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THE IMPACT OF RCRA ON COAL GASIFICATION
WASTES

August 1979

Work Performed Under Contract No. AC02-79EV10286

Fred C. Hart Associates, Inc.
New York, New York

TECHNICAL INFORMATION CENTER
UNITED STATES DEPARTMENT OF ENERGY

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THE IMPACT OF RCRA ON
COAL GASIFICATION WASTES

Prepared By:

Fred C. Hart Associates, Inc.
527 Madison Avenue
New York, New York 10022

August, 1979

Prepared For:

U.S. Department of Energy
Division of Policy Analysis
Office of Technology Impacts
Assistant Secretary for Environment
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ABSTRACT

Coal conversion processes offer the potential for almost every possible mode of environmental contamination. Potential environmental pollution will occur from huge streams of wastewater, scores of gaseous vents and enormous quantities of solid materials. The nature of the waste streams is of particular concern in view of the recently enacted Resource Conservation and Recovery Act (RCRA). The passage and implementation of RCRA poses new levels of control for the traditional solid waste disposal process and establishes a new set of material standards for hazardous wastes in which conforming materials will require even more stringent controls. Key definitions in the Act which may pertain to coal gasification wastes include hazardous waste, sludge and solid waste.

It is the goal of this report to collect, analyze, and interpret data and other technical information relevant to solid waste by-product generation, handling, and disposal at existing and future coal conversion plants. The analysis and interpretation of the collected data has been directed towards identifying gaps in the data, potential problem areas in solid waste disposal in view of RCRA, and needed research activities in the area of solid waste disposal.

TABLE OF CONTENTS

<u>CHAPTER</u>	<u>PAGE</u>
EXECUTIVE SUMMARY	1
I. INTRODUCTION	7
II. RESOURCE CONSERVATION AND RECOVERY ACT (RCRA)	9
III. COAL GASIFICATION PROCESS DESCRIPTIONS	17
General Gasification Description	17
Lurgi Process Description	19
Koppers-Totzek Process Description	22
IV. IDENTIFICATION AND CHARACTERIZATION OF SOLID WASTE STREAMS IN COAL GASIFICATION FACILITIES	26
A. Ashes and Chars From Gasification Operation and Air Pollution Control	28
B. Spent Catalysts	48
C. Inorganic Solids and Sludges From Acid Gas Removal and Air and Water Pollution Control	53
D. Tar and Oil Sludges	62
E. Biosludge	66
V. CRITICAL ANALYSIS OF IDENTIFIED SOLID WASTE STREAMS WITH RESPECT TO SECTION 3001 of RCRA	72
VI. FUTURE RESEARCH NEEDS	80

LIST OF TABLES

<u>TABLE</u>	<u>PAGE</u>
1. Scope of RCRA Hazardous Waste Management Provisions (Subtitle C)	10
2. Chemical Analysis of Selected Bottom Ashes	30
3. Chemical Analysis of Flyash	31
4. Properties of Lurgi Ash - From Gasifier Ash Hopper	33
5. A Partial Identification of Trace Elements in Coal Ash	35
6. Range in Amount of Trace Elements Present in Coal Ashes	36
7. Chemical Composition of Lurgi Ash and Slurry Super- natant Solutions of the Ash From an Illinois No. 6 Coal at Several pH's	37
8. Elements Exceeding Recommended Water Quality Levels	40
9. Representative Analyses of Coals and Chars	42
10. Lurgi Gasification: Trace Elements Concentrations (ppm) in Illinois Coal and in the Unquenched Gasifier Ash	43
11. Example of Trace Elements That May Appear in Gas During Gas Cleaning	47
12. Analysis of Drainage From Two Industrial Coal Piles	49
13. Yearly Estimated Emissions (Tons/Year) From Wesco Coal Gasification (Lurgi) Plant with Pollution Control.	50
14. Conversion Catalysts	51
15. Chemical Analysis of Lime Process Sludges on a Dry Solid Basis	55
16. Chemical Analysis of Flue Gas Desulphurization Sludges	56
17. Trace Elements in Sludge	57
18. Trace Element Concentrations From "Fixed Sludge" Leachate.	58
19. Elemental Composition of Scrubber Sludge Leachate	60

LIST OF TABLES (continued)

<u>TABLE</u>		<u>PAGE</u>
20.	Koppers-Totzek Coal Gasification Waste Analyses, Kutakya, Turkey	63
21.	By-Product Water Analysis From Synthane Gasification of Various Coals	64
22.	Composition of Wastewaters	65
23.	Major Components of German High Temperature Conversion Process Coal Tar	67
24.	Contaminants in Product Water: Gasification of Illinois No. 6 Coal	69
25.	Mass Spectrometric Analyses of Water Contaminants and Benzene -- Soluble Tar From Synthane (Laboratory - Scale) Gasification	70
26.	Preliminary Comparisons of Worst-Case Waste Streams from Coal Gasification Facilities With Proposed Hazardous Waste Criteria	75
27.	Comparison of Lurgi Process Gasifier Ash and Slag to Toxic Criteria	78

LIST OF ILLUSTRATIONS

<u>FIGURE</u>		<u>PAGE</u>
1.	Flow Plan for Coal Gasification	18
2.	Lurgi Process	20
3.	Lurgi Pressure Gasifier	21
4.	Koppers-Totzek Gasification Process	23
5.	Koppers-Totzek Two-Headed Reactor	24
6.	Process Modules Generating Solid Wastes in an Integrated High BTU Gasification Facility	27
7.	Emission Fates for Coal Conversion Process	29
8.	Sludge Disposal Schemes for a Single-Scrubber System . . .	61
9.	Contaminants in Product Water From Coal Gasification: Gas Chromatography - Mass Spectrometry Data	68

EXECUTIVE SUMMARY

In response to the higher costs and reduced supplies predicted for oil and natural gas in the future, there is a growing interest in coal gasification processes. Considerable research is being conducted to upgrade coal to "cleaner" liquid, gaseous and solid fuels. However, there are potential environmental problems which must be solved before coal gasification plants are initiated for widespread commercial applications.

