year of coal ash, which can contain considerable amounts of trace inorganics and organics. Leachate from Lurgi ash, containing high concentrations of boron, lead, cadmium, and antimony, has been shown to be

toxic to aquatic life. Few data are available on the organic species in coal gasification waste streams.

Coal liquefaction waste streams have been shown to contain many trace elements. Of greater concern here, however, are data showing that these streams contain a number of known or suspected carcinogens, including benzidine, nitrosamine, fluoranthrene, benzo(a)pyrene, -naphthylamine, benzene, and pyrene. Coal tars from both gasification and liquefaction processes are highly aromatic; studies have shown that as much as 50% of coal tar constituents contain three or more benzene rings, whereas 20% are two-ring heterocyclic compounds. Although much research needs to be done, many compounds in these organic classes have already been shown or are suspected to be carcinogenic. Naphthalene, fluoranthrene, and phenanthrene, which are found in large amounts in these tars, are toxic.

Oil shale wastes also contain toxic materials. Arsenic and selenium are two trace elements of concern, but the organics produced during the processes are of greater concern. Oil shale wastes contain phenols, heterocyclic amines, and polynuclear aromatics, which include known carcinogens (in the benzene extract of shale ash) such as 1,2-benzanthracene, 3-4-benzopyrene, 1,2,7,8-dibenzacridine, 7,12-dimethylbenz(a)anthracene, and 3-methylcholanthrene. The latter two are particularly potent carcinogens. Benzo(a)pyrene can occur in concentrations of up to 3 parts per million (ppm).

Ames tests on coal liquefaction wastes have determined that mutagenic agents occur in the basic and neutral tar fractions of high-boiling extracts of SRC-II tars. Tumor incidence was 100% following sufficient applications of heavy distillate to mouse skin. In a similar test, syncrude extracts were identified as carcinogens following application to mouse skin, whereas similar crude oil extracts were found to be noncarcinogenic. Ames tests for tar base fractions from three coal gasification processes showed more severe mutagenic effects on a particular bacteria strain than the crude tar samples themselves.

Epidemiological studies have shown that prolonged exposure to shale oil can produce skin cancer in humans. Extracts from shale wastes have been shown to be mutagenic (Ames test) and carcinogenic (mouse skin). Although data are available on some organic compounds in shale wastes, it should be noted that at least five different technologies, producing different waste streams, may be developed for oil shale retorting.

Comparison of Coal and Oil Shale Wastes to Other Waste Streams. In this portion of the study we characterized waste streams that are similar to coal and oil shale waste streams (e.g., petroleum refining, iron steel, coke scrubber sludge). Such streams were determined to be toxic as one or more of the following chemicals were present: arsenic, cadmium, chromium, lead, cyanide, phenolics, and fuel aromatics (naphthalene). A comparison of solid waste and leachates from these industries and energy industries indicates the following possible areas of energy waste regulation. Coke plant waste streams contain concentrations of phenolics on the order of 1000 ppm, and Lurgi and SRC-I waste streams contain 3500 and 45,000 ppm, respectively. Dissolved air flotation (DAF) wastes from petroleum refining contain chromium

concentrations between 28 and 260 ppm. Chromium values for bottom ash (270 ppm), fly ash (300 ppm), synthane bottom ash (240 ppm), fluidized bed combustion (FBC) spent bed (450 ppm) and Lurgi wastes (590 ppm) are all within or above this range. These values are for solids, not leachates; however, these regulated wastes were considered hazardous in the toxic category rather than the EP toxic category. Thus, no leachate tests may be necessary. Creosote wastes are considered hazardous, in part due to the presence (0.2 ppm) of benzo(a) pyrene (BAP). Coal tar has BAP concentrations of up to 2 ppm. Tars are by-products found particularly in coal liquefaction and gasification wastes.

The comparison described in the preceding paragraph is little more than cursory. However, similarities do exist between regulated "hazardous" wastes and energy wastes. Future studies and legislation will determine if it will be necessary to regulate these energy wastes in a manner similar to that used for "hazardous" wastes.

Comparison to Water Quality Criteria. Water quality criteria that allow for acceptable ambient surface water concentrations have recently been developed, most on the basis of test results, for many consent decree chemicals. Although the acceptable limits for many pollutants are very low (often on the order of g/L), concentrations of these constituents in energy solid wastes and leachates are rather high. Ash from conventional coal combustion and coal conversion and sludges from desulfurization processes can contain up to 50 trace elements, many actually found in significant quantities. Specifically, ash may contain aluminum, antimony, arsenic, barium, beryllium, boron, chlorine, chromium, cobalt, copper, gallium, germanium, iron, lead, nickel, tin, titanium, vanadium, and zinc in concentrations greater than 1000 ppm. These elements are often in forms easily dissolved and mobilized into the environment at potentially harmful levels.

Other trace constituents are also contained in coal fly and bottom ash. Benzo(a)pyrene may occur in concentrations approaching 200 ppm. Other heterocyclic amines and polynuclear aromatics in this residue are probably toxic and mutagenic.

Engineering Concerns of Disposal Site Integrity. Chemical composition data indicate a pollution problem from the leaching of many energy-related solid wastes and a need for careful site selection and monitoring. In some cases, installation of special control measures, such as liners, sealants, underground collection systems, and devices for routing ground and surface flow, may be needed. Although these control measures are potentially applicable to landfill as well as pond disposal sites, their long-term effectiveness is still a matter of concern.

There are some mechanisms by which solid waste containment areas may be breached, thus causing environmental pollution. The effectiveness of landfill cover, for example, could be decreased over the long term as a result of numerous natural phenomena, including erosion, cracking, landslide, and subsidence. Each of these phenomena can either deteriorate the structure of a landfill or produce a change in a site, thereby enhancing the rate at which contaminants reach the environment.

In many cases, landfills or ponds will be lined with either natural or artificial materials designed to provide attenuation of leachate contamination or to completely isolate the waste from the environment. The effectiveness of liner materials can decrease with time, however. For example, for a specific site condition, the leachate attenuation capacities of liner soils have limits beyond which the migration of pollutants to the environment will increase. Because most pollutants may be leached from solid residues over a long period of time, long-term protection of groundwater supplies is a serious environmental concern.

Numerous artificial liners have been proposed, including both flexible films of rubber or various plastics and nonflexible liners such as asphalt, cement, or even stabilized flue-gas desulfurization (FGD) wastes. The possible chemical reaction between the liner and a waste can result in decomposition of liner material, and thus the useful lifetimes of potential liners are a matter of concern. Flexible liners are generally guaranteed for 20-25 years, and nonflexible liners are expected to have a somewhat longer life. However long-term service data for waste containment are not yet available for either type of liner.

Solid Waste Utilization Potentials. Commercial use of solid wastes is clearly an attractive alternative to disposal, as a means of reducing both environmental impacts and costs. Only 20% of coal ash from utilities is now used; a possible increase in the use of ash and possible uses for other wastes, such as FGD sludge and fluidized-bed materials, are being evaluated. The major areas of use are in building materials, road construction, agriculture, and elemental sulfur and sulfuric acid production.

Although many technically sound applications, already developed, could potentially absorb more than the wastes generated annually, that is not likely to occur in the near future because of customer uncertainties about reliability, technical complexity of application, uniformity, and quality of products. Many of these barriers may be overcome with time, after which the extent of utilization will depend on economic considerations. Many industrial firms and research organizations are active in the development of new applications and markets for power plant coal ash.

The outlook for use of wastes other than coal ash is uncertain; for example, little use of FGD waste in the near future is foreseen. Major deterrents to the utilization of lime/limestone scrubber wastes are their variable physical and chemical properties, high transportation costs, dewatering requirements for many applications, and their inability to compete economically with other material.

Many technologies for control of sulfur dioxide and hydrogen sulfide could produce elemental sulfur or sulfuric acid as by-products. The use of recovered sulfur is limited, however, since the potential supply exceeds the total U.S. demand. Development of either new sulfur uses or acceptable methods for environmental sulfur disposal is essential.

## Problems of Other Energy-Related Wastes

Spent Geothermal Fluids. Disposal of spent geothermal fluid is a major environmental concern. Such fluids, produced when water and steam in the geothermal zone are tapped, may contain sodium chloride and bicarbonates in much higher concentrations than normally found in groundwater. Other elements such as boron, lithium, manganese, strontium, arsenic, lead, and potassium also exist in geothermal brines and may occur in high concentrations in some areas.

Oil and Gas Drilling Fluids. Oil and gas extraction wastes include drilling fluids and oil production brines. The latter are produced in association with crude oil from underground reservoirs and consist primarily of brackish waters. Drilling fluids, used in cooling and lubricating the drilling bit, transporting drill cuttings, balancing formation pressure, sealing the walls of the bore hole, and performing various other related functions, may contain many toxic substances. The basic drilling fluid predominantly used by the industry is a water-based bentonite or attapulgite clay suspension with additives to provide specifically desired properties. Many additives to drilling fluids contain materials considered toxic. Of particular concern are the bactericides (e.g., aldehydes, quaternary amines, diamine salts, sodium pentachlorophenate, and other chlorinated phenols) and corrosion inhibitors (e.g., benzoic acids, dihydroxybenzenes, substituted naphthalenes, amines, and imidazolines). Many drilling fluid additives are water soluble; therefore, leachate from drilling fluid disposal could contain dissolved toxic and caustic materials as well as a high salt concentration.

Wastes Associated with Tar Sand Development. The solid wastes from a major tar sand operation include topsoil, overburden, and tailing from tar sand extraction, and coke and oily sludge from bitumen conversion. The pollution of surface and groundwater resources may result from the leaching of salts and toxic materials from these solid wastes. However, there is a lack of quantitative information concerning the hazard characteristics of solid wastes from tar sand processing.

Radioactive Wastes. Radioactive wastes, the inevitable by-products of the generation of electricity by nuclear reactors, are encountered at all stages of the nuclear fuel cycle -- in mining and milling, in fuel fabrication, in reactor operation, in spent fuel assemblies, and in the reprocessing of spent fuel, should the last become a reality. Plutonium and other waste components present special problems since they decay very slowly and remain dangerous for hundreds of thousands of years. It would constitute a major catastrophe or a major health risk if radioactive waste materials were to escape to the environment in large quantities.

Until safe permanent disposal is devised, nuclear wastes remain a very serious health and environmental problem, and many disposal techniques are under investigation. These include deep geological burial; seabed, ice sheet, and extraterrestrial disposal; transmutation; and disposal by rock

melting in deep mine cavities and in deep drill holes. Some of these technologies are suitable for one or several types of radioactive waste. However, because some important decisions concerning nuclear energy, namely, spent fuel reprocessing and use of the breeder reactor, have been deferred indefinitely, work is continuing on methods to dispose of all kinds of wastes. Furthermore, many methods need to be researched and developed as a hedge against one or more of them proving to be technically impossible or environmentally undesirable.

### Future DOE Options

As is evident from the preceding overview, although the development of the country's energy resources is a needed national policy, this policy can have considerable impact on public health and the environment. Given uncertainties in existing data and possible regulation, it would be to DOE's benefit to develop its own program for solid wastes in the near term. This appears to be a positive step the Department could take while Congress debates the issues. This program would necessarily stress the development of an organic chemical data base and increased biological testing. DOE would thus be better prepared to develop environmental control programs based on scientific data on toxic wastes rather than waiting for a new legal definition of "toxic" and "hazardous" for a given waste stream.

To develop a program in which DOE would play the leading formative and conceptual role, a number of specific items, listed below, need to be addressed:

- (1) All solid wastes from energy systems must be evaluated and analyzed to determine their true toxic nature. These analyses should be chemical and biological. There are few data, and the sampling and analytical data that do exist apply only to a few waste streams. Emphasis should be placed on those technologies nearest to commercialization.
- (2) Control technologies for waste streams found to contain toxic or mutagenic species must be further developed and demonstrated. This effort should be directed toward the streams' isolation, containment, and ultimate disposal.
- (3) Additional research should be expended on groundwater modeling for toxic species contained in energy wastes. This effort should be specifically directed toward public health and aquatic ecosystem impacts.

These are three major areas for study. To pull these and other research and development efforts together, a center for energy toxic wastes should be established. This would provide a mechanism for the centralized collection, evaluation, and dissemination of solid and toxic waste data. Concurrently, a committee should be set up to develop requirements that would provide a consistent framework for data collection. As part of its activities, this committee would develop and oversee continuing assessment programs to evaluate the toxic nature of energy-related solid wastes on the

basis of collected data and environmental controls developments. These efforts would provide DOE with a strong continuing program for supporting solid waste policy, and research and development.



## 1 INTRODUCTION

### 1.1 BACKGROUND

Solid waste from energy technology has become a subject of increasing concern. As the regulations for air and water pollution become more stringent, a larger fraction of residuals ends up as solid waste. Some pollution control technologies such as flue gas desulfurization (FGD) not only shift the residuals from other media to the solid but also multiply the absolute quantity of wastes severalfold. Collection of residuals as solid wastes can concentrate toxic contaminants, which allows better containment and control. On the other hand, such concentration can increase occupational exposure and, if controls are inadequate, can lead to population exposures to higher concentrations of toxic materials.

An additional reason for increased concern with solid wastes from the energy sector is the recent call for increased coal use to reduce U.S. dependence on foreign oil. Moreover, it is likely that oil shale and tar sand resources will be developed. All of these technologies yield more solid wastes.

Finally, increasing public attention to the problems resulting from improper management of hazardous wastes in other industries has raised general awareness of the potential environmental problems associated with solid wastes. This has been reflected in the passage of the Resource Conservation and Recovery Act (RCRA). The RCRA has forced the energy industry to take a much closer look at solid waste disposal practices.

### 1.2 QUANTITIES OF SOLID WASTE PRODUCED

On the basis of quantitative estimates of solid wastes, we projected a significant increase in energy-related solid wastes (Table 1.1). Ash from electric utility sources was estimated to increase from  $58 \times 10^6$  tons in 1976 to  $134 \times 10^6$  tons in 1995; ash from industrial coal combustion will increase from  $7.0 \times 10^6$  tons in 1976 to  $46 \times 10^6$  tons by 2000, a sixfold increase. FGD sludge will increase fiftyfold from  $0.8 \times 10^6$  tons in 1976, to  $51 \times 10^6$  tons in 2000. These estimates were based on an energy scenario used in a DOE annual report to Congress (1978).<sup>1</sup>

The amount of solid waste from oil shale processing is also projected to increase, reaching some  $177 \times 10^6$  tons by 1995. Generation of these wastes will occur in the few counties in the Rocky Mountain region where oil shale development will occur.

One major concern about problems of solid waste from energy production entails the continued uncertainty over the disposal of high-level radioactive wastes from commercial nuclear reactors. Nuclear generation in 1995 is projected to be six times that in 1976.

Table 1.1 Estimated Solid Wastes from Energy-Related Activities ( $10^6$  Tons)<sup>a</sup>

Waste	1976	1985	1990	1995
<b>Conventional Coal Boiler</b>				
Utility				
Ash	58.0	71.0	105.0	134.0
Lime/Limestone Scrubber Sludge	0.8	5.0	30.0	51.0
Industrial				
Ash	7.0	24.0	33.0	46.0
<b>Coal Gasification</b>				
Coal Cleaning		0.2	0.7	1.8
Gasifier Ash		2.0	7.0	18.0
Boiler Ash		0.2	0.7	1.7
Boiler FGD Sludge		0.04	0.15	0.4
Biosludge		0.08	0.3	0.7
Acid Gas Clean-up		0.003	0.01	0.02
Spent Catalysts		N/A	N/A	N/A
Tar and Oil Sludges		N/A	N/A	N/A
<b>Coal Liquefaction</b>				
Coal Cleaning		2.0	2.0	18.0
Liquefaction Waste (Chars, Ash, Filter Cake)		0.9	0.9	8.0
Boiler Ash		0.025	0.025	0.2
Boiler FGD Sludge		0.03	0.03	0.3
Biosludge		0.09	0.09	0.8
Spent Catalysts		N/A	N/A	N/A
Acid Gas Clean Up		N/A	N/A	N/A
Tar and Oil Sludges		N/A	N/A	N/A
<b>Oil Shale</b>				
Raw Shale Dust		0.5	0.9	4.0
Spent Shale		19.5	39.0	173.0
Spent Shale Dust		0.04	0.08	0.35
Arsenic Waste		0.0002	0.0005	0.002
<b>Nuclear</b>				
High Level Waste ( $10^6$ x ft <sup>3</sup> )	0.007	0.02	0.03	0.04
Low Level Waste ( $10^6$ x ft <sup>3</sup> )	229.0	716.0	1030.0	1380.0

<sup>a</sup>1976 figures were estimated on the basis of energy consumption reported in DOE/EIA Monthly Energy Review. Figures for future years were estimated on the basis of Scenario C (medium supply, medium demand, medium cost) given in Ref. 1.

### 1.3 STUDY OBJECTIVES

Recently, the EPA developed interim rules for the designation and disposal of hazardous wastes.<sup>2,3</sup> Eighty-five generic (nonspecific) and process (specific) waste streams were identified as hazardous under the RCRA.

For the near term, the EPA has avoided including most energy-related wastes (e.g., coal ash and FGD sludge) on the hazardous waste list. Nevertheless, even though classified as nonhazardous, these wastes will require greater attention under the RCRA. In addition, the exemption was declared temporary while the situation is studied further. The EPA has clearly left open the possibility of classifying selected coal combustion wastes as hazardous if that should be necessary.

The study reported here was undertaken in this period of uncertainty with two objectives. The first objective is to outline the available information on energy-related solid wastes. Data on chemical composition and hazardous biological characteristics are included, supplemented by regulatory reviews and data on legally designated hazardous waste streams. The second objective is to provide disposal and utilization options. Solid waste disposal and recovery requirements specified under the RCRA are emphasized. Information presented herein should be useful for policy, environmental control, and research and development decision making regarding solid and hazardous wastes from energy production.

## 2 REVIEW OF ENVIRONMENTAL REGULATIONS

The following environmental laws affect both the quantity of solid waste produced and the manner of its management and disposal:

- Resource Conservation and Recovery Act (RCRA)
- Toxic Substances Control Act (TSCA)
- Clean Air Act (CAA)
- Federal Water Pollution Control Act (FWPCA), as amended by the Clean Water Act (CWA)
- Safe Drinking Water Act (SDWA) and Underground Injection Control Act (UICA)
- Surface Mining Control and Reclamation Act (SMCRA)

The Clean Air Act and Clean Water Act are of interest because the controls required by these laws result in greater volumes of solid wastes. The Surface Mining Control and Reclamation Act and the Safe Drinking Water Act only indirectly affect solid waste production and control. Of greater importance are the Toxic Substances Control Act, with its explicit control of toxic chemicals, and the Resource Conservation and Recovery Act, passed specifically to control solid and hazardous wastes. These laws are summarized in Table 2.1.

### 2.1 CLEAN AIR ACT (CAA) AMENDMENTS OF 1977 (PL 95-95)

Increasingly stringent air pollution control requirements have led to a growing solid waste burden. The 1970 Federal Clean Air Act Amendments established a common framework within which federal, state and local governments could work together to control air pollution. The provisions of this act were expanded by enactment of the Clean Air Act Amendments of 1977. Key elements of these laws include:

- Promulgation by the EPA of national ambient air quality standards (NAAQS) for major pollutants, including NO<sub>x</sub>, SO<sub>x</sub>, and total suspended particulates (TSP), with states having the option to establish more stringent standards.
- Development of state implementation plans (SIPs) to be submitted to the EPA for approval. In the SIP, each state specifies how the NAAQS (or its own standards, if more stringent) will be achieved (including emission limitations, compliance schedules, and enforcement provisions) within three years of promulgation of the SIP.
- Establishment by the EPA of national emission standards for certain source categories, e.g., new sources.
- Prevention of significant air quality deterioration in areas where the air quality is already better than the NAAQS.