Coal conversion processes offer the potential for almost every possible mode of environmental contamination. Potential environmental pollution will occur from huge streams of wastewater, scores of gaseous vents and enormous quantities of solid materials. The nature of the waste streams is of particular concern in view of the recently enacted Resource Conservation and Recovery Act (RCRA). The passage and implementation of RCRA poses new levels of control for the traditional solid waste disposal process and establishes a new set of material standards for hazardous wastes in which conforming materials will require even more stringent controls. Key definitions in the Act which may pertain to coal gasification wastes include hazardous waste, sludge and solid waste. Relevant sections of these definitions include:

- . hazardous waste -- "solid waste, or combination of solid wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may ... pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed or otherwise managed."
- . solid -- "any solid, semi-solid, or liquid waste generated from an ... air pollution control facility ..."
- . solid waste -- "any garbage, refuse, sludge from an ... air pollution control facility ... including solid, liquid, semi-solid, or contained gaseous material ..."

At present, there is limited data concerning the nature of solid waste streams at coal gasification plants. The objectives of this report were to collect, analyze and interpret data and other technical information relevant to solid waste by-product generation, handling and disposal at existing and future coal gasification plants. The analysis and interpretation of the collected data was to be directed towards identifying gaps in the data, potential problem areas in solid waste disposal in view of RCRA, and needed research activities in the area of solid waste disposal. These objectives were achieved in five task areas which are briefly described below:

1. Survey the various processes and subsystems in coal gasification plants to determine which generate solid waste by-products.

2. Determine the quantities and composition of the solid waste streams with emphasis on potential toxic material.
3. Review the tabulation of processes and residuals to identify potentially hazardous waste products and identify supporting literature and research on the extent to which such materials might be considered hazardous.
4. Review the current regulatory framework of categorization and disposal of solid waste material.
5. Provide a critical analysis and interpretation of the data and information gathered in areas 1-4 which will include the prediction of the level of hazard in each process and residual, and future research needs.

A description of the general gasification procedure was provided to (1) show the various process units common to most gasification facilities, and (2) depict the potential sources of effluents resulting from the gasification procedure. In addition, process descriptions were provided for both the Lurgi Process and the Koppers-Totzek Process since these processes are currently commercial while many other processes are in various stages of development.

The major sources of solid waste at coal gasification plants include the following:

1. chars and ashes from the gasification operation and air pollution control,
2. spent catalysts from shift conversion and methanation,
3. inorganic solids and sludges from acid gas removal and air and water pollution control,
4. tar and oil sludges, and
5. biosludges from water pollution control.

For each of the five major categories of solid waste listed above, a characterization of identified solid waste streams was performed. The primary objective of characterizing the identified solid waste stream was to present a range of values for potentially hazardous constituents contained in each stream, as found in both open and industry literature. The actual quantity and exact chemical composition of each solid waste stream are a function of coal type, specific processes employed and plant design. Due to the wide variations in these parameters, strict comparisons of process effluents between various gasification facilities may not be appropriate.

Comparison to Regulatory Framework

The proposed Section 3001 regulations (December 18, 1978) describe the set of criteria which a waste generator must use to determine if a waste is hazardous, and thus subject to the more stringent hazardous waste regulations. The Environmental Protection Agency (EPA) has developed eight categories which are used to determine if a waste is to be deemed hazardous: (1) ignitability, (2) corrosivity, (3) reactivity, (4) toxicity, (5) radioactivity, (6) infectiousness, (7) phytotoxicity, and (8) teratogenicity and mutagenicity. In the proposed regulations, EPA relies only on consideration of the first four characteristics because those are the only ones for which established test protocols are available.

The primary objective of this section was to assess the hazard potential of solid waste streams generated at coal gasification facilities based on a comparison of each identified waste stream with the proposed hazardous waste criteria. The comparisons were made using the maximum concentration for all potentially hazardous waste constituents. Therefore, the results represent worst-case conditions and are not intended to reflect waste stream characteristics at the average coal gasification facility. The usefulness of the results extends toward (1) identification of these waste streams likely to be listed as a hazardous waste, and (2) determination of future research needs.

Each waste stream was compared separately with each of the hazardous waste criteria, with the results indicated in the following manner:

N (NO):	The available information indicates that the waste is not hazardous according to this criteria.
Y (YES):	The available information indicates that components of the waste stream (at least worst-case values) exist in concentrations unacceptable according to this criteria.
P (POSSIBLE):	The available information indicates that concentrations of waste stream components approach values unacceptable according to this criteria.
? (NOT DETERMINABLE):	The available information is not sufficient to make a determination according to this criteria.

Table E-1 presents the preliminary results of the comparison of each waste stream with the proposed hazardous waste criteria. The criteria are listed in four categories (ignitable, corrosive, reactive and toxic) as they

TABLE E-1

PRELIMINARY COMPARISONS OF WORST-CASE WASTE STREAMS FROM COAL GASIFICATION
FACILITIES WITH PROPOSED HAZARDOUS WASTE CRITERIA

Hazardous Waste Criteria	GASIFICATION AND AIR POLLUTION CONTROL ASH		COAL PILE DRAINAGE	SPENT CATALYST	INORGANIC SOLIDS AND SLUDGES				TAR AND OIL SLUDGES	BIOSLUDGES
					SO ₂ REMOVAL	Scrubber Sludge Sludge and Leachate	Acid Gas Removal	Waste Water Treatment		
A. IGNITABLE										
1. Flash point 60°C	N	N	N	N	N	N	N	N	N	N
2. Liable to cause fires through friction, ab- sorption of moisture, etc.	N	N	N	N	N	N	N	N	N	N
3. Compressed gas	N	N	N	N	N	N	N	N	N	N
4. Oxidizer	N	N	N	N	N	N	N	N	N	N
B. CORROSIVE										
1. pH 3 or 12	?	?	Y	P	P	P	Y	P	?	?
2. Corrosion rate 0.250 on steel	?	?	?	P	?	?	?	?	?	?
C. REACTIVE										
1. Undergoes violent chemical change; reacts violently with water, etc.	N	N	N	?	N	N	N	N	N	N
2. Capable of detona- tion but requires strong initiating source	N	N	N	N	N	N	N	N	N	N
3. Capable of detona- tion at normal temp- eratures and pressures	N	N	N	N	N	N	N	N	N	N
4. Forbidden, Class A or Class B explosives	N	N	N	N	N	N	N	N	N	N

TABLE E-1 (Continued)

Hazardous Waste Criteria	<u>GASIFICATION AND AIR POLLUTION CONTROL ASH</u>		<u>COAL PILE DRAINAGE</u>	<u>SPENT CATALYST</u>	<u>INORGANIC SOLIDS AND SLUDGES</u>				<u>TAR AND OIL SLUDGES</u>	<u>BIOSLUDGES</u>
					<u>SO₂ REMOVAL</u>	Scrubber Sludge Sludge and Leachate Acid Gas Removal Waste Water Treatment				
D. TOXIC										
1. EP extract exceeds applicable threshold values	P	P	P	P	P	P	P	P	P	P

appear in the 3001 regulations. Of the four categories of hazardous waste criteria, the toxic category has the greatest potential applicability to coal gasification waste streams, followed by the corrosive category.

Based on our research, the waste stream likely to pose the greatest hazard potential is ash and char from the gasification operation and air pollution control (in part due to their large volumes), followed by inorganic solids and sludges from acid gas removal and air and water pollution control (scrubber sludge, acid gas removal sludge), followed by spent catalyst waste.

These conclusions are not meant to suggest that most coal gasification facilities or even typical plants generate hazardous wastes. They indicate merely that several waste streams at coal gasification facilities may contain concentrations of corrosive, reactive or toxic pollutants high enough to be deemed hazardous according to Section 3001 criteria. The study provides the basis for determining what areas require research. Some of the primary areas where research should be undertaken are:

1. In-depth investigation of the actual fate of wastes from coal gasification facilities into the environment.
2. Research into the mobility of materials under environmental conditions as opposed to 3001 Toxicant Extraction Procedure.
3. Investigation of process changes and disposal practices to mitigate the toxic or hazard potential of the waste streams.
4. In-depth economic analysis of the impact of RCRA on future coal gasification facilities.
5. Investigation of possible changes in disposal methods to allow recovery of potentially useful material.

The study in general showed that for some waste streams, there were considerable amounts of information, and for others, quantitative values were almost non-existent. But even where data were available, their use is limited considerably by the 3001 criteria. The only way to make an accurate determination is through testing actual waste streams and then correlating those results (when possible) with the range of industry values through a few indicator compounds.

I. INTRODUCTION

One of the consequences of the higher costs and reduced supplies predicted for oil and natural gas in the future is a growing interest in coal gasification processes. Considerable research is being conducted on methods to convert coal, our most abundant domestic fuel, to "cleaner" liquid, gaseous and solid fuels. However, there are potential environmental problems which must be solved before coal conversion plants are initiated for widespread commercial applications.

It must be remembered that coal is basically a dirty fuel. Ordinary coal combustion is an operation which generates many potential pollutants and thus requires a great amount of pollution control. Despite years of research, many of the pollution control problems associated with coal combustion still remain unsolved. Coal conversion by liquefaction or gasification will greatly compound these problems.

Coal conversion processes offer the potential for almost every possible mode of environmental contamination. Potential environmental pollution will occur from huge streams of wastewater, numerous hydrocarbon streams, scores of gaseous vents and enormous quantities of solid materials (Reference 1).

At present, there is limited information concerning where and in what form problem pollutants will occur. Consequently, research is underway to pinpoint, quantify, and analyze wastestreams from existing coal conversion systems. This information will help clarify the environmental implications of coal conversion systems and will serve as a base for subsequent pollution control technology development.

The nature of waste streams is of particular concern in view of the recently enacted Resource Conservation and Recovery Act (RCRA). The passage and implementation of RCRA established a new interest in the solid waste residues created by coal conversion processes. The regulations implementing RCRA pose new levels of control for the traditional solid waste disposal process and establish a new set of material standards for hazardous wastes in which conforming materials will require even more stringent controls. Coal conversion processes will generate enormous quantities of solid waste by-products which must be disposed of in an environmentally acceptable manner, at reasonable costs, and in compliance with governing regulations. Furthermore, the application of pollution control equipment to gaseous and liquid waste streams may be another significant source of solid waste by-products. Solid waste produced in this manner must also be disposed of in compliance with governing regulations.