Table 2.1 Summary of Regulatory Actions Affecting Hazardous Solid Wastes from Energy Industries

Regulation	Section(s) (as applicable)	Concern	Type of Control
RCRA (PL 94-580)	3	Hazardous solid wastes from energy must be prevented from entering the environment	Waste reuse; environmentally sound disposal site
	4	Large volumes of simple solid wastes must be properly disposed of	
TSCA (PL 94-469)	4,5,6,8	Chemicals produced in process or waste streams of emerging technologies must be stringently controlled if they might adversely affect worker health and safety, public health, or the environment	Process controls, EPA banning of process in case of harm to human health or the environment, extensive testing and recordkeeping
SMCRA (PL 95-87)	5	Ground and surface water contamination of mine wastes; Reclamation of spoil piles	Reclamation
FWPCA (PL 92-500) and CWA (PL 95-217)	Subtitle III	Priority pollutants from emerging technologies; Wastewater discharges must be stringently controlled	BAT and total recycle; These processes produce additional solid wastes
CAA (PL 95-95)		Stringent control of criteria pollutants and NESHAPS (Sec. 112)	ESP, scrubbers, etc. These will produce additional solid wastes
SDWA (PL 93-523) UICA (PL 95-190)		Wastes from energy process will cause groundwater pollution	RCRA type controls, requirement of permits for any deep well injections

State regulations control emissions of particulates and SO<sub>2</sub> from both old and new industrial and utility boilers. The extent of control varies from state to state. All states require particulate control, the ash becoming solid waste. SO<sub>2</sub> regulations are stringent enough to require scrubbers, thus adding to the solid waste burden.

Federal emission standards for new boilers of capacity over 250 x 10<sup>6</sup> Btu/hr were promulgated in June 1979. These standards restrict particulate emissions to 0.03 lb/10<sup>6</sup> Btu heat input. This will require over 99% control, and virtually all the ash will become solid waste. The SO<sub>2</sub> regulations are on a sliding scale and limit emissions to 1.2 lb/10<sup>6</sup> Btu and 90% removal or 0.6 lb/10<sup>6</sup> Btu and 70% removal. In all cases, some degree of scrubbing will be required, greatly increasing the quantities of solid waste produced.

## 2.2 FEDERAL WATER POLLUTION CONTROL ACT (FWPCA) PL 92-500 AS AMENDED BY THE CLEAN WATER ACT (CWA) PL 95-217

These acts are aimed at restoring and maintaining the integrity of the national waters. The Act directs the EPA to develop and enforce standards for waste discharges to navigable water or publicly owned wastewater treatment plants. The recent amendments require Best Available Technology (BAT) for 129 pollutants (consent decree pollutants), many of which are found in energy system waste streams. Control of these streams will create sludge that will require some form of disposal, thus increasing the volume of solid waste.

## 2.3 SAFE DRINKING WATER ACT (SDWA) PL 93-523 AND UNDERGROUND INJECTION CONTROL ACT (UICA) PL 95-190

The SDWA provides a program for the protection of public drinking water. This program entails the development of national drinking water standards to protect health and provides for the enforcement of such standards.

Section 1424(e) of the Act allows the EPA to designate a sole source aquifer, which, if contaminated, would create a significant public health hazard because it is the sole or principal source of drinking water for an area. Under Section 1442 of SDWA, a study of the nature and extent of the impact on underground sources of drinking water of ponds, pools, lagoons, pits and other surface impoundments will be performed. This assessment will involve an inventory of surface impoundments. The RCRA and SDWA inventories will be coordinated. The SDWA inventory and assessment will be used as a screening device to establish priorities for the RCRA inventory and the application of RCRA regulations so that the worst drinking water problems may be addressed first.

The Underground Injection Control Act was designed as a permitting program to protect the nation's aquifers from degradation. It will require permits for any deep well injection of wastes; these wastes may be liquid but are considered solid wastes under the RCRA because of their containment requirements.

## 2.4 SURFACE MINING CONTROL AND RECLAMATION ACT (SMCRA) PL 95-87

The overall objective of SMCRA is to protect the environment from the adverse effects of surface coal mining operations. The act provides for reclamation of the mined areas to a condition capable of supporting premining or better uses. Section 508 of the Act requires submission for federal or state approval of a reclamation plan as part of the request for a mining permit. Section 515 of the Act requires that the reclamation effort insure that all debris, acid forming materials, toxic materials, or materials constituting a fire hazard be treated or burned and compacted or otherwise disposed of in a manner designed to prevent contamination of ground and surface waters.

## 2.5 TOXIC SUBSTANCES CONTROL ACT (TSCA) PL 94-469

This legislation provides for regulations concerning removal of hazards from contact with the environment and public health. TSCA has, in many instances, been called a record-keeping act for the industrial sector. This act requires that an industry keep records on worker health and exposure as well as biological testing data. That function, along with the collection of data on as many hazardous species as necessary are two of the primary goals of TSCA. Four key provisions are contained in TSCA to accomplish these goals. Section 4 authorizes the EPA to order companies to test chemical substances or mixtures they manufacture or process. Section 5 requires submission of notice and testing data to the EPA before manufacture of any new chemical substance or of an existing substance for a significant new use. Section 8 authorizes the EPA to require record-keeping and reports and also requires companies to immediately report adverse information. The fourth provision (Section 6) is perhaps the most important since it allows the EPA to regulate the manufacture, processing, distribution, commercial use, labelling and disposal of chemical substances and mixtures, and ban them if necessary, if they present unreasonable risk to human health or the environment. The regulation or banning of a substance is, however, based on unreasonable risk that is so great as to outweigh the benefits of the chemical "using the least burdensome requirements."<sup>4</sup> The criteria for testing substances that may later be banned as a result of test data are:

1. Any activity involving a chemical substance that presents an unreasonable risk to the environment or health [Sec. 4(a)(1)(A)(i)].
2. There is not enough information to determine potential risk [Sec. 4(a)(1)(A)(ii) and Sec. 4(a)(1)(B)(ii)].
3. A chemical substance will be produced in substantial quantities and "(I) it enters or may be reasonably expected to enter the environment in substantial quantities or (II) there is or may be significant or substantial human exposure." [Sec. 4(a)(1)(B)(i)].<sup>5</sup>

One important TSCA regulation serving as a guideline affecting energy industries relates to the use and disposal of polychlorinated biphenyls

(PCBs). Specifically, "within six months of the effective date of this Act [TSCA] the Administrator shall promulgate rules to:

- prescribe methods for the disposal of polychlorinated biphenyls, and
- require polychlorinated biphenyls to be marked with clear and adequate warnings and instructions with respect to their processing, distribution in commerce, use, or disposal, or any combination of such activities.<sup>6</sup>

As a result of this directive, the EPA published regulations that include specific disposal mechanisms for these activities.<sup>7</sup> Disposal by incineration (Annex I) is subject to specific combustion criteria such as a two second dwell time at 1200°C for all liquids containing PCB and 3% excess oxygen in the stack gas of incinerators operating at a 99% combustion efficiency. Specific monitoring criteria for incineration were also developed, along with record keeping and reporting procedures. Chemical waste landfills (Annex II) also were required to meet specific technical standards, which included specific requirements for soils, i.e., that they be either clay pans or have high clay and silt content with:

- in-place soil thickness of 4 ft or a compacted soil liner 3 ft thick
- permeability of  $1 \times 10^{-7}$  cm/sec
- soil passing #200 Sieve > 30%
- liquid limits > 30
- plasticity index > 15
- artificial liner thickness > 30 mm

The bottom of the landfill was required to be "substantially above the historical high groundwater table." Flood plains, shorelands, and groundwater recharge areas were to be avoided. If the site was below the level of a 100-year flood, water diversion dikes around the landfill perimeter must be at least two feet above this level. Where the site was above this level, diversion structures capable of diverting all surface water run-off from a 24-hour, 25 year event must be provided. The location of the landfill should be in an area of low to moderate relief to minimize erosion and to prevent landslides.

An extensive set of requirements for monitoring and analysis was required for surface, groundwaters and leachate and includes at a minimum analysis for: (a) PCBs, (b) pH, (c) specific conductance and (d) chlorinated organics. The disposal operations themselves provided for placement to prevent damage to PCB containers and segregation from noncompatible materials. Plans were to be approved by the EPA Regional Administrator. As with incinerators, a system of record keeping and reporting was also developed.

Annex III provided rules for storage of PCB-containing materials prior to disposal. Some important requirements include:



- rain water must not reach containers
- area must be above 100-year flood plain elevation
- any piece of equipment used in storage operations must be decontaminated before removal from site.
- PCB containers must comply with DOT regulations (40 CFR 173.346 as revised 12/31/76)
- records and reports as provided by law

Annexes IV, V, and VI provided rules for decontamination, labelling, and record keeping and monitoring, respectively.<sup>8</sup> It should be noted that under the TSCA, the EPA later developed rules prohibiting manufacture, processing, distribution and use of PCBs unless provided for under certain stringent conditions.<sup>9</sup>

The thrust of PCB disposal is similar to those being developed for hazardous wastes under the RCRA. Thus, "the Agency has made a tentative decision to merge the TSCA PCB rules into the final RCRA regulations. Unfortunately, it has not been possible to complete this task to date. Both rules are lengthy and complicated and must be carefully coordinated to avoid regulatory loopholes and disruption of the ongoing TSCA PCB program. EPA expects to complete the task of integrating the RCRA regulations and TSCA PCB rules by the fall of 1980."<sup>10</sup>

## 2.6 RESOURCE CONSERVATION AND RECOVERY ACT (RCRA) PL 94-580

The primary objective of the RCRA is to ensure that solid wastes are managed properly. The program areas of particular importance to disposal of energy production waste include:

- hazardous waste management
- solid waste management (land disposal of nonhazardous solid wastes)
- resource conservation and energy recovery

The RCRA includes solids, liquids, semisolids, sludges, and contained gaseous materials as solid wastes. Wastes are included whether they are discarded, used, reused, recycled, reclaimed, stored, or transported.

The impact of the RCRA on the disposal of solid waste depends largely on whether the wastes are designated as hazardous or nonhazardous. In many cases classification will depend on analysis of the individual waste.

### 2.6.1 Resource Conservation and Energy Recovery

The Act encourages the conservation and recovery of materials and energy from wastes through a number of mechanisms. Subtitles D and F of the Act advocate state and regional solid waste planning that maximizes the utilization of valuable resources and encourages resource conservation. Solid

wastes must be utilized for resource recovery or be disposed of in sanitary landfills or in some other environmentally sound manner. Guidelines have been published to facilitate the identification and development of regional solid waste planning areas. Such regional planning is essential to the development of cost-intensive resource and energy recovery plans.

### 2.6.2 Criteria for Defining Hazardous Wastes

During the writing of this report, interim final rules were issued by the EPA for Subtitle C hazardous waste control. Specifically, regulations that addressed Sec. 3001 through 3006 were developed.<sup>11,12</sup> According to EPA cost and impact studies, the annual cost of implementing its program will be \$510 million, or less than 0.2% of the value of sales of the affected industries.<sup>13</sup>

Where possible, the RCRA will be integrated with other acts. No underground injection of hazardous waste will be allowed unless a permit is received according to the Underground Injection Control Act (PL 95-190) as promulgated by the Safe Drinking Act (PL 93-523). Ocean dumping will be regulated under the Marine Protection, Research, and Sanctuaries Act. Clean Water Act (PL 95-217) regulations will take precedence where the jurisdiction of that program allows. Thus, any hazardous waste discharge into water may be regulated under the Best Available Technology (BAT) Toxics program (Sec's. 301, 307, and 311), the pretreatment standards (Section 307), or the National Pollutant Discharge Elimination System (NPDES) permitting system (Sec. 402) of the Clean Water Act. There will be some areas in which RCRA takes precedence. One such example is where municipal sewage sludge would be considered hazardous. This waste would then be controlled under Subtitle C of the RCRA.

Integration with the Clean Air Act (PL 95-95) will occur primarily concerning volatile wastes. No program for these wastes has been developed. Integration with TSCA has already been considered in Section 2.5. At present, the Office of Surface Mining (OSM) of the Department of the Interior controls disposal of mining wastes under the Surface Mining Control and Reclamation Act (PL 95-87). The EPA is negotiating an agreement with the OSM whereby RCRA coverage of mining wastes will be covered under the SMCRA, assuming that the stringency of the controls will be equivalent to those the RCRA would impose.<sup>14</sup>

A special category of wastes listed in the December 18, 1978, Federal Register directly affects energy use and specifically coal.<sup>15</sup> In its interim rulemaking, the EPA has removed that category from consideration for a number of reasons. The first reason was mentioned in Section 1.3 concerning future legislative action on coal wastes.<sup>2</sup> Other reasons entailed the general belief that if these conventional coal combustion wastes are hazardous, the associated risk is low compared to those of other hazardous wastes. Furthermore, the EPA is presently prepared to propose without additional study, specific alternative treatment and disposal technologies.<sup>16</sup>

Along with removing the "special" waste category, the EPA believed that it was most appropriate to redefine the categories for hazardous waste in a

more rigorous manner. That is to say, corrosivity and some toxicity requirements were made more stringent. The result of this action is to exclude some wastes from "hazardous" designations. Thus, for corrosivity, the upper pH limit was moved from 12.0 to 12.5 (requiring a more basic or caustic waste for inclusion as hazardous), whereas the lower pH limit was moved from 3.0 to 2.0 (requiring a more acidic waste for inclusion as hazardous than previously defined).<sup>17</sup> One set of the toxicity requirements was modified to allow for less stringent control of wastes. The EPA addressed the problem by developing a test procedure called the Extraction Procedure (EP) designed to identify wastes likely to leach hazardous concentrations of particular toxic constituents into groundwater under conditions of improper management. Under this procedure, species were extracted in a manner designed to simulate leaching in landfills. The extract was then analyzed for parameters identified in the National Interim Primary Drinking Water Standards (NIPDWS).<sup>18</sup> The proposed regulation defined a waste as hazardous if the concentration of any parameter was in excess of ten times the NIPDWS for that parameter.<sup>19</sup> Since there were few empirical data on which to base this dilution factor, the EPA decided to revise this dilution factor to one deemed more appropriate in defining the relative cost/benefit for a hazardous waste listing. Thus, the EPA is adopting a 100-fold dilution factor from NIPDWS on the basis that any waste failing this test (i.e., concentrations are greater than 100 times the NIPDWS) has the potential to present a substantial hazard regardless of any attenuation mechanisms.<sup>20</sup>

The EPA chose two criteria for identifying hazardous waste characteristics. The first was that a characteristic could be described within the statutory definition in terms of some physical, chemical, or other properties. The second criterion was that the properties used to fulfill the first criterion could be measured by standardized and available testing protocols. On this basis, the EPA has removed organic toxicity, carcinogenicity, mutagenicity, teratogenicity, bioaccumulation potential, and phytotoxicity from the list of proposed characteristics listed in the December 18, 1978, Federal Register.<sup>21</sup> The following categories were retained, however:

- ignitability
- corrosivity (as discussed previously)
- reactivity
- EP toxicity (as redefined and discussed previously)

Two new categories consistent with EPA RCRA goals have been developed:

- (1) Acute Hazardous Waste: classified as such if it contains species that
  - have been found to be fatal to humans in low doses
  - result in oral LD<sub>50</sub>\* (rat) < 50 mg/kg

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\*LD<sub>50</sub> -- lethal dose, 50% -- is that quantity of a substance, administered either orally or by skin contact, necessary to kill 50% of exposed animals within a specified time.

- result in inhalation LC<sub>50</sub>\* (rat) < 2 mg/L
  - result in dermal LD<sub>50</sub> (rabbit) < 200 mg/kg
  - are capable of causing or significantly contributing to an increase in serious irreversible or incapacitating reversible illness<sup>22</sup>
- (2) Toxic Waste defined as waste containing species listed in Table 2.2,<sup>23</sup> unless deemed nonhazardous by the Administrator following consideration of:
- the nature of toxicity
  - concentration of toxic constituent
  - environmental transport potential
  - environmental persistence
  - rate of degradation to nonharmful species
  - bioaccumulation
  - plausible types of improper management
  - quantities of waste on a local, regional or national basis
  - nature and severity of health and environmental impacts
  - other governmental action
  - other factors as appropriate.<sup>22</sup>

The characteristics of ignitability, corrosivity, and reactivity are summarized in Subpart C, Part 261 - Identification and Listing of Hazardous Waste.<sup>22</sup> The characteristics that determine Extraction Procedure (EP) toxicity, that is, concentrations of leachate species above which the waste is considered hazardous, are summarized in Table 2.3.<sup>24</sup> As mentioned earlier, the maximum concentration of contaminants for extraction toxicity characteristics is now set at 100 times the Safe Drinking Water Standard, rather than 10 times, as originally proposed.

Tables 2.4 and 2.5 contain lists of waste streams which the EPA Administrator has defined as hazardous. The hazard code on the right hand side of each table defines the reason for defining these waste streams as hazardous according to the six characteristics discussed previously:

ignitable	(I)
corrosive	(C)
reactive	(R)
EP toxic	(E)
acute hazardous	(H)
toxic	(T) <sup>3</sup>

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\*LC<sub>50</sub> -- lethal concentration, 50% -- is that concentration of a substance, administered by inhalation, necessary to kill 50% of exposed animals within a specified time.