It is the goal of this research paper to collect, analyze, and interpret data and other technical information relevant to solid waste by-product generation, handling, and disposal at existing and future coal conversion plants. The analysis and interpretation of the collected data has been directed towards identifying gaps in the data, potential problem areas in solid waste disposal in view of RCRA, and needed research activities in the area of solid waste disposal. These objectives were achieved in five areas which are briefly described below:

1. Survey the various processes and subsystems in coal conversion plants to determine which generate solid waste by-products.
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4. Review the current regulatory framework of categorization and disposal of solid waste material.
5. Provide a critical analysis and interpretation of the data and information gathered in areas 1-4 which will include the assessment of the level of hazard in each process and residual, and future research needs.

II. THE RESOURCE CONSERVATION AND RECOVERY ACT

The primary objective of the Resource Conservation and Recovery Act (RCRA) is to ensure that solid wastes are managed properly. To accomplish such a broad objective the legislation contains provisions ranging in scope from technical and financial assistance for demonstration projects using improved solid waste management and resource recovery techniques, to prohibiting open dumping and regulating hazardous waste management. The program areas of particular importance to disposal of coal gasification wastes include:

- hazardous waste management;
- solid waste management (land disposal of non-hazardous solid wastes);
- special waste standards; and
- resource conservation and energy recovery

The U.S. EPA has already exceeded its statutory deadline of April 21, 1978, for promulgating hazardous and non-hazardous solid waste regulations. The regulations are now scheduled to become effective in July 1980.

A. Hazardous Waste Management

The cost and other implications of RCRA will be most severely felt by facilities generating hazardous waste streams. Subtitle C of the Act calls for the control of hazardous wastes for their entire lifetime, from point of generation to point of disposal. To accomplish this objective, all parties participating in the handling of hazardous wastes (generators; transporters; and, treatment, storage, and disposal facilities) must comply with a manifest system, in addition to other applicable technical and performance standards. Monitoring, inspection, and enforcement mechanisms are provided in order to ensure compliance. Consequently, if any of the waste streams generated are determined to be hazardous, mandatory handling procedures will be required under RCRA.

The scope of the RCRA hazardous waste provisions is outlined in Table 1. The salient features of several programs being developed under this subtitle are discussed below.

Hazardous Waste Definition. Section 3001 provides for a two-phased identification of hazardous wastes. First, criteria will be promulgated for identifying the characteristics of hazardous waste. Secondly, on the basis of these criteria, a list of specific hazardous wastes will be developed.

TABLE 1

SCOPE OF RCRA HAZARDOUS WASTE MANAGEMENT PROVISIONS (SUBTITLE C)

Section 3001: Hazardous Waste Criteria/Listing

- . Promulgate Criteria to Identify Characteristics
- . Issue Listing

Section 3002: Hazardous Waste Generator Standards

- . Record-keeping and Reporting
- . Labeling of Containers
- . Manifest System

Section 3003: Hazardous Waste Transporter Standards

- . Record-keeping
- . Labeling
- . Compliance with Section 3002 Manifest System
- . Compliance with DOT Regulations

Section 3004: Owners/Operators of Treatment/Storage/Disposal

- . Record-keeping/Reporting/Manifest System
- . Monitoring/Inspection
- . Location/Design/Construction
- . Maintenance/Operation
- . Contingency Plans
- . Ownership
- . Financial Responsibility

Section 3005: Permits for Treatment/Storage/Disposal Facilities

- . Hazardous Waste Data
- . Site of Treatment/Storage/Disposal

Section 3005: Authorized State Hazardous Waste Programs

- . Equivalent to Federal Program
- . Consistent with Other State Programs
- . Adequate Enforcement with Subtitle C

Section 3010: Notification

- . Generators/Transporters/Treatment/Storage/Disposal Must Notify EPA
- . Required within Three (3) Months After Promulgation of Section 3001 Hazardous Wastes Identification

To determine if a waste is hazardous, and thus subject to the more stringent hazardous waste regulations, EPA has defined eight criteria for evaluation. These are: (1) ignitability; (2) corrosivity; (3) reactivity; (4) toxicity; (5) radioactivity; (6) infectiousness; (7) phytotoxicity; and (8) teratogenicity and mutagenicity. In the proposed regulations, EPA relies only on consideration of the first four characteristics because those are the only ones for which established tests protocols are available.* EPA has published an Advance Notice of Proposed Rulemaking that would, if promulgated, expand the characteristics to include radioactivity, unnatural genetic activity, bioaccumulation, and separate considerations of toxicity to aquatic organisms, terrestrial plants and humans. These four criteria (ignitability, corrosivity, reactivity and toxicity), are discussed in detail in Chapter V.

Generators. Persons generating 100 kilograms or less of hazardous waste per month are exempted from Subtitle C management requirements. These wastes, however, must be disposed in facilities which meet criteria pursuant to Section 4004 of Subtitle D of RCRA (i.e., in sanitary landfills or in some other environmentally adequate manner). All other generators are subject to manifest, record-keeping, and reporting requirements, and may treat, store, or dispose of their hazardous waste only in permitted facilities meeting the requirements of Sections 3004 and 3005.

Treatment, Storage, and Disposal Facilities. Section 3004 of RCRA mandates the establishment of such "performance standards" applicable to owners and operators of hazardous waste treatment, storage and disposal facilities, "as may be necessary to protect human health and the environment." This mandate gives the EPA jurisdictional authority in all media--air, land, and surface/groundwater. Under this section, the Agency will promulgate requirements respecting a broad scope, including record-keeping, reporting, the manifest system, monitoring, inspections, siting, design, construction, maintenance, operation, contingency plans, and ownership.

EPA, in order to develop regulations capable of achieving this broad mandate, has adopted a dual-standard strategy. In appropriate sections, both "mandatory" and procedural" standards will be promulgated. Mandatory standards are ambient-type standards, limiting the amount of pollution which will be licensed in the general environment. The regulatory basis for ambient standards is protection of public health and the environment. This approach encourages inventiveness, and hence provides flexibility, in determining how compliance will be attained in individual cases. From the regulator's point of view, however, the primary disadvantage of ambient standards is that they are difficult to enforce, due to both the difficulty in establishing a cause/effect relationship, and the expense of the sampling and analysis required to prove such a relationship.

* Using these four criteria; the EPA has compiled a list of about 160 hazardous wastes and waste streams.

In the light of this deficiency, "procedural" standards will also be promulgated. These standards are primarily operation and design/construction-oriented; they identify specific techniques and/or equipment to be utilized.

Permittees will be encouraged to adopt suggested procedural standards. These standards will serve as the basis for the review of a permit application and the issuance of a permit. A facility which complies "with all applicable mandatory standards and follows all relevant procedures... shall be considered in compliance as long as the facility permit conditions are not violated." This approach, then, will serve both to facilitate and accelerate the permit review process as well as to establish a uniform basis for granting permits. If the applicant wishes to use a procedural approach differing from the procedures described in the applicable section:

"he/she must demonstrate to the satisfaction of the Administrator that the alternative procedure complies with all applicable mandatory standards, and that it achieves groundwater and air objectives or is technically equivalent to the procedures described in the applicable section. The necessary demonstration shall be made in the form of engineering calculations, pilot plant data, or other test data (e.g., hydrogeologic studies) required by the Administrator."

Even if the permit is granted, additional operational conditions could be added to it. For instance, all facilities having the potential for groundwater pollution are required to install groundwater and leachate monitoring systems. However, if a facility uses procedures not outlined in regulations:

"...the Administrator may impose additional monitoring requirements as necessary to detect the possibility of a violation of air and groundwater objectives in sufficient time to initiate remedial action and prevent the actual occurrence of a violation."

It is envisaged that most facilities will choose to incorporate procedural standards, especially with respect to such sensitive issues as siting, in order to avoid the burden of proof and concurrent costs involved in establishing and confirming compliance.

Permits. The U.S. EPA has made the decision to integrate the NPDES and RCRA permit programs into a single and comprehensive permit process. As structured, the EPA's Office of Water Enforcement, currently responsible for the issuance of NPDES permits, will be writing permits incorporating applicable requirements under both the Clean Water Act and RCRA.

According to the latest EPA memorandum, permits will be written in the following order of priority:

Off-site hazardous waste management facilities,
whether or not they have an NPDES permit;

- . Indirect dischargers to sewers that are subject to pretreatment standards;
- . Industries affected by the BAT toxics effluent guidelines (the memo says RCRA permits will be issued when NPDES permits for those industries are revised);
- . Other industries which have NPDES direct discharge permits (the memo says RCRA priorities will prevail for these industries, however, and RCRA and NPDES permits will be issued simultaneously); and
- . All others, including on-site disposers not subject to pretreatment of NPDES regulations.

State Programs. RCRA clearly intends States to assume primary responsibility for implementation and enforcement of the Act. The Federal role would be one of "oversight" of State operations. Section 2006 regulations published in the Federal Register on February 1, 1978 identify three types of program authorization a State may receive: full authorization, in which the State assumes complete responsibility from program administration; interim authorization, in which states assume program responsibility on a temporary two-year basis during which they are expected to rectify short-falls preventing achievement of full-authorization status; and partial authorization, in which EPA and the State would jointly administer the program. This latter form of authorization is available to States only after the completion of the two-year interim period and only if the State lacks sufficient legislative authority to assume all aspects of the program. In this case, the EPA would assume responsibility for those portions of the program for which the the State lacks authority.

Time Frame. The EPA plans to promulgate all regulations under this subtitle in January 1980. The regulations would become effective six months afterwards, in July 1980.

B. Land Disposal of NonHazardous Solid Wastes

RCRA contains a number of provisions governing land disposal of non-hazardous solid wastes. Section 4004 calls for the development of criteria classifying sanitary landfills and open dumps. The EPA, in fulfillment of this requirement, published in February 6, 1978, Federal Register, proposed criteria defining what it will treat as environmentally adequate solid waste disposal facilities. These proposed rules will generally prohibit the siting of facilities in environmentally sensitive areas. Sensitive areas include wetlands, floodplains, permafrost areas, critical habitats of endangered species, and recharge zones of sole source aquifers. Before a new site may be located or an existing site be expanded in a sensitive area the facility must clearly demonstrate that no feasible alternative exists and that no significant adverse impact on the environment or public health will occur. A "clear demonstration" will entail the complete and accurate assessment of hydrogeologic, engineering, technological, environmental, economic, and other pertinent factors.

These regulations encourage but do not require the installation of monitoring systems. The Agency feels a facility which has a minimal pollution potential, either due to the low volume or innocuous nature of its wastes or as a result of the management practices employed, should not be required to invest in monitoring systems.

The Act calls for states to establish the regulatory authority necessary to upgrade or close all inadequate facilities (i.e., open dumps) within a five-year time frame. There are no statutory requirements for states to implement or enforce this prohibition. However, if such appropriate provisions are not included, states will not be eligible for Federal financial assistance under Subtitle D of RCRA, "State or Regional Solid Wastes Plans."