Table 2.2 Hazardous Constituents Identified in the RCRA

Acetaldehyde	Chlorinated benzenes, N.O.S.
(Aceto)phenylmercury	Chlorinated ethane, N.O.S.
Acetonitrile	Chlorinated naphthalene, N.O.S.
3-(alpha-Acetylbenzyl)-4-hydroxycoumarin and salts	Chlorinated phenol, N.O.S.
2-Acetylaminofluorene	Chloroacetaldehyde
Acetyl chloride	Chloroalkyl ethers
1-Acetyl-2-thiourea	p-Chloroaniline
Acrolein	Chlorobenzene
Acrylamide	Chlorobenzilate
Acrylonitrile	1-(p-Chlorobenzoyl)-5-methoxy-2- methylindole-3-acetic acid
Aflatoxins	p-Chloro-m-cresol
Aldrin	1-Chloro-2,3-epoxybutane
Allyl alcohol	2-Chloroethyl vinyl ether
Aluminum phosphide	Chloroform
4-Aminobiphenyl	Chloromethane
6-Amino-1,3a,2,8,6a,8b-hexahydro-6- (hydroxymethyl)-6a-methoxy-5- methylcarbamate azirino(2',3':3,4) pyrrolo(1,2-a)indole-4,7-dione (ester) (Mitomycin C)	Chloromethyl methyl ether
6-(Aminomethyl)-3-isoxazolol	2-Chloronaphthalene
4-Aminopyridine	2-Chlorophenol
Amitrole	1-(o-Chlorophenyl)thiourea
Antimony and compounds, N.O.S. <sup>1</sup>	3-Chloropropionitrile
Arsenite	alpha-Chlorotoluene
Arsenic and compounds, N.O.S.	Chlorotoluene, N.O.S.
Arsenic acid	Chromium and compounds, N.O.S.
Arsenic pentoxide	Chrysene
Arsenic trioxide	Citrus red No. 2
Auramine	Copper cyanide
Azaserine	Creosote
Barium and compounds, N.O.S.	Crotonaldehyde
Barium cyanide	Cyanides (soluble salts and complexes), N.O.S.
Benz[c]acridine	Cyanogen
Benz[a]anthracene	Cyanogen bromide
Benzene	Cyanogen chloride
Benzenearsonic acid	Cycasin
Benzenethiol	2-Cyclohexyl-4,6-dinitrophenol
Benzidine	Cyclophosphamide
Benzo[a]anthracene	Daunomycin
Benzo[b]fluoranthene	DDD
Benzo[j]fluoranthene	DDE
Benzo[a]pyrene	DDT
Benzotrichloride	Diallate
Benzyl chloride	Dibenz[a,h]acridine
Beryllium and compounds, N.O.S.	Dibenz[a,j]acridine
Bis(2-chloroethoxy)methane	Dibenz[a,h]anthracene(Dibenzo[a,h] anthracene)
Bis(2-chloroethyl) ether	7H-Dibenzo[c,g]carbazole
N,N-Bis(2-chloroethyl)-2-naphthylamine	Dibenzo[a,e]pyrene
Bis(2-chloroisopropyl) ether	Dibenzo[a,h]pyrene
Bis(chloromethyl) ether	Dibenzo[a,j]pyrene
Bis(2-ethylhexyl) phthalate	1,2-Dibromo-3-chloropropane
Bromoacetone	1,2-Dibromoethane
Bromomethane	Dibromomethane
4-Bromophenyl phenyl ether	Di-n-butyl phthalate
Brucine	Dichlorobenzene, N.O.S.
2-Butanone peroxide	3,3'-Dichlorobenzidine
Butyl benzyl phthalate	1,1-Dichloroethane
2-sec-Butyl-4,6-dinitrophenol (DNBP)	1,2-Dichloroethane
Cadmium and compounds, N.O.S.	trans-1,2-Dichloroethane
Calcium chromate	Dichloroethylene, N.O.S.
Calcium cyanide	1,1-Dichloroethylene
Carbon disulfide	Dichloromethane
Chlorambucil	2,4-Dichlorophenol
Chlordane (alpha and gamma isomers)	2,6-Dichlorophenol
	2,4-Dichlorophenoxyacetic acid (2,4-D)
	Dichloropropane

Table 2.2 (Cont'd)

Dichlorophenylarsine	Hexachloroethane
1,2-Dichloropropane	1,2,3,4,10,10-Hexachloro-1,4,4a,5,8,8a-hexahydro-1,4:5,8-endo,endo-dimethanonaphthalene
Dichloropropanol, N.O.S.	Hexachlorophene
Dichloropropene, N.O.S.	Hexachloropropene
1,3-Dichloropropene	Hexaethyl tetraphosphate
Dieldrin	Hydrazine
Diepoxybutane	Hydrocyanic acid
Diethylarsine	Hydrogen sulfide
0,0-Diethyl-S-(2-ethylthio)ethyl ester of phosphorothioic acid	Indeno(1,2,3-c,d)pyrene
1,2-Diethylhydrazine	Iodomethane
0,0-Diethyl-S-methylester phosphorodithioic acid	Isocyanic acid, methyl ester
0,0-Diethylphosphoric acid, O-p-nitrophenyl ester	Isosafrole
Diethyl phthalate	Kepone
0,0-Diethyl-O-(2-pyrazinyl)phosphorothioate	Lasiocarpine
Diethylstilbestrol	Lead and compounds, N.O.S.
Dihydrosafrole	Lead acetate
3,4-Dihydroxy-alpha-(methylamino)-methyl benzyl alcohol	Lead phosphate
Di-isopropylfluorophosphate (DFP)	Lead subacetate
Dimethoate	Maleic anhydride
3,3'-Dimethoxybenzidine	Malononitrile
p-Dimethylaminoazobenzene	Melphalan
7,12-Dimethylbenz(a)anthracene	Mercury and compounds, N.O.S.
3,3'-Dimethylbenzidine	Methapyrilene
Dimethylcarbamoyl chloride	Methomyl
1,1-Dimethylhydrazine	2-Methylaziridine
1,2-Dimethylhydrazine	3-Methylcholanthrene
3,3-Dimethyl-1-(methylthio)-2-butanone-O-((methylamino) carbonyl)oxime	4,4'-Methylene-bis-(2-chloroaniline)
Dimethylnitrosoamine	Methyl ethyl ketone (MEK)
alpha, alpha-Dimethylphenethylamine	Methyl hydrazine
2,4-Dimethylphenol	2-Methylacetonitrile
Dimethyl phthalate	Methyl methacrylate
Dimethyl sulfate	Methyl methanesulfonate
Dinitrobenzene, N.O.S.	2-Methyl-2-(methylthio)propionaldehyde-O-(methylcarbonyl) oxime
4,6-Dinitro-o-cresol and salts	N-Methyl-N-nitro-N-nitrosoguanidine
2,4-Dinitrophenol	Methyl parathion
2,4-Dinitrotoluene	Methylthiouracil
2,6-Dinitrotoluene Di-n-octyl phthalate	Mustard gas
1,4-Dioxane	Naphthalene
1,2-Diphenylhydrazine	1,4-Naphthoquinone
Di-n-propylnitrosamine	1-Naphthylamine
Disulfoton	2-Naphthylamine
2,4-Dithiobiuret	1-Naphthyl-2-thiourea
Endosulfen	Nickel and compounds, N.O.S.
Endrin and metabolites	Nickel carbonyl
Epichlorohydrin	Nickel cyanide
Ethyl cyanide	Nicotine and salts
Ethylene diamine	Nitric oxide
Ethylenebisdithiocarbamate (EBDC)	p-Nitroaniline
Ethyleneimine	Nitrobenzene
Ethylene oxide	Nitrogen dioxide
Ethylenethiourea	Nitrogen mustard and hydrochloride salt
Ethyl methanesulfonate	Nitrogen mustard N-oxide and hydrochloride salt
Fluoranthene	Nitrogen peroxide
Fluorine	Nitrogen tetroxide
2-Fluoroacetamide	Nitroglycerine
Fluoroacetic acid, sodium salt	4-Nitrophenol
Formaldehyde	4-Nitroquinoline-1-oxide
Glycidylaldehyde	Nitrosamine, N.O.S.
Halomethane, N.O.S.	N-Nitrosodi-N-butylamine
Heptachlor	N-Nitrosodiethanolamine
Heptachlor epoxide (alpha, beta, and gamma isomers)	N-Nitrosodiethylamine
Hexachlorobenzene	N-Nitrosodimethylamine
Hexachlorobutadiene	N-Nitrosodiphenylamine
Hexachlorocyclohexane (all isomers)	N-Nitrosodi-N-propylamine
Hexachlorocyclopentadiene	N-Nitroso-N-ethylurea
	N-Nitrosomethylethylamine
	N-Nitroso-N-methylurea

Table 2.2 (Cont'd)

N-Nitroso-N-methylurethane	Tetrachloroethene (Tetrachloroethylene)
N-Nitrosomethylvinylamine	Tetrachloromethane
N-Nitrosomorpholine	2,3,4,6-Tetrachlorophenol
N-Nitrosornicotine	Tetraethylthiopyrophosphate
N-Nitrosopiperidine	Tetraethyl lead
N-Nitrosopyrrolidine	Tetraethylpyrophosphate
N-Nitrososarcoside	Thallium and compounds, N.O.S.
5-Nitro-o-toluidine	Thallic oxide
Octamethylpyrophosphoramidate	Thallium (I) acetate
Oleyl alcohol condensed with 2 moles ethylene oxide	Thallium (I) carbonate
Osmium tetroxide	Thallium (I) chloride
7-Oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid	Thallium (I) nitrate
Parathion	Thallium selenite
Pentachlorobenzene	Thallium (I) sulfate
Pentachloroethane	Thioacetamide
Pentachloronitrobenzene (PCNB)	Thiosemicarbazide
Pentachlorophenol	Thiourea
Phenacetin	Thiuram
Phenol	Toluene
Phenyl dichloroarsine	Toluene diamine
Phenylmercury acetate	o-Toluidine hydrochloride
N-Phenylthiourea	Tolylene diisocyanate
Phosgene	Toxaphene
Phosphine	Tribromomethane
Phosphorothioic acid, O,O-dimethyl ester, O-ester with N,N-dimethyl benzene sulfonamide	1,2,4-Trichlorobenzene
Phthalic acid esters, N.O.S.	1,1,1-Trichloroethane
Phthalic anhydride	1,1,2-Trichloroethane
Polychlorinated biphenyl, N.O.S.	Trichloroethene (Trichloroethylene)
Potassium cyanide	Trichloromethanethiol
Potassium silver cyanide	2,4,5-Trichlorophenol
Pronamide	2,4,6-Trichlorophenol
1,2-Propanediol	2,4,5-Trichlorophenoxyacetic acid (2,4,5-T)
1,3-Propane sulfone	2,4,5-Trichlorophenoxypropionic acid (2,4,5-TP) (Silvex)
Propionitrile	Trichloropropane, N.O.S.
Propylthiouracil	1,2,3-Trichloropropane
2-Propyn-1-ol	0,0,0-Triethyl phosphorothioate
Pyridine	Trinitrobenzene
Reserpine	Tris(1-azridinyl)phosphine sulfide
Saccharin	Tris(2,3-dibromopropyl) phosphate
Satrole	Trypan blue
Selenious acid	Uracil mustard
Selenium and compounds, N.O.S.	Urethane
Selenium sulfide	Vanadic acid, ammonium salt
Selenourea	Vanadium pentoxide (dust)
Silver and compounds, N.O.S.	Vinyl chloride
Silver cyanide	Vinylidene chloride
Sodium cyanide	Zinc cyanide
Streptozotocin	Zinc phosphide
Strontium sulfide	
Strychnine and salts	
1,2,4,5-Tetrachlorobenzene	
2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)	
Tetrachloroethane, N.O.S.	
1,1,1,2-Tetrachloroethane	
1,1,2,2-Tetrachloroethane	

<sup>1</sup>The abbreviation N.O.S. signifies those members of the general class "not otherwise specified" in this listing.

Source: Ref. (22).

Table 2.3 Maximum Concentration of Contaminants for Characteristics of EP Toxicity

EPA Hazardous Waste Number	Contaminant	Maximum Concentration Milligrams Per Liter)
D004	Arsenic	5.0
D005	Barium	100.0
D006	Cadmium	1.0
D007	Chromium	5.0
D008	Lead	5.0
D009	Mercury	0.2
D010	Selenium	1.0
D011	Silver	5.0
D012	Endrin (1,2,3,4,10,10-hexachloro-1,7 epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo, endo-5,8-dimethano naphthalene	0.02
D013	Lindane (1,2,3,4,5,6-hexachlorocyclohexane, gamma isomer	0.4
D014	Methoxychlor (1,1,1-Trichloro-2,2-bis [p-methoxyphenyl] ethane)	
D015	Toxaphene (C <sub>10</sub> H <sub>10</sub> Cl <sub>8</sub> , Technical chlorinated camphene, 67-69 percent chlorine)	0.5
D016	2,4-D, (2,4-Dichlorophenoxyacetic acid)	10.0
D017	2,4,5-TP Silvex (2,4,5-Trichlorophenoxypropionic acid)	1.0

Source: Ref. (25)

Table 2.6 lists the chemical species for which each waste stream was deemed hazardous.<sup>25</sup> Section 261.33 of Part 261 deals with chemical products, off-specification products, and spill residues.<sup>26</sup> These parameters are not as important in terms of energy use and comparative studies as are the characteristics, waste streams, and chemicals discussed previously and listed in Tables 2.2 through 2.6. Although no coal use streams are listed, five petroleum refining streams are listed as containing toxic hazardous wastes.

### 2.6.3 Testing and Analysis Procedures

An imperative part of RCRA definition and enforcement comes from the proper use of sampling, testing, and analysis procedures and protocols. Many tests are standard and had previously been developed by the EPA or the American Society for Testing and Materials (ASTM), or both. However, given the nature of the unique sampling and analytical problems associated with standardized solid wastes measurements, the EPA developed protocols and publications to document these new methods. These procedures are summarized in Table 2.7. Details of these procedures are given in an EPA report



Table 2.4 Hazardous Waste from Nonspecific Sources

Industry and EPA hazardous waste No.	Hazardous waste	Hazard code
Generic:		
F001	The spent halogenated solvents used in degreasing, tetrachloroethylene, trichloroethylene, methylene chloride, 1,1,1-trichloroethane, carbon tetrachloride, and the chlorinated fluorocarbons; and sludges from the recovery of these solvents in degreasing operations.	(T)
F002	The spent halogenated solvents, tetrachloroethylene, methylene chloride, trichloroethylene, 1,1,1-trichloroethane, chlorobenzene, 1,1,2-trichloro-1,2,2-trifluoroethane, o-dichlorobenzene, trichlorofluoromethane and the still bottoms from the recovery of these solvents.	(T)
F003	The spent non-halogenated solvents, xylene, acetone, ethyl acetate, ethyl benzene, ethyl ether, n-butyl alcohol, cyclohexanone, and the still bottoms from the recovery of these solvents.	(T)
F004	The spent non-halogenated solvents, cresols and cresylic acid, nitrobenzene, and the still bottoms from the recovery of these solvents.	(T)
F005	The spent non-halogenated solvents, methanol, toluene, methyl ethyl ketone, methyl isobutyl ketone, carbon disulfide, isobutanol, pyridine and the still bottoms from the recovery of these solvents.	(T, T)
F006	Wastewater treatment sludges from electroplating operations.	(T)
F007	Spent plating bath solutions from electroplating operations.	(R, T)
F008	Plating bath sludges from the bottom of plating baths from electroplating operations.	(R, T)
F009	Spent stripping and cleaning bath solutions from electroplating operations.	(R, T)
F010	Quenching bath sludge from oil baths from metal heat treating operations.	(R, T)
F011	Spent solutions from salt bath pot cleaning from metal heat treating operations.	(R, T)
F012	Quenching wastewater treatment sludges from metal heat treating operations.	(T)
F013	Flotation tailings from selective flotation from mineral metals recovery operations.	(T)
F014	Cyanidation wastewater treatment tailing pond sediment from mineral metals recovery operations.	(T)
F015	Spent cyanide bath solutions from mineral metals recovery operations.	(R, T)
F016	Dewatered air pollution control scrubber sludges from coke ovens and blast furnaces.	(T)

Source: Ref. 3.

*Test Methods for Evaluating Solid Waste*,<sup>29</sup> which was prepared as required by law.<sup>27,28</sup> The methods are summarized for most of the toxic chemical species in Tables 2.8 and 2.9.<sup>29</sup>

The biggest difficulty from an analytical standpoint will be to ensure that extraction protocols are rigorously followed. Although the methodology produced reasonable reproducibility, some problems were encountered in this regard,<sup>30-32</sup> and such problems must be monitored closely. A possible solution would be to certify testing laboratories using procedures similar to those followed for certifying laboratories for drinking water analysis. The laboratories to be certified would differ in many areas, but mechanisms for certification, testing, and recordkeeping could be standardized.

#### 2.6.4 Solid Waste Disposal Requirements

The Section 4004 criteria for Solid Waste Disposal were issued in final form on September 13, 1979. The eight criteria address a broad range of health and environmental effects including floodplains, endangered species, surface water, groundwater, disease, air, application to land used in the production of food chain crops, and safety. These criteria are for determining which solid waste disposal facilities and practices pose a reasonable probability of adverse effects on health or the environment.<sup>33</sup>

The criteria apply to the full range of practices for the disposal of solid waste with the following exceptions:

- agricultural wastes, including manures and residues, returned to the soil as fertilizers or soil conditioners
- overburden from mining operations intended for return to the mine site

Table 2.5 Hazardous Waste from Specific Sources

Industry and EPA hazardous waste No.	Hazardous waste	Hazard code
Wood Preservation: K001	Bottom sediment sludge from the treatment of wastewaters from wood preserving processes that use creosote and/or pentachlorophenol	(R)
<b>Inorganic Pigments:</b>		
K002	Wastewater treatment sludge from the production of chrome yellow and orange pigments	(R)
K003	Wastewater treatment sludge from the production of molybdate orange pigments	(R)
K004	Wastewater treatment sludge from the production of zinc yellow pigments	(R)
K005	Wastewater treatment sludge from the production of chrome green pigments	(R)
K006	Wastewater treatment sludge from the production of chrome oxide green pigments (anhydrous and hydrated)	(R)
K007	Wastewater treatment sludge from the production of iron blue pigments	(R)
K008	Oven residue from the production of chrome oxide green pigments	(R)
<b>Organic Chemicals:</b>		
K009	Distillation bottoms from the production of acetaldehyde from ethylene	(R)
K010	Distillation side cuts from the production of acetaldehyde from ethylene	(R)
K011	Bottom stream from the wastewater stripper in the production of acrylonitrile	(R, T)
K012	Still bottoms from the final purification of acrylonitrile in the production of acrylonitrile	(R, T)
K013	Bottom stream from the acetonitrile column in the production of acrylonitrile	(R, T)
K014	Bottoms from the acetonitrile purification column in the production of acrylonitrile	(R, T)
K015	Still bottoms from the distillation of benzyl chloride	(R)
K016	Heavy ends or distillation residues from the production of carbon tetrachloride	(R)
K017	Heavy ends (still bottoms) from the purification column in the production of epichlorohydrin	(R)
K018	Heavy ends from fractionation in ethyl chloride production	(R)
K019	Heavy ends from the distillation of ethylene dichloride in ethylene dichloride production	(R)
K020	Heavy ends from the distillation of vinyl chloride in vinyl chloride monomer production	(R)
K021	Aqueous spent antimony catalyst waste from fluoromethanes production	(R)
K022	Distillation bottom tars from the production of phenol/acetone from cumene	(R)
K023	Distillation light ends from the production of phthalic anhydride from naphthalene	(R)
K024	Distillation bottoms from the production of phthalic anhydride from naphthalene	(R)
K025	Distillation bottoms from the production of nitrobenzene by the nitration of benzene	(R)
K026	Stripping still tails from the production of methyl ethyl pyridines	(R)
K027	Centrifuge residue from toluene diisocyanate production	(R, T)
K028	Spent catalyst from the hydrochlorinator reactor in the production of 1,1,1-trichloroethane	(R)
K029	Waste from the product stream stripper in the production of 1,1,1-trichloroethane	(R)
K030	Column bottoms or heavy ends from the combined production of trichloroethylene and perchloroethylene	(R)
<b>Pesticides:</b>		
K031	By-products salts generated in the production of MSMA and cacodylic acid	(R)
K032	Wastewater treatment sludge from the production of chlordane	(R)
K033	Wastewater and scrub water from the chlorination of cyclopentadiene in the production of chlordane	(R)
K034	Filter solids from the filtration of hexachlorocyclopentadiene in the production of chlordane	(R)
K035	Wastewater treatment sludges generated in the production of creosote	(R)
K036	Still bottoms from toluene reclamation distillation in the production of disulfoton	(R)
K037	Wastewater treatment sludges from the production of disulfoton	(R)
K038	Wastewater from the washing and stripping of phorate production	(R)
K039	Filter cake from the filtration of diethylphosphorodithionic acid in the production of phorate	(R)
K040	Wastewater treatment sludge from the production of phorate	(R)
K041	Wastewater treatment sludge from the production of toxaphene	(R)
K042	Heavy ends or distillation residues from the distillation of tetrachlorobenzene in the production of 2,4,5-T	(R)
K043	2,6-Dichlorophenol waste from the production of 2,4-D	(R)
<b>Explosives:</b>		
K044	Wastewater treatment sludges from the manufacturing and processing of explosives	(R)
K045	Spent carbon from the treatment of wastewater containing explosives	(R)
K046	Wastewater treatment sludges from the manufacturing, formulation and loading of lead-based initiating compounds	(R)
K047	Pink/red water from TNT operations	(R)
<b>Petroleum Refining:</b>		
K048	Dissolved air flotation (DAF) float from the petroleum refining industry	(R)
K049	Slip oil emulsion solids from the petroleum refining industry	(R)
K050	Heat exchanger bundle cleaning sludge from the petroleum refining industry	(R)
K051	API separator sludge from the petroleum refining industry	(R)
K052	Tank bottoms (lead) from the petroleum refining industry	(R)
<b>Leather Tanning Finishing:</b>		
K053	Chrome (blue) trimmings generated by the following subcategories of the leather tanning and finishing industry: hair pulp/chrome tan/retan/wet finish; hair save/chrome tan/retan/wet finish; retan/wet finish; no beamhouse; through-the-blue; and shearing.	(R)
K054	Chrome (blue) shavings generated by the following subcategories of the leather tanning and finishing industry: hair pulp/chrome tan/retan/wet finish; hair save/chrome tan/retan/wet finish; retan/wet finish; no beamhouse; through-the-blue; and shearing.	(R)
K055	Buffing dust generated by the following subcategories of the leather tanning and finishing industry: hair pulp/chrome tan/retan/wet finish; hair save/chrome tan/retan/wet finish; retan/wet finish; no beamhouse; and through-the-blue.	(R)
K056	Sewer screenings generated by the following subcategories of the leather tanning and finishing industry: hair pulp/chrome tan/retan/wet finish; hair save/chrome tan/retan/wet finish; retan/wet finish; no beamhouse; through-the-blue; and shearing.	(R)
K057	Wastewater treatment sludges generated by the following subcategories of the leather tanning and finishing industry: hair pulp/chrome tan/retan/wet finish; hair save/chrome tan/retan/wet finish; retan/wet finish; no beamhouse; through-the-blue and shearing.	(R)
K058	Wastewater treatment sludges generated by the following subcategories of the leather tanning and finishing industry: hair pulp/chrome tan/retan/wet finish; hair save/chrome tan/retan/wet finish; and through-the-blue.	(R, T)
K059	Wastewater treatment sludges generated by the following subcategory of the leather tanning and finishing industry: hair save/non-chrome tan/retan/wet finish.	(R)
<b>Iron and Steel:</b>		
K060	Ammonia still lime sludge from coking operations	(R)
K061	Emission control dust/sludge from the electric furnace production of steel	(R)
K062	Spent pickle liquor from steel finishing operations	(R, T)
K063	Sludge from lime treatment of spent pickle liquor from steel finishing operations	(R)
Primary Copper: K064	Acid plant blowdown slurry/sludge resulting from the thickening of blowdown slurry from primary copper production	(R)
Primary Lead: K065	Surface impoundment solids contained in and dredged from surface impoundments at primary lead smelting facilities	(R)
<b>Primary Zinc:</b>		
K066	Sludge from treatment of process wastewater and/or acid plant blowdown from primary zinc production	(R)
K067	Electrolytic anode slimes/sludges from primary zinc production	(R)
K068	Cadmium plant leach residue (iron oxide) from primary zinc production	(R)
Secondary Lead: K069	Emission control dust/sludge from secondary lead smelting	(R)

Source: Ref 3.

Table 2.6 Basis for Listing Hazardous Wastes

EPA hazardous waste No.	Hazardous constituents for which listed	EPA hazardous waste No.	Hazardous constituents for which listed
F001.....	tetrachloroethylene, methylene chloride, trichloroethylene, 1,1,1-trichloroethane, chlorinated fluorocarbons, carbon tetrachloride	K020.....	ethylene dichloride, 1,1,1-trichloroethane, 1,1,2-trichloroethane, tetrachloroethanes (1,1,2,2-tetrachloroethane and 1,1,1,2-tetrachloroethane), trichloroethylene, tetrachloroethylene, carbon tetrachloride, chloroform, vinyl chloride, vinylidene chloride
F002.....	tetrachloroethylene, methylene chloride, trichloroethylene, 1,1,1-trichloroethane, chlorobenzene, 1,1,2-trichloro-1,2,2-trifluoroethane, o-dichlorobenzene, trichlorofluoromethane	K021.....	antimony, carbon tetrachloride, chloroform
F003.....	N.A.	K022.....	phenol, tars (polycyclic aromatic hydrocarbons)
F004.....	creosols and cresylic acid, nitrobenzene	K023.....	phthalic anhydride, maleic anhydride
F005.....	methanol, toluene, methyl ethyl ketone, methyl isobutyl ketone, carbon disulfide, isobutanol, pyridine	K024.....	phthalic anhydride, polymeric tar-like materials, naphthoquinone
F006.....	cadmium, chromium, nickel, cyanide (complexed)	K025.....	meta-dinitrobenzene, 2,4-dinitrotoluene
F007.....	cyanide (salts)	K026.....	paraaldehyde, pyridines, 2-picoline
F008.....	cyanide (salts)	K027.....	toluene disocyanate, toluene-2,4-diamine, tars (benzodimazapone)
F009.....	cyanide (salts)	K028.....	1,1,1-trichloroethane, vinyl chloride
F010.....	cyanide (salts)	K029.....	1,2-dichloroethane, 1,1,1-trichloroethane, vinyl chloride, vinylidene chloride, chloroform
F011.....	cyanide (salts)	K030.....	hexachlorobenzene, hexachlorobutadiene, hexachloroethane, 1,1,1,2-tetrachloroethane, 1,1,2,2-tetrachloroethane, ethylene dichloride
F012.....	cyanide (complexed)	K031.....	arsenic
F013.....	cyanide (complexed)	K032.....	hexachlorocyclopentadiene
F014.....	cyanide (complexed)	K033.....	hexachlorocyclopentadiene
F015.....	cyanide (salts)	K034.....	hexachlorocyclopentadiene
F016.....	cyanide (complexed)	K035.....	creosole, benz(a)anthracene, benz(b)fluoranthene, benzo(a)pyrene
K001.....	benzene, benz(a)anthracene, benzo(a)pyrene, chrysene, 4-nitrophenol, toluene, naphthalene, phenol, 2-chlorophenol, 2,4-dimethyl phenol, 2,4,6-trichlorophenol, pentachlorophenol, 4,6-dinitro-o-cresol, tetrachlorophenol	K036.....	toluene, phosphorodithioic and phosphorothioic acid esters
K002.....	chromium, lead	K037.....	toluene, phosphorodithioic and phosphorothioic acid esters
K003.....	chromium, lead	K038.....	phosphate, formaldehyde, phosphorodithioic and phosphorothioic acid esters
K004.....	chromium	K039.....	phosphorodithioic and phosphorothioic acid esters
K005.....	chromium, lead	K040.....	phosphate, formaldehyde, phosphorodithioic and phosphorothioic acid esters
K006.....	chromium	K041.....	toxaphene
K007.....	cyanide (complexed), chromium	K042.....	hexachlorobenzene; ortho-dichlorobenzene
K008.....	chromium	K043.....	2,4-dichlorophenol, 2,6-dichlorophenol, 2,4,6-trichlorophenol
K009.....	chloroform, formaldehyde, methylene chloride, methyl chloride, paraaldehyde, formic acid	K044.....	N.A.
K010.....	chloroform, formaldehyde, methylene chloride, methyl chloride, paraaldehyde, formic acid, chloroacetaldehyde	K045.....	N.A.
K011.....	acrylonitrile, acetonitrile, hydrocyanic acid	K046.....	lead
K012.....	acrylonitrile, acetonitrile, acrolein, acrylamide	K047.....	N.A.
K013.....	hydrocyanic acid, acrylonitrile, acetonitrile	K048.....	chromium, lead
K014.....	acetonitrile, acrylamide	K049.....	chromium, lead
K015.....	benzyl chloride, chlorobenzene, toluene, benzotrithloride	K050.....	chromium
K016.....	hexachlorobenzene, hexachlorobutadiene, carbon tetrachloride, hexachloroethane, perchloroethylene	K051.....	chromium, lead
K017.....	epichlorohydrin, chloroethers [bis(chloromethyl) ether and bis (2-chloroethyl) ethers], trichloropropane, dichloropropanols	K052.....	lead
K018.....	1,2-dichloroethane, trichloroethylene, hexachlorobutadiene, hexachlorobenzene	K053.....	chromium
K019.....	ethylene dichloride, 1,1,1-trichloroethane, 1,1,2-trichloroethane, tetrachloroethanes (1,1,2,2-tetrachloroethane and 1,1,1,2-tetrachloroethane), trichloroethylene, tetrachloroethylene, carbon tetrachloride, chloroform, vinyl chloride, vinylidene chloride	K054.....	chromium
		K055.....	chromium, lead
		K056.....	chromium, lead
		K057.....	chromium, lead
		K058.....	chromium, lead
		K059.....	N.A.
		K060.....	cyanide, naphthalene, phenolic compounds, arsenic
		K061.....	chromium, lead, cadmium
		K062.....	chromium, lead
		K063.....	chromium, lead
		K064.....	lead, cadmium
		K065.....	lead, cadmium
		K066.....	lead, cadmium
		K067.....	lead, cadmium
		K068.....	lead, cadmium
		K069.....	chromium, lead, cadmium

N.A.—Waste is hazardous because it meets either the ignitability, corrosivity or reactivity characteristic.

Source: Ref. 25.

Table 2.7 Test Methods for Evaluating Solid Wastes

Method	Reference Method
<b>Sampling</b>	
Extremely viscous liquid	ASTM <sup>a</sup> D140-70 D346-75 D420-69 D1452-65
Fly Ash	ASTM D2234-76
Containerized liquid wastes	EPA (new methods)
Liquid waste from ponds, lagoons, etc.	EPA (new methods)
<b>Analysis</b>	
Ignitability	ASTM D-93-79 or ASTM D-3278-78
Corrosivity	EPA (new methods)
Reactivity	45 FR 33122 Section 261.23
EP Toxicity	EPA (new methods) or 45 FY 33127 (Appendix II)
Acute hazard	See Sec. 2.2.1
Toxic	See Sec. 2.2.1

<sup>a</sup>American Society for Testing and Materials.

- domestic sewage or treated domestic sewage (criteria do apply to disposal of sludge resulting from the treatment of domestic sewage)
- solid or dissolved materials in irrigation return flows
- source, special nuclear or by-product materials
- industrial discharges subject to permits under Section 402 of the Clean Water Act as amended
- hazardous waste disposal facilities subject to regulation under Subtitle C of RCRA
- underground well injection facilities subject to regulations for the Underground Injection Control Program.<sup>34</sup>

The criteria are flexible and provide the opportunity for state and local solid waste management agencies to take into account site-by-site variations and make assessments on local conditions. The EPA tried to set specific performance standards that defined unacceptable environmental effects so as to provide a concise and measurable means of determining compliance. However, in some situations it was not possible to devise a meaningful performance standard for an environmental effect, given the lack of experience with regulation of solid waste.<sup>33</sup>

The criteria are the same for existing facilities and new facilities, although it was suggested that there be less stringent criteria for existing

Table 2.8 Analytical Methods for Organic Chemicals

Compound	Sample handling class/fraction	Non-GC methods	Measurement techniques			Compound	Sample handling class/fraction	Non-GC methods	Measurement techniques		
			GC/MS	Conventional GC	Detector				GC/MS	Conventional GC	Detector
Acetonitrile	Volatile		8.24	8.03	NSD	Nitrobenzene	Extractable/BN		8.25	8.09	FID
Acrolein	Volatile		8.24	8.03	NSD	4-Nitrophenol	Extractable/A		8.24	8.04	ECD, FID
Acrylamide	Volatile		8.24	8.01	FID	Paraldehyde (trimer of acetaldehyde)	Volatile		8.24	8.01	FID
Acrylonitrile	Volatile		8.24	8.03	NSD	Pentachlorophenol	Extractable/A		8.25	8.04	ECD
Benzene	Volatile		8.24	8.02	PID	Phenol	Extractable/A		8.25	8.04	ECD, FID
Benz(a)anthracene	Extractable/BN	8.10 (HPLC)	8.25	8.10	FID	Phorate	Extractable/BN			8.22	FPD
Benzo(a)pyrene	Extractable/BN	8.10 (HPLC)	8.25	8.10	FID	Phosphorodithioic acid esters	Extractable/BN			8.06	ECD, FID
Benzo(b)fluoranthene	Extractable/BN	8.10 (HPLC)	8.25	8.12	ECD					8.09	ECD, FID
Benzotrichloride	Extractable/BN		8.24	8.01	HSD					8.22	FPD
Benzyl chloride	Volatile or Extractable/BN		8.25	8.12	ECD					8.06	ECD, FID
			8.25	8.10	FID	Phthalic anhydride	Extractable/BN		8.25	8.06	ECD, FID
			8.24	8.01	HSD					8.09	ECD, FID
Bis(2-chloroethoxy)methane	Volatile		8.24	8.01	HSD	2-Picoline	Extractable/BN		8.25	8.06	ECD, FID
Bis(2-chloroethyl)ether	Volatile		8.24	8.01	HSD					8.09	ECD, FID
Bis(2-chloroisopropyl)ether	Volatile		8.24	8.01	HSD	Pyridine	Extractable/BN		8.25	8.06	ECD, FID
Carbon disulfide	Volatile		8.24	8.01	HSD					8.09	ECD, FID
Carbon tetrachloride	Volatile		8.24	8.01	HSD	Tetrachlorobenzene(s)	Extractable/BN		8.25	8.12	ECD
Chlordane	Extractable/BN		8.25	8.08	HSD	Tetrachloroethane(s)	Volatile		8.24	8.01	HSD
Chlorinated dibenzodioxins	Extractable/BN		8.25	8.08	ECD	Tetrachloroethene	Volatile		8.24	8.01	HSD
Chlorinated biphenyls	Extractable/BN		8.25	8.08	HSD	Tetrachlorophenol	Extractable/A		8.24	8.04	ECD
Chloroacetaldehyde	Volatile		8.24	8.01	HSD	Toluene	Volatile		8.24	8.02	PID
Chlorobenzenes	Volatile		8.24	8.01	HSD	Toluenediamine	Extractable/BN		8.25		
				8.02	PID	Toluene diisocyanate(s)	Extractable/nonspecific		8.25	8.06	FID
Chloroform	Volatile		8.24	8.01	HSD	Toxaphene	Extractable/P		8.25	8.06	HSD
Chloromethane	Volatile		8.24	8.01	HSD	Trichloroethane	Volatile		8.24	8.01	HSD
2-Chlorophenol	Extractable/BN		8.25	8.04	FID, ECD	Trichloroethene(s)	Volatile		8.24	8.01	HSD
Chrysene	Extractable/BN	8.10 (HPLC)	8.25	8.10	FID	Trichlorofluoromethane	Volatile		8.24	8.01	HSD
Creosote	Extractable/BN		8.25	8.10	ECD	Trichlorophenol(s)	Extractable/A		8.25	8.04	HSD
Cresol(s)	Extractable/A		8.25	8.04	FID, ECD	2,4,5-TP (Silvex)	Extractable/A		8.25	8.40	HSD
Crotylic acid(s)	Extractable/A		8.25	8.04	FID, ECD	Trichloropropane	Volatile		8.24	8.01	HSD
Dichlorobenzene(s)	Extractable/BN		8.25	8.01	HSD	Vinyl chloride	Volatile		8.24	8.01	HSD
				8.02	PID	Vinylidene chloride	Volatile		8.24	8.01	HSD
				8.12	ECD	Xylene	Volatile		8.24	8.02	PID
Dichloroethane(s)	Volatile		8.24	8.01	HSD						
Dichloromethane	Volatile		8.24	8.01	HSD						
Dichlorophenoxy-acetic acid	Extractable/A		8.25	8.40	HSD						
Dichloropropanol	Extractable/BN		8.25	8.12	ECD						
2,4-Dimethylphenol	Extractable/A		8.25	8.04	FID, ECD						
Dinitrobenzene	Extractable/BN		8.25	8.09	FID, ECD						
4,6-Dinitro-o-cresol	Extractable/A		8.25	8.04	FID, ECD						
2,4-Dinitrotoluene	Extractable/BN		8.25	8.09	FID, ECD						
Endrin	Extractable/P		8.25	8.06	HSD						
Ethyl ether	Volatile		8.24	8.01	FID						
				8.02	FID						
				8.01	FID						
Formaldehyde	Volatile		8.24	8.01	FID						
Formic acid	Extractable/BN		8.25	8.06	FID						
Heptachlor	Extractable/P		8.25	8.06	HSD						
Hexachlorobenzene	Extractable/BN		8.25	8.12	ECD						
Hexachlorobutadiene	Extractable/BN		8.25	8.12	ECD						
Hexachloroethane	Extractable/BN		8.25	8.12	ECD						
Hexachlorocyclopentadiene	Extractable/BN		8.25	8.12	ECD						
Lindane	Extractable/P		8.25	8.06	HSD						
Maleic anhydride	Extractable/BN		8.25	8.06	ECD, FID						
Methanol	Volatile		8.24	8.01	FID						
Methomyl	Extractable/BN	8.32 (HPLC)									
Methyl ethyl ketone	Volatile		8.25	8.01	FID						
				8.02	FID						
Methyl isobutyl ketone	Volatile		8.25	8.01	FID						
				8.02	FID						
Naphthalene	Extractable/BN		8.25	8.10	FID						
Naphthoquinone	Extractable/BN		8.25	8.06	ECD, FID						

\* Analyze for phenanthrene and carbazole; if these are present in a ratio between 1.4:1 and 8:1, creosote should be considered present.

ECD = Electron capture detector; FID = Flame ionization detector; FPD = Flame photometric detector; HSD = Halide specific detector; HPLC = High pressure liquid chromatography; NSD = Nitrogen-specific detector; PID = Photoionization detector.

Source: Ref. 29.

Table 2.9 Analytical Methods for Inorganic Species

Species	Sample Handling Class	Measurement Technique	Method Number
Antimony	Digestion	Atomic Absorbtion-Furnace/Flame	8.50
Arsenic	Gaseous Hydride	Atomic Absorbtion-Flame	8.51
Barium	Digestion	Atomic Absorbtion-Furnace/Flame	8.52
Cadmium	Digestion	Atomic Absorbtion-Furnace/Flame	8.53
Chromium	Digestion	Atomic Absorbtion-Furnace/Flame	8.54
Cyanides	Hydrolysis	Atomic Absorbtion-Spectroscopy	8.55
Lead	Digestion	Atomic Absorbtion-Furnace/Flame	8.56
Mercury	Cold Vapor	Atomic Absorbtion	8.57
Nickel	Digestion	Atomic Absorbtion-Furnace/Flame	8.58
Selenium	Gaseous Hydride Digestion	Atomic Absorbtion-Furnace/Flame	8.59
Silver	Digestion	Atomic Absorbtion-Furnace/Flame	8.60

Source: Ref. 29.

facilities. However, with regard to implementation of the criteria, the Act does recognize the need to continue controlled use of existing facilities, while alternatives that comply with the criteria are being developed. A state may issue compliance schedules that allow use of the facility while it is being upgraded or while alternative options are developed.<sup>35</sup>

In addition, the criteria apply to both small and large facilities, both urban and rural. The EPA felt that exclusion of small facilities would foster the development of additional small facilities in order to escape the cost of compliance.<sup>36</sup> The standards established in the criteria constitute minimum requirements. The criteria do not preempt other state and federal requirements.<sup>33</sup>

The states have the responsibility of evaluating existing disposal facilities to determine whether they comply with the Section 4004 criteria. Those facilities that do not satisfy the criteria are "open dumps", and the EPA will publish a list of open dumps in the Federal Register. The inventory of "open dumps" will serve two major functions. First, it will inform Congress and the public about the extent of the problem. Second, it will provide an agenda for action by identifying problem facilities routinely used for disposal which should be addressed in state solid waste management plans in accordance with Section 4003 of the Act.<sup>37</sup> Specific criteria developed in Section 4004 from disposal of solid wastes are discussed below.