C. Special Waste Standards

The EPA has designated a number of "special wastes" under the proposed hazardous waste regulations. The Agency's rationale for the special waste distinction is threefold:

1. large volumes of these wastes are generated;
2. portions of these wastes will probably be identified as hazardous, although limited available information indicates that they pose a relatively low hazard to the environment; and
3. these wastes generally are not amenable to the control techniques required for disposal of a hazardous waste.

The list of designated special wastes currently includes:

1. cement kiln dust;
2. phosphate mining beneficiation and processing wastes;
3. utility waste (fly ash, bottom ash and scrubber sludge);
4. gas and oil drilling muds and oil production brines;
5. uranium mining wastes; and
6. other mining waste.

The EPA intends to develop special standards governing the disposal of these wastes. In the interim, the Agency has proposed disposal requirements for special wastes less stringent than those mandated for other wastes considered hazardous.

D. Resource Conservation and Energy Recovery

The Act encourages the conservation and recovery of materials and energy from wastes through a number of mechanisms. Subtitle D of the Act advocates state and regulatory solid waste planning which 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 facilitating 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 plants.

Section 4008 authorizes Federal financial assistance to states, counties, municipalities, and intermunicipal agencies with respect to the implementation of resource recovery services. This provision recognizes the multiple issues that must be considered prior to the development of a successful project. Assistance is authorized for "facility planning and feasibility studies; expert consultation; surveys and analyses of market needs; marketing of recovered resources; technology assessment; legal expenses; construction feasibility studies; source separation projects; and fiscal or economic investigations or studies." EPA will also make available technical assistance teams to state and local governments at no cost. These teams will include technical, marketing, financial and institutional specialists and will assist in planning activities.

Subtitle E requires the Secretary of Commerce to encourage the greater commercialization of proven resource recovery technology through the development of specifications for recovered materials; the promotion of proven technology; and the dissemination of applicable information.

RCRA also contains R&D authorities. Under Subtitle H, EPA is authorized to provide financial support for research, development and the demonstration of promising recovery techniques. "Promising Techniques" will encompass more than just technological advances. Projects employing innovative approaches to institutional economic and political obstacles to resource recovery will also be eligible for support.

Thus, under RCRA, it is possible for the EPA to contract directly with the private sector for the construction of full-scale demonstration facilities and the construction of pilot plants. However, funding for construction grants, loans, and loan guarantees to subsidize the construction of full-scale resource recovery facilities was not provided, and it is unlikely that such funding will be provided in the future.

Federal support for resource recovery systems will also be forthcoming from the Department of Energy (DOE). The Energy Resource and Development Administration Authorization of 1978 (P.L. 95-288) increased DOE's capability in this area. Titles II and IV give DOE authority to provide loan guarantees for demonstration projects.

In order to avoid duplication of effort, EPA and ERDA (not part of DOE) signed an inter-agency agreement regarding division of responsibilities. The agreement states that "for those energy-related projects of mutual

interest, planning will be conducted jointly, following which project responsibility will be assigned to one agency." The agreement further says that "new project responsibility will generally rest with EPA." DOE, however, will have responsibility for "input and evaluation of the energy-research-related portion of the project." The mechanics for implementing the agreement have not been totally resolved.

III. COAL GASIFICATION PROCESS DESCRIPTIONS

In this section, a description of coal gasification technologies is provided to: (1) depict the various process units common to most gasification facilities; and (2) indicate the potential sources of effluents resulting from the gasification procedure. First, the general coal gasification procedure is described. Next, process descriptions are provided for both the Lurgi Process and the Koppers-Totzek Process since these processes are currently commercial while many other processes are in various stages of development. Technological details were obtained from the references cited. Mention of specific process details (gasification temperature, specific pollution control equipment, etc.) is not meant to suggest that all gasification facilities or even a typical facility conform to these specifications. This information was provided merely to give a general representation of coal gasification procedures.

A. General Gasification Description

Gasification is a process by which coal or any suitable solid or liquid hydrocarbon is converted into gas. The conversion of the feedstock to gas is usually accomplished by a controlled partial-oxidation reaction.

The flow diagram in Figure 1 schematically illustrates a typical coal gasification system. Certain gasification processes may require different types of units or the addition of process units.

The first step in coal gasification entails obtaining coal from the mine, storing it, and preparing the coal for the gasification process. Coal preparation usually consists of reducing its size (crushing) to that necessary for gasification and, possibly, drying the coal.

Gasification involves the reaction of coal with steam and oxygen at high temperature and high pressure. In general, air is used as the oxidant to manufacture low-BTU gas, oxygen to produce medium-BTU gas. Since the gasification process is endothermic, a portion of the coal is burned to supply the necessary heat for the reaction of steam with coal. The exact composition of the gasification products are related to the gasifier operating conditions (temperature and pressure), the oxidant, and the feedstock. The product of the gasification reaction is a mixture of hot, raw gases which must be cleaned, shifted, and methanated (if high-BTU gas is desired). The primary components of most coal-derived fuel gases are carbon monoxide, hydrogen, methane, carbon dioxide, nitrogen and water. The major by-products of the gasification process are:

1. slag and ash;
2. considerable quantities of tars and heavy hydrocarbons (applicable to gasifiers operating at low temperatures).

MAIN GASIFICATION TRAIN

UTILITIES AND ENVIRONMENTAL CONTROLS

Figure 1. FLOW PLAN FOR COAL GASIFICATION

SOURCE: Reference 1.