### Floodplains

The three components of this criterion are that facilities or practices in flood plains shall not: (1) restrict the flow of the base flood (a flood with a 1% or greater chance of occurring in any one year); (2) reduce temporary water storage of the floodplain; and (3) result in a washout of solid

waste that would pose a hazard to human life, wildlife, or land or water resources.<sup>33</sup>

It is generally desirable to locate disposal facilities outside of floodplains because wastes may be carried from the site, affecting downstream water quality and structures. In addition, filling the floodplain may restrict the flow of water causing greater flooding upstream, reduce the effectiveness of the flood-flow retaining capacity, and cause more rapid flooding downstream. The floodplain criterion prevents these adverse impacts; however, it does not prohibit location of a facility in a floodplain.

#### Endangered Species

The endangered species criterion states that facilities or practices shall not cause or contribute to the "taking" of any endangered or threatened species of plants, fish, or wildlife or destroy or modify the critical habitat of these species.<sup>38</sup>

The "taking" definition is very broadly stated and encompasses a variety of adverse effects. Taking is defined as harassing, harming, pursuing, hunting, wounding, killing, trapping, capturing or collecting or attempting to engage in such conduct. The proposed criteria used a "jeopardize" standard; however, it was decided that it was inappropriate for a definition that would be applied to a vast number of site specific conditions and that the "taking" definition was more in keeping with EPA's general intent to establish concise, measurable performance standards wherever possible.<sup>39</sup>

#### Surface Water

The surface water criterion requires compliance with the Clean Water Act (CWA) as amended. It requires that a facility or practice shall not (1) cause a discharge of pollutants in violation of the National Pollutant Discharge Elimination System (NPDES) under Section 402 of the CWA, (2) cause a discharge of dredged or fill materials that is in violation of Section 404 of the CWA, and (3) cause nonpoint pollution of waters that violates the legal requirements of implementing the water quality management plan developed under Section 208 of the CWA.<sup>38</sup>

In the final regulation, EPA has sought to coordinate the surface water standards with programs developed under the CWA. However, concerns have been raised over the ability of NPDES permitting agencies to process applications and issue permits for point source discharges of pollutants from solid waste disposal facilities because not many permits have been issued for such discharges.<sup>40</sup> In addition, very few approved state 208 plans exist.

#### Groundwater

The groundwater criterion states that a facility or practice shall not contaminate underground drinking water beyond the solid waste boundary or any boundary established by an approved state solid waste management agency.<sup>41</sup>

Contamination occurs when leachate from the disposal activity causes the concentrations of certain pollutants in groundwater to either (1) exceed the maximum contaminant level (based on the primary drinking water standards specified for that pollutant), or (2) increase at all where the background concentration of the pollutant already exceeds the applicable contaminant level. An underground drinking water source is an aquifer currently supplying drinking water for human consumption or an aquifer in which the concentration of total dissolved solids is less than 10,000 mg/L.<sup>40</sup>

In establishing the criterion, the EPA recognized that groundwater quality is important for other uses and that differing standards may be appropriate for these other purposes; however, at this time human health effects from direct consumption have the highest priority. In addition, the EPA has developed standards for drinking water but has not established standards for other uses.<sup>40</sup>

### Disease

The criterion states that the facility must control the vectors of disease through the periodic application of cover material or other techniques that are appropriate to public health. The criterion also closely defines the conditions under which sewage sludge or septic tank pumpings may be applied to the land surface.<sup>42</sup>

### Air

The air criterion has two components. First, there shall be no opening burning of residential, commercial, institutional, or industrial solid waste. This provision does not apply to infrequent burning of agricultural wastes, silvicultural waste, land clearing debris, and debris from emergency cleanup operations. Second, air emissions caused by a solid waste disposal facility shall not violate requirements developed for SIP's under the Clean Air Act.<sup>42</sup> No variance on open burning was allowed because it does not lessen the need for disease vector control or leachate control for maintaining groundwater quality. In addition, variance procedures would be difficult to administer because of the dynamic nature of the many variables involved (e.g., wind speed, and vertical dispersion efficiency of the burn).<sup>43</sup>

### Safety

The regulation requires that the concentration of explosive gases do not exceed 25% of the lower explosive limit for the gases in the facility structure and the lower explosive limit for gases at the property boundary. The criterion also contains provisions dealing with fires, bird hazards to air craft, and access.<sup>42</sup> Although this standard could potentially be applicable to several explosive gases, it is presently only applied to methane.<sup>43</sup>

The issues that might affect implementation of Section 4004 for disposal of solid wastes are discussed below.



### Criteria Flexibility

The criteria were designed to be flexible so that state and local solid waste management agencies can take site-specific conditions into account; however, this flexibility may present a problem. There is concern that too much room exists for individual interpretation and that inspection and evaluation of disposal facilities and subsequent listing on EPA's open dump list may be a very subjective undertaking despite the efforts to make the criteria as objective as possible.<sup>44</sup>

Flexibility is a key issue, especially when one takes into account that most states have little experience in solid waste management and few if any, precedents have been set. Under such conditions, it is difficult for industry to determine how the state plans to act. The EPA has developed a manual (see Ref. 45) to instruct states on how to conduct the inventory, and they will hold training sessions for state personnel; however, it will be up to the individual states to interpret the criteria, conduct the open dump inventory, and determine the process for compliance.

### Institutional Barriers

Once of the most critical problems in solid waste management today is the lack of acceptable disposal facilities due, in part, to public opposition to their siting. EPA recognizes this fact and hopes that implementation of the criteria will increase the credibility of disposal operations, thereby aiding in reducing public opposition to acceptable and needed facilities.<sup>33</sup> However, others feel that citizen reaction against facilities will actually intensify because the EPA is calling attention to the bad practices of the past and present by publishing the open dump inventory. Although public opposition may eventually change, it is unlikely that it will do so in the immediate future. Implementation of the RCRA criteria and development of effective solid waste management programs will take years and it is unlikely that public opinion will change before that time.

### State Preparedness

An important issue revolves around the question of whether or not the states are prepared to use the criteria to evaluate solid waste disposal facilities. Indications are that most states are not ready. Solid waste management programs in many states are in their infancy. Implementation of the criteria will place a variety of new responsibilities on the states including development and implementation of new laws and regulations, development of assessment procedures, and establishment of monitoring wells. Some criteria will be more easily met than others, but it appears that a majority of the states are not prepared to use a majority of the criteria. Table 2.10 provides a summary of the degree of readiness of the states.

#### 2.6.5 Hazardous Waste Disposal Requirements

The regulations for hazardous waste disposal under Section 3004 of the Act set interim operating and technical standards for the treatment, storage,

Table 2.10 State Readiness to Use the Solid Waste Disposal Criteria

Criteria	Territories and States Not Complying	Comments
Open burning of refuse	22	
Open burning of dis-eased plants	14	About half the jurisdiction require regulations upgraded
Gas emission	27	Monitoring requirements will affect almost every jurisdiction
Fire control	7	No difficulties complying
Bird hazard to aircraft	33	Urban Northwest will experience problems
Access	0	No difficulties complying
Surface water	53	Totally new sets of regulations and procedures in all jurisdictions
Groundwater	48	Substantial changes in monitoring procedures
Endangered species	50	Total revision of existing laws and regulations
Disease vectors	1	No difficulties complying
Floodplains	21	Some procedural changes in all jurisdictions

Source: Ref. 44.

and disposal of hazardous wastes. However, the EPA is aware that it may take several years, in some cases, to adequately develop the data necessary to resolve the more complex technical issues raised by the regulations in a way that will allow promulgation of national, acceptable, detailed standards.<sup>46</sup>

The interim regulations will go into effect in November 1980. By this time all existing facilities must have applied to the EPA for a permit and upgraded their facilities to meet the interim standards. As soon as a facility applies for a permit it obtains interim status, however, EPA recognizes that processing permits could take years for some facilities.

Theoretically, a facility could obtain a permit from a state solid waste management agency; however, it is not anticipated that any states will have approved hazardous waste management programs in the near future. The interim status standards are minimum requirements that the EPA feels are broadly applicable to large numbers of facilities and vast amounts of hazardous wastes. The standards address manifests, recordkeeping, reporting, waste

analysis, training, contingency plans, groundwater monitoring, and closure (see Table 2.11 for a complete listing). These standards have a significant degree of flexibility.<sup>46</sup>

These interim status standards, however, are only the bare outline of what will occur in Phases II and III. EPA expects to publish the Phase II regulations in the fall of 1980. They will be a set of technical regulations based on the agency's best engineering judgement of technical requirements that a facility must meet. The regulations will allow permits to be processed in a manner that takes into account both site-specific factors and the nature of the waste being handled. The Phase III regulations will be more definitive counterparts of the Phase II regulations and are expected to make the permitting process even more straightforward. The Phase III standards may also include standards for specific industries and wastes that require special management standards. No date has been set for the issuance of these regulations.<sup>47</sup>

The EPA used three major criteria to decide which standards should apply during the interim status. First, the standards had to be met in a straightforward manner without need for substantial interpretation by the EPA. The intent of the EPA was to minimize individual contact during the interim status period so it can concentrate on other aspects of this program. Second, it had to be possible for compliance to be achieved within the six-month period between the date the regulations were promulgated and the date they became effective. The EPA thought it unreasonable to require costly construction that might be disallowed or required to be modified during the final permitting process.<sup>46</sup> Although, the EPA used these criteria as guidelines to develop the interim regulations, they also included requirements that are exceptions to these guidelines when such requirements were judged to be of unusual importance. The two main exceptions to these criteria are the postclosure and groundwater regulations, which will be discussed in more detail below.

#### Hazardous Waste Disposal - Interim Status Standards

Table 2.11 provides a list of all items subject to regulation under the Interim Status Standards for Owners and Operators of Hazardous Waste Treatment Storage and Disposal Facilities. The closure and groundwater monitoring standards are considerably more specific and strict than the other interim standards. However, the EPA felt that the benefits obtained from early implementation substantially outweighed the disadvantages. The closure standard requires that facilities closed during interim status will be required to meet full closure and postclosure care requirements, including the requirement to have the plans for those activities approved by the EPA. Although facilities will have an additional 12 months to comply, all hazardous waste landfills, surface impoundments, and land treatment facilities must have groundwater monitoring systems unless a hydrogeological study demonstrates that such a system is unnecessary. The delayed schedule for compliance was allowed so that there would be sufficient time to install the systems.<sup>48</sup>

Table 2.11 Interim Status Standards for Hazardous Waste Disposal

Subpart	Section
<b>B - General Facility Standards</b>	265.10 Applicability
	265.11 Identification number
	265.12 Required notices
	265.13 General waste analysis
	265.14 Security
	265.15 General inspection requirements
	265.16 Personnel training
265.17 General requirements for ignitable, reactive, or incompatible wastes	
<b>C - Preparedness and Prevention</b>	265.30 Applicability
	265.31 Maintenance and operation of facility
	265.32 Required equipment
	265.33 Testing and maintenance of equipment
	265.34 Access to communications or alarm system
	265.35 Required aisle space
	265.36 [Reserved]
265.37 Arrangements with local authorities	
<b>D - Contingency Plan and Emergency Procedures</b>	265.50 Applicability
	265.51 Purpose and implementation of contingency plan
	265.52 Content of contingency plan
	265.53 Copies of contingency plan
	265.54 Amendment of contingency plan
	265.55 Emergency coordinator
	265.56 Emergency procedures

Table 2.11 (Cont'd)

Subpart		Section
E - Manifest System, Recordkeeping, and Reporting	265.70	Applicability
	265.71	Use of manifest system
	265.72	Manifest discrepancies
	265.73	Operating record
	265.74	Availability, retention, and disposition of records
	265.75	Annual report
	265.76	Unmanifested waste report
	265.77	Additional reports
	265.78-265.89	[Reserved]
	F - Groundwater Monitoring	265.90
265.91		Groundwater monitoring system
265.92		Sampling and analysis
265.93		Preparation, evaluation, and response
265.94		Recordkeeping and reporting
265.95-265.109		[Reserved]
G - Closure and Postclosure	265.110	Applicability
	265.111	Closure performance standard
	265.112	Closure plan; amendment of plan
	265.113	Time allowed for closure
	265.114	Disposal or decontamination of equipment
	265.115	Certification of closure
	265.116	[Reserved]
	265.117	Post-closure care and use of property; period of care
	265.118	Post-closure plan; amendment of plan
	265.119	Notice to local land authority
	265.120	Notice in deed to property
265.121-265.139	[Reserved]	

Table 2.11 (Cont'd)

Subpart	Section
H - Financial Requirements	265.140 Applicability
	265.141 [Reserved]
	265.142 Cost estimate for facility closure
	265.143 [Reserved]
	265.144 Cost estimate for post-closure monitoring and maintenance
	265.145-265.169 [Reserved]
	I - Use and Management of Containers
265.171 Condition of containers	
265.172 Compatibility of waste with container	
265.173 Management of containers	
265.174 Inspections	
265.175 [Reserved]	
265.176 Special requirements for ignitable or reactive waste	
265.177 Special requirements for incompatible wastes	
265.178-265.189 [Reserved]	
J - Tanks	265.190 Applicability
	265.191 [Reserved]
	265.192 General operating requirements
	265.193 Waste analysis and trial tests
	265.194 Inspections
	265.195-265.196 [Reserved]
	265.197 Closure
	265.198 Special requirements for ignitable or reactive waste
	265.199 Special requirements for incompatible wastes
	265.200-265.219 [Reserved]

Table 2.11 (Cont'd)

Subpart	Section
K - Surface Impoundments	265.220 Applicability
	265.221 [Reserved]
	265.222 General operating requirements
	265.223 Containment system
	265.224 [Reserved]
	265.225 Waste analysis and trial tests
	265.226 Inspections
	265.227 [Reserved]
	265.228 Closure and post-closure
	265.229 Special requirements for ignitable or reactive waste
	265.230 Special requirements for incompatible wastes
	265.231-265.249 [Reserved]
	L - Waste Piles
265.251 Protection from wind	
265.252 Waste analysis	
265.253 Containment	
265.254-265.255 [Reserved]	
265.256 Special requirements for ignitable or reactive waste.	
265.257 Special requirements for incompatible wastes	
265.258-265.269 [Reserved]	
M - Land Treatment	265.270 Applicability
	265.271 [Reserved]
	265.272 General operating requirements
	265.273 Waste analysis
	265.274-265.274 [Reserved]
	265.276 Food chain crops.
	265.277 [Reserved]
	265.278 Unsaturated zone (zone of aeration) monitoring

## Issues

Many of the same issues that are associated with solid waste disposal apply to hazardous waste disposal. The issue of public opposition to siting is even more intense for hazardous waste disposal facilities. The data from a recent study indicate that successful siting in most regions of the country is dubious at best, and grim at worst, using present siting approaches.<sup>49</sup> Both state and EPA preparedness is going to be a factor in both the development and implementation of hazardous waste regulations. It is clear that hazardous waste disposal practices are not going to change overnight. It will be several years before both the states and the EPA develop the technical expertise and effective management plans to deal with the disposal problem.

### 2.6.6 Future Options

Disposal requirements for both solid wastes and hazardous wastes will continually be refined as more information becomes available. As states begin to develop their own solid waste management programs, many of them will add more stringent standards than those required by the "open dump" inventory criteria. Hazardous waste regulations are truly in their infancy, and the EPA is already planning on issuing more detailed and technical standards.

The development of new approaches to hazardous waste siting will be critical to the success of the RCRA. It is estimated that between 1980 and 1985 about 100 new hazardous waste facilities will be needed,<sup>50</sup> and public opposition is considered to be the most critical problem in the siting of these facilities. National publicity concerning abandoned sites has made citizens increasingly aware of hazardous waste problems. Even if opposition is not successful, opponents may increasingly turn to the courts to delay siting.<sup>49</sup>

Unless circumstances change, it will be up to the states, not the EPA, to play the lead role in siting. Thus, it will be up to the states to develop and implement innovative approaches to siting. However, the EPA plans to provide assistance and is considering grants for projects that develop different approaches to siting. The first such grant is for the New England Regional Commission, which will develop siting criteria for the New England states, explore compensation and incentive approaches, and develop a region-wide implementation strategy.<sup>50</sup>



### 3 SOURCES AND NATURE OF ENERGY-RELATED SOLID WASTES

Solid wastes from energy-related activities can vary in form from liquids and wet sludges to dry particles, depending on the technology and process. This section presents characteristics of the wastes from conventional coal combustion, atmospheric fluidized bed combustion, coal gasification, coal liquefaction, oil shale mining and retorting, and other energy activities including geothermal, tar sands, nuclear, and gas and oil exploration.

This characterization of solid waste is of a general nature since there is a great deal of variation in the quantity and composition of wastes even within the same technology. For example, the character of the coal will determine both the quantities and composition of coal ash. The amount of ash produced will depend on the ash content of the coal which can vary from 5 to 25%. The quantities of trace elements in coals can also vary widely.

The quantity of waste produced is dependent in large part on air pollution regulations. The amount of spent solid from fluidized bed combustion (FBC) or sludge from flue gas desulfurization (FGD) will depend on both the sulfur content of the coal and the amount of SO<sub>2</sub> that needs to be removed to comply with regulations. The nature of the waste depends on the particular technology employed. Some gasifiers produce a dry ash whereas others produce a molten slag.

We compared the quantities of solid waste produced by the various technologies at a heat input of 10<sup>12</sup> Btu. In order to take into consideration the different efficiencies of the processes, we also considered the waste produced from the production of 10<sup>12</sup> Btu of energy. Both sets of values are listed in Table 3.1. However, care must be taken when comparing such technologies since the forms of energy produced are different, e.g., electricity from FBC and gas from coal gasification.

#### 3.1 SOLID WASTES ASSOCIATED WITH COAL UTILIZATION

Utilization of coal as an energy source results in large amounts of solid waste in six major categories: (1) Chars and ashes from combustion and conversion (gasification and liquefaction), (2) inorganic solids and sludges from FBC, air and water pollution control, and acid gas removal, (3) tars and oil sludges, (4) biosludges, (5) spent catalysts, and (6) coal cleaning wastes. Some, if not all, of these wastes may pose environmental hazards if not managed carefully. This section reviews the sources and characteristics of these wastes. Their hazard potentials are discussed in Sec. 4.

The wastes listed above are produced regularly from energy generation activities. There are other wastes that are typically part of a processing step and not commonly handled. These process streams may be under high pressure or temperature and pose a serious danger to occupational safety. If wastes from these streams must be removed from the system because of process malfunction or mishap, e.g., valve, pump, or line failure, the handling and deposition of these wastes in an environmentally sound manner may become a significant problem. Characterization of transient material from process failure is outside the scope of the present study. It would require a more

Table 3.1 Quantities of Solid Waste Generated

Technology and Waste Stream	Solid Waste Generation	
	tons/10 <sup>12</sup> Btu heat input (dry weight)	tons/10 <sup>12</sup> Btu produced (dry weight)
<b>Conventional Coal Boiler</b>		
Ash	5,000	16,000
Limestone/limestone scrubber sludge	5,200	16,000
<b>AFBC</b>		
Ash	5,000	13,000
Spent bed material	12,500	33,800
<b>Coal Gasification</b>		
Coal cleaning	1,330	2,300
Gasifier ash	13,000	22,480
Boiler ash	1,160	2,000
Boiler FGD sludge	280	480
Spent catalysts	NA <sup>a</sup>	NA
Acid gas cleanup sludge	17	30
Tar and oil sludges	NA	NA
Biosludges	500	850
<b>Coal Liquefaction</b>		
Coal cleaning	17,055	27,070
Liquefaction waste (chars, ash, filter cake)	7,000	11,100
Boiler ash	225	360
Spent catalysts	NA	NA
Acid gas cleanup sludge	NA	NA
Boiler FGD sludge	260	420
Tar and oil sludges	NA	NA
Biosludges	730	1,160
<b>Oil Shale</b>		
Raw shale dust	--	4,600
Spent shale	--	180,000
Spent shale dust	--	360
Arsenic waste	--	0.5
Spend catalysts	--	2.0
<b>Nuclear Energy</b>		
High-level waste (ft <sup>3</sup> )	5	16
Low-level waste (ft <sup>3</sup> )	165,000	500,000

<sup>a</sup>NA = not available.

exhaustive literature search, a more detailed analysis of the available data, and direct sampling and testing of process streams. It should be noted that the issues relating to the hazard potential of these wastes are significant and should be addressed when data are available.

### 3.1.1 Coal Ash and Char

Ashes and chars are the primary solid residue produced in coal utilization processes. The characteristics of solid residues produced from combustion and conversion (gasification and liquefaction) could be somewhat different and are discussed separately below.

#### 3.1.1.1 Ash From Coal Combustion

Coal combustion produces several types of ash ranging in diameter from  $< 1\mu$  to 4 cm and consisting of the inorganic mineral constituents present in coal, as well as the incompletely burned organic matter.

Fly ash is that fraction of noncombustible coal residue that is too small to settle out in the combustion chamber and becomes suspended in the high velocity flue gas. The fly ash fraction generally consists of fine spherical particles ranging in diameter from 0.5 to 100  $\mu$ . As much as 5% by weight or 20% by volume of fly ash consists of cenospheres, which are silicate glass spheres filled with nitrogen and carbon dioxide. These very lightweight particles tend to float on ash pond surfaces.

The bottom ash fraction of the coal combustion residue is composed primarily of coarser, heavier particles with porous surfaces. If the bottom ash melts to slag at burner operating temperatures, the residue resolidifies as angular, black particles with a glassy appearance.

The type of particulate collector employed determines the particle size distribution and total surface area of the collected fly ash. An electrostatic precipitator collects a much higher percentage of the very small particles (smaller than 1.5  $\mu$ ) than does a mechanical collector. The collected fly ash, however, is much less sensitive to changes in efficiency of collection than is the fly ash released to the atmosphere. The difference is most dramatic in the total mass. A change from 98% removal of total mass to 99% removal results in slightly more than a 1% increase in the mass of fly ash collected but a 50% decrease in the mass emitted to the atmosphere.

Mather<sup>51</sup> analyzed size-differentiated fractions of fly ash and concluded that lithophile materials (aluminosilicates) and alkalis (Na and K) were generally more concentrated in the finer fractions and thus in ash collected by an electrostatic precipitator. Magnetite-hematite materials (iron-bearing) were more concentrated in the coarser fractions of ash collected from the mechanical collector than they were in ash collected from the electrostatic precipitator. Carbon particles also increased in abundance as the particle size increased. Natusch<sup>52</sup> demonstrated that the toxic trace elements arsenic, antimony, cadmium, lead, selenium and thallium were most concentrated in the smallest respirable particles emitted from coal burning plants. These elements are probably volatilized during combustion and

preferentially adsorb or condense on small particles with the greatest surface area. As collection efficiency is increased, larger fractions of these particles with high concentrations of toxic elements will be collected as solid waste. Since the total additional mass is small, however, this will not lead to great changes in the overall concentration of these toxic elements in the solid waste.

The major constituents of coal ash, including silicon, aluminum, iron, and calcium, make up 95-99% of the total composition. Minor constituents, such as magnesium, titanium, sodium, potassium, sulfur, and phosphorus, generally make up 0.5-3.5%. Coal ash can also contain trace concentrations of from 20 to 50 elements, including antimony, arsenic, barium, beryllium, boron, copper, fluorine, lead, manganese, mercury, molybdenum, nickel, selenium, tellurium, thallium, tin, uranium, vanadium, and zinc. A partial identification of trace elements in coal ash is given in Table 3.2.<sup>53</sup>

Trace Elements - Coal ash is composed almost entirely of oxides. The composition varies over a wide range and there is no typical ash analysis. Table 3.3 gives the range of variation of the principal constituents of coal ash.<sup>54</sup>

Available data indicate that partitioning and concentration of trace metals occur during combustion and that certain elements can concentrate in selected size ranges of particulates.<sup>55,56</sup> Enrichment and volatilization behavior of trace elements in coal combustion is determined by the geochemical properties of the elements, the nature of the combustion process, and the reactions occurring in the emission control devices. Geochemically, the trace elements in coal are separated into four general classes: (I) lithophile; (II) chalcophile; (III) volatile elements; and (IV) unclassified elements.<sup>57</sup> Trace elements in each class are listed in Table 3.4.

Trace elements in Class I are lithophiles and are associated with aluminosilicate minerals in coal. As such they are high boiling compounds and do not decompose on combustion. Elements in this class are not enriched during combustion.

Class II elements are generally present in coal as sulfides. These sulfides may be fairly volatile or, upon combustion may decompose, leaving the trace elements in the vapor phase. The volatile sulfides or elements can then condense on the extensive surface area presented by particulates, thus leading to a surface enrichment. This enrichment is usually most prevalent in the fine particle fraction.

Class III elements boil below the furnace and flue gas temperatures and can exit from the stack as vapors.

The elements in Class IV are judged to exhibit behavior intermediate between the first two groups. Chromium and nickel tend to show chalcophile (or volatile) characteristics.

Many recent studies have attempted to quantify the chemical constituents of coal ash. Table 3.5 is a composite of these studies, showing the maximum and minimum value found for 64 elements present in bottom ash and

Table 3.2 A Partial Identification of Trace Elements in Coal Ash

Aluminum (Al)	Gallium (Ga)	Samarium (Sm)
Antimony (Sb)	Germanium (Ge)	Scandium (Sc)
Arsenic (As)	Hafnium (Hf)	Selenium (Se)
Barium (Ba)	Holmium (Ho)	Silicon (Si)
Beryllium (Be)	Indium (In)	Silver (Ag)
Bismuth (Bi)	Iodine (I)	Sodium (Na)
Boron (B)	Iron (Fe)	Strontium (Sr)
Bromine (Br)	Lanthanum (La)	Tantalum (Ta)
Cadmium (Cd)	Lead (Pb)	Tellurium (Te)
Calcium (Ca)	Lithium (Li)	Terbium (Tb)
Cerium (Ce)	Lutetium (Lu)	Thallium (Tl)
Cesium (Cs)	Magnesium (Mg)	Thorium (Th)
Chlorine (Cl)	Manganese (Mn)	Tin (Sn)
Chromium (Cr)	Mercury (Hg)	Titanium (Ti)
Cobalt (Co)	Molybdenum (Mo)	Tungsten (W)
Copper (Cu)	Neodymium (Nd)	Uranium (U)
Dysprosium (Dy)	Nickel (Ni)	Vanadium (V)
Erbium (Er)	Niobium (Nb)	Ytterbium (Yb)
Europium (Eu)	Potassium (K)	Yttrium (Y)
Fluorine (F)	Praseodymium (Pr)	Zinc (Zn)
Gadolinium (Gd)	Rubidium (Rb)	Zirconium (Zr)

Source: Ref. 53.

flyash. The studies were made on different sizes and types of systems with respect to megawatt output, furnace type, collector configuration, and, of course, type of coal burned.<sup>54</sup> The data illustrate a tremendous variability in the concentrations of many elements present in coal ashes.

Trace Organics - Researchers at Oak Ridge National Laboratory have reported trace quantities of hydrocarbon compounds in coal ash.<sup>59</sup> Individual hydrocarbon compounds exhibited concentration ranges from 66-816 ppb, with a total detected concentration of about 9 ppm. The C28-C30 hydrocarbons were in greatest concentration, with C29 the highest. Table 3.6 summarizes the estimated hydrocarbon concentration in the ash sampled. The same ash was analyzed by ORNL for the presence of polycyclic aromatic hydrocarbons (PAH). Concentrations were low, ranging generally from about 10 to 20 ppb for

Table 3.3 Major Chemical Constituents  
of Coal Ash

Constituents	Range (%)
Silica (SiO <sub>2</sub> )	6.0 - 68
Alumina (Al <sub>2</sub> O <sub>3</sub> )	4.0 - 44
Ferric Oxide (Fe <sub>2</sub> O <sub>3</sub> )	1.0 - 44
Calcium Oxide (CaO)	0.2 - 52
Magnesium Oxide (MgO)	0.1 - 14
Titanium Dioxide (TiO <sub>2</sub> )	0.4 - 4.17
Potassium Oxide (K <sub>2</sub> O)	0.1 - 4.0
Sodium Oxide (Na <sub>2</sub> O)	0.09 - 28
Sulfur Trioxide (SO <sub>3</sub> )	0.1 - 32
Carbon (C) and Volatiles	0.1 - 20

Source: Ref. 54.

Table 3.4. The Separation of Elements in the  
Geochemical Classification Scheme

Class I	Class II	Class III	Class IV
Al Mn	As	Hg	Cr
Ba Rb	Cd	Cl	Cs
Ce Sc	Cu	Br	Na
Co Si	Ga	F	Ni
Eu Sm	Pb		U
Fe Sr	Sb		V
Hf Ta			
K Th			
La Ti			
Mg			

Source: Ref. 58

Table 3.5 Chemical Constituents of Bottom Ash and Flyash

Element	Flyash (ppm)		Bottom Ash/Slag (ppm)	
	Minimum	Maximum	Minimum	Maximum
Aluminum (Al)	11,500.0	144,000.0	88,000.00	135,000.0
Antimony (Sb) <sup>a</sup>	0.8	1,000.0	0.14	12.0
Arsenic (As) <sup>a</sup>	2.3	1,700.0	0.98	40.0
Barium (Ba)	96.0	13,900.0	500.00	4,000.0
Beryllium (Be) <sup>a</sup>	1.0	1,000.0	3.00	10.6
Bismuth	<10.0	30.0	--	--
Boron (B)	10.0	3,000.0	70.00	300.0
Bromine (Br)	0.3	670.0	2.00	11.0
Cadmium (Cd) <sup>a</sup>	0.1	250.0	<0.50	<250.0
Calcium (Ca)	5,400.0	177,100.0	8,400.00	50,600.0
Cerium (Ce)	28.0	320.0	84.00	310.0
Cesium (Cs)	1.4	17.0	7.70	--
Chlorine (Cl)	13.0	25,000.0	<1,100.00	1,800.0
Chromium (Cr) <sup>a</sup>	11.0	7,400.0	15.00	270.0
Cobalt (Co)	6.0	1,500.0	3.60	380.0
Copper (Cu) <sup>a</sup>	30.0	3,020.0	2.80	720.0
Dysprosium (Dy)	4.2	31.0	37.00	--
Europium (Eu)	1.0	16.7	1.11	15.0
Fluorine (F)	0.4	624.0	10.60	100.0
Gallium (Ga)	10.0	10,000.0	5.00	64.0
Germanium (Ge)	<10.0	11,000.0	--	--
Gold (Au)	0.004	0.5	0.10	--
Hafnium (Hf)	1.4	11.0	4.60	8.5
Indium (In)	0.1	2.4	1.00	--
Iodine (I)	0.1	200.0	9.50	--
Iron (Fe)	7,800.0	289,000.0	27,000.00	203,000.0
Lanthanum (La)	17.0	270.0	155.00	75.0
Lead (Pb) <sup>a</sup>	3.1	1,600.0	<5.00	35.0
Lithium (Li)	77.0	120.0	60.00	78.0
Lutetium (Lu)	0.41	4.3	2.50	--
Magnesium (Mg)	4,900.0	60,800.0	4,500.00	32,500.0
Manganese (Mn)	31.0	4,400.0	100.00	720.0
Mercury (Hg) <sup>a</sup>	0.01	22.0	0.01	<4.0

Table 3.5 (Cont'd)

Element	Flyash (ppm)		Bottom Ash/Slag (ppm)	
	Minimum	Maximum	Minimum	Maximum
Molybdenum (Mo)	6.5	500.0	3.00	45.0
Nickel (Ni) <sup>a</sup>	1.8	8,000.0	10.00	700.0
Niobium (Nb)	16.0	<20.0	12.00	<20.0
Palladium (Pd)	0.2	--	--	--
Phosphorus (P)	600.0	2,500.0	300.00	1,600.0
Platinum (Pt)	0.7	--	--	--
Potassium (K)	1,534.0	34,700.0	7,300.00	15,800.0
Rhodium (Rh)	0.02	--	--	--
Rubidium (Rb)	25.0	300.0	48.00	300.0
Samarium (Sm)	3.7	43.0	8.20	46.0
Scandium (Sc)	2.0	400.0	10.00	85.0
Selenium (Se) <sup>a</sup>	1.2	<500.0	0.08	7.7
Silicon (Si)	196,000.0	271,000.0	180,000.00	273,000.0
Silver (Ag) <sup>a</sup>	1.0	50.0	25.00	--
Sodium (Na)	1,180.0	20,300.0	1,800.00	13,100.0
Sulfur (S)	0.11	0.25	0.06	0.09
Strontium (Sr)	40.0	9,600.0	170.00	1,800.0
Tantalum (Ta)	0.5	2.6	0.95	1.03
Tellurium (Te)	0.11	10.0	<0.02	--
Thallium (Tl)	1.1	100.0	0.25	0.30
Thorium (Th)	1.8	68.0	12.00	15.0
Tin (Sn)	<3.0	4,250.0	--	--
Titanium (Ti)	400.0	15,900.0	3,300.00	7,210.0
Tungsten (W)	2.9	42.0	38.00	--
Uranium (U)	0.8	30.1	6.78	14.9
Vanadium (V)	20.0	1,180.0	44.00	670.0
Ytterbium (Yb)	1.7	23.0	18.00	0.0
Yttrium (Y)	21.0	800.0	30.00	44.0
Zinc (Zn) <sup>a</sup>	14.0	13,000.0	24.00	950.0
Zirconium (Zr)	100.0	5,000.0	220.00	--

<sup>a</sup>On the EPA list of 65 priority pollutants.

Source: Ref. 54.



Table 3.6 Estimated Saturated n-Hydrocarbon Concentrations in Coal Ash

Component	Concentration, ppb
C <sub>15</sub>	T <sup>a</sup>
C <sub>16</sub>	192
C <sub>17</sub>	608
C <sub>18</sub>	740
C <sub>19</sub>	383
C <sub>20</sub>	308
C <sub>21</sub>	528
C <sub>22</sub>	548
C <sub>23</sub>	480
C <sub>24</sub>	308
C <sub>25</sub>	319
C <sub>26</sub>	366
C <sub>27</sub>	516
C <sub>28</sub>	664
C <sub>29</sub>	816
C <sub>30</sub>	660
C <sub>31</sub>	596
C <sub>32</sub>	344
C <sub>33</sub>	199
C <sub>34</sub>	66
Total	8.6 ppm

<sup>a</sup>T = Trace.

Source: Ref. 59.

individual species. The total PAH concentration was estimated to be at maximum about 0.2 ppm. Table 3.7 gives the PAH concentrations found in the ash sampled.

Concentrations of monomethyl and dimethyl sulfate in fly ash collected in the flue-line of a power plant burning low-sulfur coal were found to be as high as 830 ppm. Dimethyl sulfate has been shown to have mutagenic and carcinogenic properties.\*

\*Lee, M.L., et al., *Dimethyl and Monomethyl Sulfate: Presence in Coal Fly Ash and Airborne Particulate Matter*, Science, 207:186-188 (1980).

Table 3.7 Estimated Polycyclic Aromatic Hydrocarbon (PAH) Concentration in Coal Ash

PAH	Concentration ppb
Naphthalene	8.3
2-Methylnaphthalene	5.0
1-Methylnaphthal	5.2
Biphenyl	10.3
1,6- and/or 1,3-Dimethylnaphthalene	T <sup>a</sup>
2,6-Dimethylnaphthalene	T <sup>a</sup>
1,5- and/or 2,3-Dimethylnaphthalene	T <sup>a</sup>
9,10-Dihydroanthracene	12.6
Phenanthrene	17.6
2-Methylanthracene	9.1
1-Methylphenanthrene	<24.8 <sup>b</sup>
Fluoranthene	<13.4 <sup>b</sup>
Pyrene	<19.0 <sup>b</sup>
1,2-Benzofluorene	36.8
2,3-Benzofluorene	11.8
1-Methylpyrene	T
Picene	T
Total	<0.2 ppm <sup>b</sup>

<sup>a</sup>T = Trace

<sup>b</sup>< = Interference allows estimate only of maximum possible concentration.

Source: Ref. 59.

Polycyclic aromatic hydrocarbons are among the most common chemical carcinogens. Considering coal's polycyclic aromatic nature, it is not surprising that many coal products are potentially carcinogenic. Even in the late 1700s it was recognized that some coal products were carcinogenic, as evidenced by the high incidence of scrotal cancer in chimney sweeps working in areas where bituminous coal was used as fuel.

Radionuclides - The presence of radionuclides in coal ash was studied by Coles, et al.<sup>57</sup> Natural radionuclides identified in coal bottom ash and fly ash are listed in Table 3.8. The results of their analysis of specific concentrations of the various radionuclides in ash are given in Table 3.9. All of the radionuclides studied do become enriched in ash relative to the

Table 3.8 Natural Radionuclides Observed in Coal, Bottom Ash, and Flyash

Natural Decay Chain Origin	Source After Fractionation	Gamma-Producing Nuclide	Gamma Energy (keV)
$^{232}\text{Th}$	$^{228}\text{Ra}$	$^{228}\text{Ac}$	338
$^{232}\text{Th}$	$^{228}\text{Ra}$	$^{228}\text{Ac}$	911
$^{232}\text{Th}$	$^{228}\text{Th}$	$^{212}\text{Pb}$	238
$^{232}\text{Th}$	$^{228}\text{Th}$	$^{208}\text{Tl}$	583
$^{238}\text{U}$	$^{234}\text{Th}$	$^{234}\text{Th}$	63
$^{238}\text{U}$	$^{226}\text{Ra}$	$^{226}\text{Ra}$	185
$^{238}\text{U}$	$^{226}\text{Ra}$	$^{214}\text{Pb}$	295
$^{238}\text{U}$	$^{226}\text{Ra}$	$^{214}\text{Pb}$	352
$^{238}\text{U}$	$^{214}\text{Bi}$	$^{214}\text{Bi}$	609
$^{238}\text{U}$	$^{214}\text{Bi}$	$^{214}\text{Bi}$	1120
$^{238}\text{U}$	$^{214}\text{Bi}$	$^{214}\text{Bi}$	1764
$^{238}\text{U}$	$^{210}\text{Pb}$	$^{210}\text{Pb}$	46
$^{235}\text{U}$	$^{235}\text{U}$	$^{235}\text{U}$	185

Source: Ref. 57.

input coal and in general tend to concentrate on the finer particles. The control of radionuclide emissions to the atmosphere may become a major EPA initiative under NESHAPS requirements.

### 3.1.1.2 Ash and Char From Coal Conversion

Three types of coal ash can be produced in gasification and liquefaction operations: (1) dry (including fly ash); (2) melted (slag); or (3) softened (self-agglomerating). Some conversion processes, such as Synthane gasification, and H-Coal liquefaction, also produce char.

Nearly all of the inorganic constituents present in the feed coal are contained in the ashes and chars. Reported values for the residual carbon in ash and char range from a few percent to over 50%. The carbonaceous material in chars and ashes is primarily elemental carbon with small amounts of highly polymeric aromatic and heterocyclic organics.