After the gasification step, the product gas is scrubbed to remove some of the undesirable constituents. Tar or product liquor is used as the scrubbing agent to (1) lower the temperature of the product gas so that components with higher boiling points (phenols, tar) can be removed, and (2) reduce particulates.

If a high-BTU product is desired, a CO-shift conversion process is usually included after the gasification process to generate more hydrogen. Specifically, the hydrogen to carbon monoxide ratio should have a value of about 3.75:1 for the methanation step (Reference 2). The CO-shift conversion process allows the proper ratio to be achieved by reacting carbon monoxide with steam to produce carbon dioxide and hydrogen.

Next, the product gas is routed to an acid gas removal unit. During the gasification process most of the sulfur present in the coal is converted to hydrogen sulfide; some is transformed to carbonyl sulfate. These components must almost always be removed from the gas stream. With the exception of fuel gas applications, carbon dioxide is normally also removed.

The final step in high-BTU gas production is methanation. This process upgrades medium-BTU synthesis gas to a methane rich product of pipeline quality, called substitute natural gas (SNG).

B. Lurgi Process Description

All modern industrial techniques for the conversion of coal originated in Germany (circa 1915). One of the first techniques for the gasification of coal was the Lurgi process. In 1930 the Lurgi process was developed for the gasification of noncaking coals. The product gas had either a low or intermediate heating value.

Today, Lurgi process technology is a viable method for producing either a low- or a medium-BTU product, depending on the oxidant. A typical Lurgi process plant is shown in Figure 2. Overall, the Lurgi process is quite similar to other methods of coal gasification processes. The major difference is the gasification step itself. The Lurgi process, as shown in Figure 3, uses a pressurized (350-450 psig) fixed-bed gasifier, which operates either with air or oxygen and steam (Reference 2). In the gasifier, there is a countercurrent flow of reactants. This encourages heat transfer from the hot gases at the bottom of the gasifier to the cooler incoming coal.

The gasifier has essentially three process zones. Devolatilization of the coal occurs in the first zone. As the coal drops down to the second zone, it is gasified by the reaction of carbon with steam. The third zone encompasses the grate area, where carbon is burned to supply the heat used in the gasification process.

Ash settles out through the grate and is deposited into an ash hopper. The hot, raw product gas existing from the top of the reactor contains coal dust, oil, naphtha, phenol, ammonia, tar oil, ash, char and other constituents (Reference 1). This mixture is passed through a scrubber and cooling tower to remove the tar. Next, the raw gas stream travels through a

Figure 2. LURGI PROCESS

Source: Reference 1

FIGURE 3: LURGI PRESSURE GASIFIER

SOURCE: REFERENCE 3

waste heat boiler in order to reduce its temperature. Approximately one-half of the cooled gas undergoes shift conversion to generate supplemental hydrogen, while the other half passes directly to the gas purification system.

The shift conversion process manufactures hydrogen by the "water-gas shift" reaction (Reference 1). It is designed to produce a hydrogen to carbon monoxide ratio of over 3:1 in the total gas stream prior to the methanation process. The shift conversion product stream is mixed with the by-pass gas stream from the gasification unit. This mixture is then cooled before being sent to the gas purification unit.

The key section of the gas purification unit is the Rectisol system. The Rectisol system utilizes a cold methanol process to remove acid gases such as H_2S , COS and CO_2 (Reference 1). Actually, all types of sulfur compounds and large amounts of combustibles can be removed by the Rectisol system. Drying and reducing the CO_2 level before final pipeline compression is also accomplished by the gas purification system. The "cleansed" gas stream from the Rectisol unit is next piped to the methanation area, where the product gas is upgraded to a methane-rich product of pipeline quality (SNG). Finally, the SNG is compressed to pipeline pressure and dried.

C. Koppers-Totzek Process Description

Another commercially available method for coal conversion is the Koppers-Totzek process. The major elements of a typical Koppers-Totzek process plant is shown in Figure 4. The Koppers-Totzek process basically relies on an atmospheric pressure, oxygen-blown, entrained-flow gasifier to produce a tar-free intermediate-BTU product gas (Reference 2). A widely used Koppers-Totzek gasifier is depicted in Figure 5. Any type or rank of coal, including the fine grades, can be gasified by this process.

Coal preparation involves pulverizing the coal to 70% less than 200 mesh (0.003 in.) particles and then drying. The coal is screw-fed to the gasifier nozzles, where it is thoroughly mixed with oxygen and steam. The operating temperature of the gasifier is quite high (approximately 3000°F) (Reference 3). Consequently, tars, phenols and light oils are destroyed in the combustion process. The high operating temperature also produces slagging of the ash. A portion of the slag leaves at the base of the reactor while the remaining portion passes overhead with the gas. Approximately half of the coal ash is emitted as fine fly ash (Reference 3). The very hot product gases are waterspray-cooled before entering a waste heat boiler. Additional cooling of the product gas to a temperature of about 350°F is performed by the waste heat boiler (Reference 3). During the cooling process, sufficient quantities of superheated, high pressure steam are produced to supply the required process steam and to run the air compressors for the oxygen plant.

After the product gas is cooled in the waste heat boiler, it is sent to a high-energy scrubbing system. This treatment greatly reduces the loading of entrained solids in the product gas stream. The scrubber waste stream contains approximately one-half of the slag in addition to various dissolved

GASIFICATION PROCESS

AUXILIARY FACILITIES

Figure 4. KOPPERS-TOTZEK GASIFICATION PROCESS

SOURCE: Reference 1

FIGURE 5: KOPPERS-TOTZEK TWO-HEADED REACTOR

SOURCE: REFERENCE 3

gases (H_2S , etc.). This stream is sent to a clarifier to remove solids and then it passes through a cooling tower to process out dissolved gases.