### Char Characteristics<sup>60,61</sup>

If carbon removal during the conversion process is incomplete, char will be produced. Char is the solid residue after removal of moisture and volatile matter from coal. Depending on the nature of the process, coal

Table 3.9 Contents of the Various Radionuclides in Coal, Bottom Ash, and Fly Ash<sup>a</sup>

	ppm			pCi/g <sup>b</sup>						
	U	Th	K	40K	228Th	228Ra	210Pb	226Ra	238U	235U
Plant A <sup>c</sup>										
Coal	0.71	1.6	860	0.73	0.17	0.17	0.26	0.21	0.24	0.012
ESP fly ash	5.6	15	9400	8.1	1.7	1.7	1.4	2.3	1.9	0.093
Bottom ash	4.6	14	7900	6.8	1.5	1.5	0.58	1.9	1.5	0.072
Plant B <sup>d</sup>										
Coal	2.6	5.0	1660	1.4	0.56	0.55	0.68	0.64	0.85	0.037
ESP fly ash	11	22	7400	6.3	2.4	2.4	2.2	2.9	3.5	0.14
Bottom ash	8.4	19	7200	6.2	2.2	2.1	0.84	2.5	2.8	0.11
Scrubber ash	11	22	7200	6.2	2.5	2.5	2.8	3.0	3.6	0.14
Plant B <sup>d</sup> Post-ESP (stack)										
Fly ash (mmd) <sup>e</sup>										
17 μm	16	25	8200	7.0	2.8	2.7	4.3	3.3	5.4	0.17
6 μm	20	31	8600	7.3	3.3	3.5	10	4.6	6.8	0.28
3.8 μm	30	36	8600	7.4	3.3	4.0	14	5.3	10	0.39
2.5 μm	36	38	8100	7.0	3.3	4.2	17	5.9	12	0.50

<sup>a</sup>10-20% propagated 1 error from the mean.

<sup>b</sup>Picocuries per gram.

<sup>c</sup>Samples from Plant A; input coal contains 11.3% H<sub>2</sub>O, 9.2% ash, and 0.52% sulfur.

<sup>d</sup>Samples from Plant B; input coal contains 6.8% H<sub>2</sub>O, 23.2% ash, and 0.46% sulfur.

<sup>e</sup>mmd = mass median diameter determined by centrifugal sedimentation.

Source: Ref. 57.

conversion can produce net char amounts ranging between 10 and 55% of coal feed weight.<sup>53</sup> A single gasification plant can produce as much as four to five million tons of char per year. In general, there is a considerable reduction in total sulfur, volatile matter, hydrogen, and oxygen in char, compared to the original coal. Table 3.10 shows the analyses of the coal feeds and resulting chars for the synthane gasification process.<sup>53</sup> Table 3.11 shows the analysis of the inorganic content of the char from the H-Coal liquefaction process using Illinois #6 coal.<sup>62</sup>

After extraction, char can be used in a variety of ways. Provided that there is sufficiently high carbon content, char can be used for conversion chamber feedstock, utility combustion fuel as a hydrocarbon source, or as an absorbent in pollution control devices. Ash produced from utilization of char may have characteristics similar to that from combustion or conversion of coal.

#### Ash Characteristics<sup>60,61</sup>

The composition of ash from conversion processes is a function of the coal characteristics, severity of treatment, and location within a reactor

Table 3.10 Representative Analyses of Coals and Chars (Wt. %)

Component	Illinois Number 6	Western Kentucky	Wyoming Subbituminous	North Dakota Lignite	Pittsburgh Steam
<b>Coals</b>					
Moisture	8.3	4.3	18.1	20.6	2.5
Volatile matter	37.5	34.6	31.9	32.9	30.9
Fixed carbon	43.0	44.5	32.0	38.2	51.5
Ash	11.2	16.6	18.0	8.3	15.1
Hydrogen	5.3	4.7	5.4	5.7	4.7
Oxide	15.9	10.9	30.3	32.6	9.3
Carbon	63.0	62.7	45.2	51.5	68.4
Nitrogen	1.1	1.2	0.6	0.7	1.2
Sulfur	3.5	3.9	0.5	1.2	1.3
<b>Chars</b>					
Moisture	0.8	1.2	0.5	1.2	1.4
Volatile matter	4.0	4.8	5.1	10.0	1.6
Fixed carbon	69.9	63.3	38.1	50.2	69.3
Ash	25.3	30.7	56.3	38.6	27.7
Hydrogen	1.0	1.0	1.0	0.9	1.0
Oxygen	1.3	1.1	1.2	0.0	1.7
Carbon	70.4	64.5	40.6	58.9	68.9
Nitrogen	0.6	0.7	0.4	0.2	0.5
Sulfur	1.4	2.0	0.5	2.0	0.2

Source: Ref. 53.

Table 3.11 Inorganic Elements in the Mineral Residue from the H-Coal Process Utilizing Illinois Number 6 Coal

Element	Concentration in Coal Residue (ppm)
Aluminum (Al)	17,253
Antimony (Sb)	1.2
Arsenic (As)	1.5
Barium (Ba)	40
Beryllium (Be)	1.8
Boron (B)	300
Bromine (Br)	6.7
Cadmium (Cd)	0.4
Calcium (Ca)	7,862
Cerium (Ce)	16
Cesium (Cs)	1.7
Chlorine (Cl)	1,000
Chromium (Cr)	27.5
Cobalt (Co)	4.45
Copper (Cu)	14
Europium (Eu)	0.69
Fluorine (F)	100
Gallium (Ga)	4.6
Germanium (Ge)	4.9
Gold (Au)	-
Hafnium (Hf)	0.86
Iron (Fe)	23,662
Lanthanum (La)	9.8
Lead (Pb)	32
Lithium (Li)	-
Lutecium (Lu)	0.024
Magnesium (Mg)	884
Manganese (Mn)	77
Mercury (Hg)	-
Molybdenum (Mo)	6.4
Nickel (Ni)	21
Phosphorus (P)	44
Potassium (K)	2,490
Rubidium (Rb)	16
Samarium (Sm)	2.3
Scandium (Sc)	4.1
Selenium (Se)	-
Silicon (Si)	39,641
Silver (Ag)	0.16

Table 3.11 (Cont'd)

Element	Concentration in Coal Residue (ppm)
Sodium (Na)	619
Strontium (Sr)	30
Sulfur (S)	18,000
Tantalum (Ta)	0.17
Tellurium (Te)	0.1
Thallium (Tl)	1.7
Thorium (Th)	3.5
Tin (Sn)	0.6
Titanium (Ti)	1,019
Tungsten (W)	4.4
Uranium (U)	5.7
Vandium (V)	33
Ytterbium (Yb)	1.0
Yttrium (Y)	-
Zinc (Zn)	71
Zirconium (Zr)	41

Source: Ref. 62.

bed. Similar to coal combustion ash, major components of conversion ash include such substances as  $\text{SiO}_2$ ,  $\text{Fe}_2\text{O}_3$ , and  $\text{Al}_2\text{O}_3$ ; lesser components will include  $\text{CaO}$ ,  $\text{MgO}$ , and  $\text{SO}_3$ . In addition, many trace elements will be included and enriched in comparison to their abundance in coal. However, it is possible that the composition of conversion ash may vary substantially from that of ash generated in conventional power plants because portions of the ash may be produced by different pathways (e.g., at lower temperature in some conversion processes).

A few studies have generated the data on the composition of coal and the ash from coal conversion. Trace element concentrations of coal and the ash generated by various conversion processes are given in Tables 3.12 and 3.13.<sup>53,63</sup>

### 3.1.2 Inorganic Solids and Sludges

The major sources of inorganic solids and sludges from coal utilization facilities include: (1) sludges and solids from  $\text{SO}_2$  emission control processes; (2) spent residues from FBC boilers; (3) bottom sludges from acid gas treatment processes; and (4) sludges from chemical treatment of wastewater and water supplies. Sources and characterization of these wastes are presented below.

Table 3.12 Trace Element Concentrations (ppm) in Illinois Coal and in the Unquenched Gasifier Ash Obtained from Lurgi Gasification

Element	Illinois Number 5 Coal			Ash		
	Peabody <sup>a</sup>	Argonne <sup>b</sup>		Peabody <sup>a</sup>	Argonne <sup>b</sup>	
Ag	0.3			3.0		
As	1.6	1.9	+ 1.003 (B)	0.3		
B	307			673		
Ba					490	+ 250 (B)
Be	2.2	2.0	+ 0.1	22	19.8	+ 1.0
Br		6.6	+ 1.0 (A)			
Cd	<0.3			<0.3		
Ce					41	+ 4 (AA)
Co	3.7	3.8	+ 0.6 (A)		38	+ 4 (AA)
Cr	15	15	+ 2 (A)	551	592	+ 59 (AA)
Cs					11	+ 2 (A)
Cu	10			273		
Dy						
Eu						
F	59	55	+ 11		4.6	+ 0.9
Fe (x10 <sup>4</sup> )		1.3	+ 0.1 (AA)		15	+ 2 (AA)
Hg	0.20	0.17	+ 0.02	0.01	0.016	+ 0.002
K (x10 <sup>3</sup> )		1.3	+ 0.1 (AA)		14	+ 1 (AA)
La		3.6	+ 0.5 (A)		42	+ 4 (AA)
Li	5.5			54		
Mn	21	23	+ 2 (AA)	338	305	+ 30 (AA)
Mo	7			8		
Na (x10 <sup>2</sup> )		2.8	+ 0.3 (AA)		29	+ 3 (AA)
Ni	32			462		
Pb	30	28.1	+ 2.8	219	200	+ 10
Sb	0.3	0.1	+ 0.02 (A)	0.3	19	+ 2 (AA)
Sc		1.6	+ 0.2 (AA)			
Se		9	+ 5 (B)			
Sm						
Ta					1.3	+ 0.7 (B)
Tb				181		
V	21			181		
Yb					11	+ 2 (B)
Zn (x10 <sup>2</sup> )	1.82	2.4	+ 1.2 (B)	15.8	16	+ 2 (A)



Table 3.12 (Cont'd)

Element	Illinois Number 6 Coal					Ash				
	Peabody <sup>a</sup>		Argonne <sup>b</sup>			Peabody <sup>a</sup>		Argonne <sup>b</sup>		
Ag	0.3					3.8				
As	1.0	2.1	+	1.0	(B)	0.1				
B	132					622				
Ba										
Be	1.8	1.55	+	0.08		14	13.4	+	0.7	
Br		4.1	+	0.7	(A)					
Cd	<0.3					<0.3				
Ce							38	+	4	(AA)
Co	4.3	3.2	+	0.5	(A)	40	34	+	3	(AA)
Cr	22	18.3	+	2.7	(A)	705	806	+	81	(AA)
Cs										
Cu	12					239				
Dy							8.5	+	1.3	(A)
Eu		0.2	+	0.1	(B)					
F	79	79	+	16			5.2	+	1.0	
Fe (x10 <sup>4</sup> )		1.2	+	0.1	(AA)		13	+	1	(AA)
Hg	1.00 <sup>c</sup>	1.18	+	0.12		0.04	0.007	+	0.001	
K (x10 <sup>3</sup> )		1.5	+	0.1	(AA)		16	+	2	(AA)
La		3.9	+	0.4	(AA)		40	+	20	(B)
Li	9.2					74				
Mn	20	18.6	+	1.9	(AA)	243	156	+	16	(AA)
Mo	7					6				
Na (x10 <sup>2</sup> )		3.0	+	0.3	(AA)		27	+	3	(AA)
Ni	14					456				
Pb	12	8.0	+	0.8		96	46.0	+	2.3	
Sb	0.1				(C)	0.2				
Sc		2.1	+	0.2	(AA)		24	+	2	(AA)
Se					(C)					
Sm		0.005	+	0.003	(B)					
Ta										
Tb							3.1	+	1.6	(B)
V	29					301				
Yb		1.4	+	0.7	(B)		11	+	2	(A)
Zn (x10 <sup>2</sup> )	0.43				(C)	4.69				(C)

<sup>a</sup>The precision of the Peabody results is estimated to be +10% in all cases.

<sup>b</sup>The accuracy of the Argonne results for mercury is estimated to be 10%; the precision of the Argonne results for beryllium is +5%; for lead +5 to 10%; for fluorine +20%. The confidence ratings shown for the Argonne results obtained by neutron activation analysis correspond to the following accuracy levels: AA--10%; A--+15%; B--+50%; and C--identification only.

<sup>c</sup>Not representative of seam; contamination suspected.

Source: Ref. 53.

Table 3.13 Chemical Composition of Coal Ashes From Gasification/Liquefaction Plants

Element	Waste 1	Waste 2	Waste 3	Waste 4
		wt. %		
Al	8.8	10.1	8.8	6.7
Ca	18.5	2.9	2.2	2.4
Fe	3.8	13.4	17.2	13.3
K	0.6	1.5	1.4	1.4
Mg	4.9	0.8	0.5	0.5
Na	0.3	1.8	0.2	0.3
Ti	0.5	0.6	0.6	0.4
Si	17.9	22.5	20.1	16.4
S	0.4	0.3	3.8	4.0
C	1.0	1.8	1.7	20.2
		µg/g		
Ag	1.0	0.3	0.3	0.5
B	287.3	1302.2	590.7	386.4
Ba	654.5	454.0	531.0	1013.0
Be	10.3	18.1	12.6	6.3
Cd	1.0	0.8	1.6	5.0
Ce	146.5	85.2	25.9	49.6
Co	7.2	137.3	33.7	16.3
Cr	78.1	386.1	642.0	145.4
Cu	29.8	61.9	93.5	58.7
Ga	65.9	103.6	106.0	98.6
La	152.1	92.5	89.2	61.4
Li	86.3	80.7	63.7	41.4
Mn	3987.2	425.4	293.2	249.4
Mo	4.0	18.8	72.6	43.5
Nb	17.2	11.9	1.7	1.3
Ni	73.0	254.0	150.0	148.0
P	466.7	275.5	436.3	544.8
Sc	30.2	24.4	19.3	12.4
Sr	519.8	503.3	182.1	139.1
Th	28.8	16.2	15.8	12.2
V	154.3	237.2	449.5	416.8
Y	54.8	53.6	41.1	23.8
Zn	8.3	65.7	96.1	413.2
Zr	191.7	196.6	170.2	97.4

Source: Ref. 63.

### 3.1.2.1 SO<sub>2</sub> Emission Control Wastes

Most of the sulfur in coal is converted to sulfur dioxide in combustion and to hydrogen sulfide in conversion. In combustion processes, removal of SO<sub>2</sub> from flue gas is necessary to meet the Clean Air Act requirements. Removal of sulfur compounds from raw coal-conversion gas prior to gas processing is necessary to prevent fouling of catalysts.

In coal conversion processes, sulfur recovery units are used to convert stripped sulfur compounds to either dilute sulfuric acid or elemental sulfur. The vast majority of sulfur recovery units are designed to utilize Claus technology and to recover sulfur in its elemental form. Tail gas treatment units are usually included as part of the Claus technology units to reduce sulfur emissions. Unrecovered sulfur in Claus plant tail gas includes mainly hydrogen sulfide, elemental sulfur, sulfur dioxide, and lesser amounts of other sulfur compounds. Sulfur dioxide removal technologies developed for industries such as power plants and sulfuric acid plants may be directly applicable to Claus emissions from coal facilities.

The removal of sulfur dioxide by means of scrubbers is accomplished by two general processes -- throwaway and regenerable. The first scrubber type refers to those flue gas desulfurization scrubbers that produce a solid waste stream that is not at present marketable and requires disposal. Regenerable scrubber systems are those which, because of their specific chemical reactions, produce a marketable product of sulfur and, in some cases, regenerate the solvent for reuse. Some common examples of regenerable processes are the Wellman-Lord Sulfite, Westvaco Activated Carbons, AI Aqueous Carbonate, and IFP Catalytic, all of which produce a usable sulfur by-product, such as elemental sulfur, sulfuric acid, or gypsum.

Some sulfur by-products, such as elemental sulfur and gypsum, are likely to contain impurities originating from coal. The nature and extent of contamination are, however, largely unknown, and tests to determine the quality of sulfur by-products from the standpoint of their environmental effects are required.

The wet throwaway processes are at present the major systems used by the utilities for several reasons including lower capital costs in comparison to regenerable processes, availability and ease of use of sorbent, and relative simplicity. They have the major disadvantage of producing large amounts of waste. No dry systems are at present operating commercially. However, four companies have developed spray dryer-based systems, and these are expected to be operating by 1980 and 1981.<sup>64</sup> The dry systems do not at present achieve as high a degree of SO<sub>2</sub> removal as do the wet systems. However, the NSPS for utility boilers will require some degree of scrubbing, and dry systems could be used in conjunction with low sulfur coal. They may also be used by industry if SO<sub>2</sub> scrubbing is required under the NSPS being developed by the EPA.

The major wet scrubbing systems employ a slurry of either lime or limestone to remove the SO<sub>2</sub> and produce a waste consisting of calcium sulfate, calcium sulfite and unreacted limestone. Factors influencing the composition of sludge from a specific application include composition of the coal, the alkali added, the scrubber process operation, oxidation, and alkali utilization efficiency. Chemical analyses of lime process sludges from various power plant sources are shown in Tables 3.14 and 3.15. They reveal that a great many elements can be included in FGD sludge and that the sludge component concentrations can be highly variable.<sup>53</sup> Concentrations of trace elements in leachate from ponded scrubber sludges are the focus of the greatest concern about impacts from flue gas desulfurization processes. As can be seen in Table 3.16, which contains results of leachate monitoring, the

Table 3.14 Chemical Analysis of Lime Process Sludges on a Dry Solid Basis (%)

Component	Sample <sup>a</sup>					
	A	B	C	D	E	F
CaO	18.1	43.2	40.7	43.4	25.6	43.8
MgO	2.4	0.2	b	0.0001	1.2	b
Total sulfur	7.2	18.9	18.1	20.0	10.9	22.9
SO <sub>2</sub>	12.1	33.0	32.9	29.2	10.8	45.8
SO <sub>3</sub>	2.9	5.9	4.8	13.6	13.6	c
CO <sub>2</sub>	3.2	6.7	2.3	7.1	2.2	1.0
Free carbon	b	b	b	2.8	0.14	c
SiO <sub>2</sub>	31.6	4.9	3.76	0.58	21.3	0.18
Al <sub>2</sub> O <sub>3</sub>	18.3	3.4	1.71	12.1	11.3	0.39
Fe <sub>2</sub> O <sub>3</sub>	4.3	0.6	0.86	0.39	5.6	0.29
Na <sub>2</sub> O	b	b	b	0.35	0.76	0.09
K <sub>2</sub> O	b	b	b	0.03	0.98	0.01
Free base as CaO	0.3	1.3	7.9	0.06	0.06	c

<sup>a</sup>A-power station prior to fly ash collections; B-power station after ash collection; C-Chemico using carbide lime; D-power plant using proprietary scrubbing; E-wet limestone pilot plant scrubber; F-molybdenum sulfide pilot plant scrubbing effluent.

<sup>b</sup>Not determined.

<sup>c</sup>Not detected.

Source: Ref. 53.

concentration of arsenic, barium, boron, cadmium, chromium, lead, mercury, and selenium in leachate equals or exceeds public water supply standards.

In addition to trace elements, the chemical oxygen demand (COD), total dissolved solids (TDS), and the higher levels of sulfate, chloride, calcium, and magnesium are additional sources of potential pollution.

The quality of wet scrubber wastes can be improved by oxidation to gypsum or by chemical stabilization. These treatments are discussed in Sec. 5.

The major dry systems are either a spray drier or dry injection. In the spray drier, the flue gas is contacted with a calcium-based slurry or sodium solution such that the gas is evaporated to apparent dryness. The dry injection system involves the introduction of a dry sorbent, the most promising being nahcolite (sodium bicarbonate), into the flue gas. The

Table 3.15 Chemical Analysis of Flue Gas Desulfurization Sludges

Component	Sludge	Elutriate/Leachate
Total organic carbon (elutriate only)		X
Total solids	X	
Dissolved solids		X
Suspended solids (leachate only)		X
pH		X
Hardness (elutriate only)		X
Conductivity		X
Arsenic	X	X
Beryllium	X	X
Cadmium	X	X
Calcium	X	X
Chromium	X	X
Copper	X	X
Lead	X	X
Magnesium	X	X
Manganese	X	X
Mercury	X	X
Nickel	X	X
Selenium	X	X
Zinc	X	X
Chloride		X
Cyanide	X	X
Fluoride (calcium fluoride sludge only)		
Nitrate	X	X
Nitrite	X	X
Sulfate	X	X
Sulfite	X	X

Source: Ref. 53.

resulting waste, consisting of a dry mixture of sodium or calcium sulfite and sulfate, is collected by a baghouse. A major difference between the dry and wet systems is that in the majority of wet systems, the ash is collected by a precipitator prior to the scrubber, whereas in the dry systems the ash and scrubbing waste are collected together.

Very little information is available on the characteristics of dry scrubbing wastes. The lime spray dryer systems are expected to have similar impacts to wet lime/limestones systems. However, being dry, the waste should be easier to handle and dispose. There is, however, concern about the sodium-based systems because sodium compounds are 100 times more soluble than calcium compounds.<sup>65</sup>

### 3.1.2.2 FBC Spent Residues

Fluidized bed combustion (FBC) technology involves the combustion of crushed coal in a bed of inert ash and limestone or dolomite, which has been

Table 3.16 Elemental Composition of Scrubber Sludge Leachate

Element	Public Water Supply Standard	Leachate Composition (mg/L)		Drinking Water Standard Exceeded
		Max.	Min.	
As	0.05	0.130 0.300	0.0010 0.0080	yes
Ba	1.00	2.000	0.0020	yes
B	1.00	40.000	0.2200	yes
Cd	0.01	0.047	0.0005	yes
Cr	0.05	0.011 0.250	0.0010	yes
Cu	1.00	0.560	0.0020	no
Pb	0.010	0.040	0.0030	yes
Hg	0.002	0.070 0.003	0.0004	yes
Ni	--	0.050	0.0150	no
Se	0.01	0.540	0.0005	yes
V	--	0.200	0.1000	--
Zn	5.00	4.200	0.0100	no

Source: Ref. 54.

fluidized by the injection of combustion air through the bottom of the bed. The limestone or dolomite in the bed reacts with the sulfur dioxide released by the combustion of the coal and forms a solid sulfate material that can be disposed of as a stable dry solid along with the ash. Instead of disposal sulfated lime residues can be regenerated for reuse in the combustor by contacting it with an appropriate reducing agent under appropriate conditions (e.g., hydrogen and carbon monoxide gases at about 2000°F in a fluidized bed).

There are two major waste streams, both dry, from a FBC plant, the spent bed material and the elutriated fines captured by particulate collection equipment. Potentially, very large amounts of solid waste will be produced if regeneration is not used. At a Ca/S mole ratio of 2:1, the FBC process generates about 0.35 to 0.40 pound of waste per pound of coal burned. This is more than a conventional system and should amount to about 700,000 tons per year at a typical 500 MW plant.<sup>66</sup>

Using limestone as the sorbent the spent bed material is expected to be composed primarily of calcium sulfate and calcium oxide in the approximate ratio of 2:3, with small amounts of calcium carbonate and magnesium oxide.<sup>67</sup> If dolomite is used, the major components are calcium sulfate and magnesium

oxide in the approximate proportion of 3:1.<sup>68</sup> It is expected that virtually all the coal ash will be elutriated along with approximately 40% of the spent bed material. About 12% of the carbon is unburnt in the main bed and is elutriated. There will then be a carbon burn up cell that will combust an additional 90% of the remaining carbon. This leaves about 1% of the original carbon in the solid waste. The elutriated material will be collected in a cyclone followed by a baghouse. It is expected that the collected particulate matter will be added to the bed material for disposal.

FBC spent sorbent does not contain  $\text{CaSO}_3$ , which, in the form of its hemihydrate, tends to occlude water and impart thixotropic properties to the slurry (sludge) discharged by the FGD systems. Thus, even if exposed to rainwater or runoff water, FBC spent sorbent is not expected to form a sludge. However, the greater solubility of  $\text{CaSO}_4$ , compared to  $\text{CaSO}_3$  (2000-3000 vs. 40 ppm), poses a somewhat greater threat of groundwater pollution by leaching. Also, if the calcium oxide is "active," a water runoff of very high pH would result. This possibility has been verified by leaching tests.<sup>70,71</sup> However, it is also possible that calcium oxide could be rendered "inactive" if it is surrounded by an insoluble calcium sulfate shell. There is some evidence that such a shell may form, at least under certain operating conditions.<sup>67</sup>

The retention of trace elements by the ash will be higher than their retention in the ash of a conventional boiler. Therefore a larger total quantity of trace elements will be present in the waste material. The total concentration, however, might not differ greatly due to the larger amounts of material.<sup>67</sup>

Preliminary tests on the spent bed material and collected elutriated matter from the DOE's Morgantown Energy Research Center<sup>72</sup> suggest that the following leachate characteristics do not appear to present problems. Total organic carbon and sulfide leachate concentrations are below detection limits. Leachate concentrations of trace metals, for which some type of drinking water standard, regulation, or criterion exists, through the EPA, the Public Health Service, or the World Health Organization (Ag, As, Ba, Be, Cd, Cr, Co, Fe, Hg, Mn, Ni, Pb, Se, Sn, and Zn), are below the water drinking standards. However, these conclusions are tentative.

### 3.1.2.3 Acid Gas Treatment Sludges

In coal gasification and liquefaction technologies, removal of  $\text{H}_2\text{S}$  and trace sulfur species from raw product gas from the conversion reactor is necessary to prevent catalyst poisoning in the subsequent methanation step. Removal of  $\text{CO}_2$  is also necessary to obtain a product gas with heating value equivalent to that of natural gas.  $\text{H}_2\text{S}$  and  $\text{CO}_2$  may be removed either simultaneously or separately, depending on the specific acid gas removal process chosen and its design.

Acid gas removal processes utilize at least one of three possible techniques: (1) absorption into a solvent, (2) chemical conversion into another compound, and (3) adsorption on solids. Depending on the characteristics of the acid gas and the acid gas treatment process employed, a sorbent blowdown containing a high concentration of solids (including some organics) may be produced. The treatment of this stream may generate a sludge requiring disposal. Such a sludge would most likely contain coal-derived particulate

matter, sorbent, and sorbent degradation products.<sup>73</sup> Characteristic data of acid gas treatment sludges are not available.

#### 3.1.2.4 Sludges From Chemical Treatment of Water and Wastewater

In coal-fired combustion or conversion facilities, large quantities of water are used in treatment of coal, as feed for boilers or conversion reactors, and for cooling or quenching. Water treatment chemicals are used to demineralize and clarify most water supplies.

On the other hand, there are wastewater streams from coal combustion or conversion facilities, such as: (1) coal washing effluents, (2) sluice water from slags and ashes, (3) gas liquor (coal conversion), and (4) condensates from steam units. These wastewater streams require treatment before being discharged or reused.

Some wastewater streams are highly contaminated. For example, the gas liquor of coal conversion contains various components of the product gas (carbon monoxide, carbon dioxide, hydrogen, hydrogen cyanide, and methane) in addition to pollutants such as sulfur and nitrogen compounds, ash, phenols, emulsified tar and oils, and soluble salts. Soluble salts may accumulate in aqueous streams in concentrations as high as 300 ppm.<sup>53</sup>

Water supply and wastewater treatment may involve the use of chemicals such as lime, iron, and aluminum salts for chemical precipitation (e.g., of heavy metals) or for coagulation of particles from process wastewaters. The sludge produced from such chemical treatments may contain precipitated inorganics (e.g., ferric and aluminum hydrolysis products, other metal hydroxides, and calcium carbonate) and inorganic particulate matter removed from the wastewater.

#### 3.1.3 Tars and Oil Sludges

Tars and oils are produced in several coal conversion processes. Some of these such as BIGAS, CO<sub>2</sub>-Acceptor, and Synthane ("deep-bed" coal injection mode of operation), produce little or no tar and oil. Other processes including (gasification)-Hygas, Lurgi, Slugging Gasifier, and COGAS, and (liquefaction)-H-Coal, SRC, and Donor Solvent, produce varied quantities of tar and oil.

Initially, tars and oils may be contained in process water, the treatment of which by gravity separation and/or flotation and by emulsion breaking results in the production of tar and oil sludges. These sludges can contain considerable amounts of water depending on the nature of the raw wastewater and emulsions and the system design. Oil content ranging from 7% to as much as 98% has been reported in sludges from the API separators in petroleum refineries. The organic fraction of the sludge is expected to have characteristics similar to the bulk tars and oils in the process. Furthermore, tar and oil sludge is likely to contain high levels of coal-derived organic and inorganic particulate matter.<sup>53</sup> Table 3.17 lists the major components of coal tar produced in the German high-temperature conversion process. The highest reported concentrations are for naphthalene, phenanthrene, and fluoranthene.<sup>73</sup>



Table 3.17 Major Components of German High-Temperature Conversion Process Coal Tar

Component	Boiling point (°C)	Melting point (°C)	Average Weight (%)
Naphthalene	217.9	80.3	10.0
Phenanthrene	338.4	100.0	5.0
Fluoranthene	383.5	111.0	3.3
Pyrene	393.5	150.0	2.1
Acenaphthylene	270.0	93.0	2.0
Fluorene	297.9	115.0	2.0
Chrysene	441.0	256.0	2.0
Anthracene	340.0	218.0	1.8
Carbazole	354.8	244.4	1.5
2-Methylnaphthalene	241.1	34.6	1.5
Diphenyloxide	285.1	85.0	1.0
Indene	182.4	-1.5	1.0
Acridine	343.9	111.0	0.6
1-Methylnaphthalene	244.7	-30.5	0.5
Phenol	181.8	40.9	0.4
Cresol	202.2	12.2	0.4
Benzene	80.1	5.5	0.4
Diphenyl	255.0	69.2	0.4
Acenaphthene	227.5	95.0	0.3
2-Phenylnaphthalene	359.8	101.0	0.3
Toluene	110.6	-95.0	0.3
Chinoline	237.1	-14.2	0.3
Diphenylenesulfide	331.4	97	0.3
Thionaphthene	219.9	31.3	0.3
m-Xylene	139.1	-47.9	0.2
o-Cresol	191.1	31.0	0.2
p-Cresol	201.9	34.7	0.2
Isochinoline	243.3	26.5	0.2
Chinaldine	247.6	-1.0	0.2
Phenanthridine	349.5	107.0	0.2
7,8-Benzochinoline	340.2	52.0	0.2
2,3-Benzodiphenyloxide	394.5	208.0	0.2
Indole	254.7	52.5	0.2
3,5-Dimethylphenol	221.7	63.3	0.1
2,4-Dimethylphenol	210.9	24.5	0.1
Pyridine	115.3	-41.8	0.02
a-Picoline	129.4	-66.7	0.02
b-Picoline	144.1	-18.3	0.01
y-Picoline	145.4	3.7	0.01
2,6-Intidine	144.0	-6.1	0.01
3,4-Intidine	158.4	-64.0	0.01

Source: Ref. 73.

### 3.1.4 Biosludges

In gasification and liquefaction processes, the raw gas scrubber water for gas quenching can be highly contaminated. For example, the gas quench water from gasification processes such as Lurgi, Synthane, and Hygas contain high levels of organics (e.g., up to 6600 mg/L of phenols and up to 10,000 mg/L of total organic carbon). These quench waters also contain varying concentrations of trace organics such as carbazoles, benzofurans and benzo(a)-pyrenes, which can be hazardous. Table 3.18 presents the identification and levels of organics in product water from a coal gasification process. In addition to trace organics, the quench waters can also contain significant levels of certain trace elements originally present in the coal. Table 3.19 presents the trace elements concentrations in Synthane and HYGAS quench waters

Table 3.18 Organics in Product Water from Gasification of Illinois No. 6 Coal<sup>a</sup>

Compound	Quantity (ppm)
Phenol	3400
Cresols	2840
C <sub>2</sub> -Phenols	1090
C <sub>3</sub> -Phenols	110
Dihydrics	250
Benzofuranols	70
Indanols; acetophenones	150
Hydroxybenzaldehyde; benzoic acids	60
Naphthols	160
Indenols	90
Benzofurans	NA <sup>b</sup>
Dibenzofurans	NA
Biphenols	40
Benzothiophenols	110
Pyridines	NA
Quinolines	NA
Indoles	NA

<sup>a</sup>Low-voltage mass spectrometry data.

<sup>b</sup>NA: Not available.

Source: Ref. 53.

Table 3.19 Trace Elements Reported in Product Gas Quench Waters

Element	Trace Element Concentration (mg/L)		% of Element Originally Present in Coal Lurgi (at Sasol)
	Synthane PDU <sup>a</sup>	Hygas Pilot Plant	
Hg	0.027	-	32
As	0.001	-	90
Zn	0.13	37-63	-
Mn	0.2	40-206	36
Cr	0.043	<24	-
F	39	-	42
B	43	251-12000	3.5
Be	-	<2	1.6
Cd	-	<20	35
Pb	-	<60	3.2
V	-	<200	0.06
Sb	-	-	36

<sup>a</sup>Process Development Unit.

Source: Ref. 73.

and the percentages of the trace elements found in the aqueous condensate from the Lurgi facility at SASOL, South Africa, and originally present in the coal.<sup>73</sup>

When biological processes are employed for the treatment of quench water and other aqueous wastes, the degradation of organics and the physical entrapment of settling suspended particles produce a biosludge. Sludges produced in the activated sludge and trickling filtration processes are settled in the clarifiers, which follow the aeration tank or the trickling filter. In these processes a portion of the settled sludge is recycled to the aeration tank or the trickling filter, while the excess sludge is wasted and requires disposal. Sludges removed from final clarifiers typically contain 2 to 5% solids, which generally contain 50 to 70% volatile matter. When lagoons and stabilization basins are used for biological treatment, the biological sludge that is produced, and the settleable matter in the raw wastewater, settle to the bottom; the degradable material in the settled sludge undergoes aerobic and/or anaerobic decomposition. Depending on the nature and quantity of the solids in the raw wastewater and the lagoon design, periodic cleaning of the lagoons to remove the settled sludge may be necessary. Certain elements (e.g., heavy metals) and refractory organics that may be present in

the raw wastewater at relatively low concentrations may concentrate in the biosludges. Trace organics and metals may present an environmental problem for disposal of biosludge from coal conversion.

### 3.1.5 Spent Catalysts

Many types of catalysts are used in coal gasification and liquefaction technologies (see Table 3.20). These catalysts are used to enhance chemical reactions (coal conversion, shift, methanation) and process stream purification. While some organics are used as catalysts, the majority of catalysts are metal-containing solid particles. For example, the shift catalysts are generally cobalt molybdate-based, and the methanation catalysts are nickel-based materials supported on an inert substance such as alumina or silica.

Due to contamination, catalyst activity decreases with increased operating time. Catalysts are frequently poisoned (deactivated) by free carbon, sulfur, and chlorine. The characteristics of the feedstock and catalyst, as well as the operating conditions, are factors that determine the rate of catalyst deactivation. The conceptual design for commercial SNG facilities in the U.S. assumes a catalyst life of six months to two years.<sup>53</sup>

Spent catalysts can either be regenerated by returning to the manufacturer, or disposed of along with other solid wastes such as coal ash. Because of the proprietary nature of the catalysts, very little information relative to their environmental effects is available. However, it is possible that disposal of spent catalysts may cause environmental problems. For example, it has been indicated that the spent catalysts from both shift conversion and methanation operations contain coal-derived trace elements (e.g., arsenic, cadmium), elemental carbon, and highly polymeric organic materials, in addition to cobalt and/or nickel originally existing in the catalysts.<sup>73</sup>

### 3.1.6 Coal Cleaning Wastes

About half of the total coal mined in the U.S. is prepared or cleaned before use to remove some of the noncombustible materials. Coal cleaning is usually done at the minehead, although some may be done at utilization sites. Coal cleaning wastes consist of rocks and mineral matter such as clays, quartz, pyrites, marcasite, as well as small amounts of residual coal and unidentified matter. The rejected material represents, on the average, about 20% by weight of the raw coal.

Most of the coal in the U.S. is cleaned by physical methods.<sup>74</sup> The mineral wastes produced by such methods amount to 100 million tons per year. Coal cleaning is receiving increased attention as a means of reducing the coal sulfur content, and the annual production rate of coal cleaning waste is expected to double within a decade.<sup>75</sup>

It has been known for several years that the acidic drainage from coal refuse disposal sites is often highly contaminated with various species such as iron, manganese, and sulfate ions. More recently Los Alamos Scientific Laboratory has investigated the structure, weathering, and leaching behavior

Table 3.20 Catalysts Used in Coal Conversion Processes

Catalysts	Use
Activated carbon	Purification
Iron oxide	Purification
Methanol	Purification
Propylene carbonate	Purification
Sodium carbonate	Purification
Potassium carbonate	Purification
Amines	
Monethanolamine	Purification
Diethanolamine	Purification
Diglycolamine	Purification
Zinc oxide	Purification
Cobalt-molybdenum	Shift conversion, liquefaction (hydrotreating), purification
Limestone-dolomite	Sulfur recovery
Molten salt	
Nickel	Methanation or liquefaction
Vanadium	
Dolomite	Purification
Bauxite	Sulfur recovery
Iron	Shift conversion or liquefaction
Isopropyl ether	Phenol recovery
n-methyl-2-pyrrolidine	Purification
Dimethyl ether polyethylene glycol	Purification
K <sub>3</sub> AsO <sub>3</sub>	Liquefaction
Tungsten	Liquefaction
Zinc chloride	Liquefaction
Sodium sulfite	Purification
Co-Mo/SiO <sub>2</sub> -Al <sub>2</sub> O <sub>3</sub>	Liquefaction
Sulfoxide	Sulfur recovery
Chelated iron salt	Sulfur recovery
Nickel-tungsten	Liquefaction (hydrotreating)
Ruthenium	Methanation

Source: Ref. 53.

of trace elements in selected samples of coal cleaning wastes.<sup>76,77</sup> The study revealed the great potential of these wastes for releasing harmful quantities of trace elements.

Oxidative degradation of the pyrite and marcasite present in the coal cleaning wastes produces leachates with pH values below 2, which would put many untreated coal cleaning wastes on the corrosive waste list, even under the recently relaxed RCRA criteria. The highly acidic leachates can easily dissolve a variety of trace elements present in the wastes, including fluorine, aluminum, manganese, iron, cobalt, nickel, copper, zinc, arsenic, and lead. Some of these elements (e.g., copper, zinc, and cadmium) have been found in concentrations significantly exceeding public water supply criteria (see Table 3.21). On the basis of a priority system using the MEG (Multimedia Environmental Goals) system, six elements (iron, aluminum, manganese, calcium, nickel, and zinc) were identified as present at levels of possible environmental concern, particularly for the wastes resulting from high sulfur coal. The severity of contamination caused by the low sulfur waste would be less pronounced than that caused by the high sulfur wastes.

Table 3.21 Trace Element Concentration for Drainage Produced by Illinois Basin Coal Refuse

Element	Leachates Concentration (mg/L)	EPA Public Water Supply Criteria (mg/L)
Na	21 - 700	-
Mg	61 - 369	-
Al	8.1 - 910	-
K	21 - 28	-
Ca	130 - 532	-
Mn	5.6 - 44	-
Fe	610 - 12,000	-
Co	3.7 - 28	-
Ni	5.6 - 43	-
Cu	0.3 - 8	-
Zn	2.2 - 55	5.0
Cd	0.02 - 0.24	0.01
pH	1.7 - 2.9	5.9

Source: Ref. 77.