The next step in the gasification sequence is compression of the product gas. After compression, the gas is sent to the acid gas removal unit. This unit utilizes an amine system (methyldiethanolamine) for the removal of H_2S at about $120^{\circ}F$ (Reference 1). A high concentration of H_2S is produced in the sour gas stream and can be treated by a Claus plant.² The scrubbed product gas still contains significant amounts of sulfur compounds and much of the CO_2 . This is acceptable for a low-BTU fuel product. However, if a high-BTU fuel is desired, additional treatment will be required before the methanation process.

IV. IDENTIFICATION AND CHARACTERIZATION OF SOLID WASTE STREAMS IN COAL GASIFICATION FACILITIES

Solid waste generated by coal gasification facilities result from a number of processes and sub-systems at the plant. Any material entering the conversion facility may be a potential pollutant. Although the various coal gasification technologies have different processing units, similarities of their waste streams and waste management practices allow them to be examined simultaneously. The major sources of solid waste from gasification processes (Reference 4) are:

1. chars and ashes from the gasification operation and air pollution control,
2. spent catalysts from shift conversion and methanation,
3. inorganic solids and sludges from acid gas removal and air and water pollution control,
4. tar and oil sludges, and
5. biosludges from water pollution control.

The flow diagram shown in Figure 6 schematically illustrates the process modules generating solid wastes. Almost all integrated facilities would produce ash, spent catalyst and inorganic solids and sludges. Gasification facilities may or may not generate the other types of wastes depending on (1) the specific gasification process used, and (2) the type of wastewater treatment processes employed.

The actual quantity and exact chemical composition of each solid waste stream are a function of coal type, specific processes employed and plant design. For example, the coal type determines to a large extent the size and cost of sidestream processing trains and affects the quantity of solid waste discharges. Operative design features such as temperature, the number and type of process stops, and the process sequence itself are critical design features influencing process emissions. Due to the wide variations in design operating conditions, coal feed, and plant size, strict comparisons of process emissions between various gasification facilities may not be appropriate. The objective of this section is, therefore, to present a range of values for potentially hazardous constituents contained in each waste stream, as found in both open and industry literature, in order to identify the wastes most likely to be affected by RCRA regulations.

All the coal-derived compounds plus added materials are contained in the various process streams (including products and byproducts). For the majority of pollutants, control and treatment processes are available for controlling emissions or transforming them to environmentally acceptable forms. Control technologies available to minimize pollutants generated in the conversion areas include particulate control, stack gas control, acid gas treatment, wastewater treatment, char treatment, heat control, and noise

Figure 6. PROCESS MODULES GENERATING SOLID WASTES IN AN INTEGRATED HIGH BTU GASIFICATION FACILITY

SOURCE: REFERENCE 4

abatement. The role of pollution control equipment in coal conversion processes is demonstrated in Figure 7. Converting pollutants to less offensive forms, rather than their complete elimination, is the main objective of control and treatment processes. Although desirable, achievement of zero effluent can develop into an infinite process since clean-up processes often generate their own pollutants which require treatment.

Emissions from control and treatment facilities include (1) converted and fugitive pollutants resulting from process emission streams, and (2) substances used within the treatment facilities. Disposal options for these emissions include use as landfill or minefill, the resale of by-products to other industries, or return for additional treatment.

A. Ashes and Chars from Gasification Operation and Air Pollution Control

The primary solid residues produced in coal gasification processes are ashes or chars. Ash is the noncombustible residue (mainly mineral matter) from the combustion of dried coal and has little or no heating value. On the other hand, char can be recycled as a fuel for the parent gasification process or another industry. The actual quantity and chemical make-up of the solid wastes depend largely on coal type and the specific processing steps used.

Three types of ash can be produced in gasification operations: (1) dry (including fly ash and particulate matter), (2) melted (slag) or (3) softened (self-agglomerating). Cyclones, electrostatic precipitators, or wet scrubbers are used to remove fly ash or particulate matter from the gas streams. In general, water is used to quench the melted ashes removed from the bottom of the gasifier (e.g., Lurgi Process). A wet sludge containing the major portion of the ash is formed from the settling of the quench slurry. The characteristics of the solids present in the ash sludge should be quite similar to that of the dry ash. Nearly all of the inorganic constituents present in the feed coal are contained in the ash and chars. Reported values for the residual carbon in ash/char range from a few percent to over 50% (Reference 4). The carbonaceous material in chars and ashes is primarily elemental carbon with small amounts of highly polymeric aromatic and heterocyclic organics (Reference 4).

Gasifier ash is quite similar to boiler bottom ash. Bottom ash is the coarser, heavier residue which accumulates in the furnace bottom in one of two forms: as a loose, dry ash or as a viscous fluid (slag). Difficulties in handling the gasifier ash can be encountered because of its size and abrasive nature. The major components of bituminous coal bottom ash are SiO_2 , Fe_2O_3 , and Al_2O_3 ; lesser components are CaO , MgO , Na_2O , K_2O and SO_3 . Chemical analyses of selected bottom ashes are provided in Table 2.

Ash composition is a function of the coal's origin, rank, and location within a bed. Nearly all trace elements are enriched in comparison to their abundance in the earth's crust. Table 3 compares the chemical analyses of subbituminous and bituminous coal ash.

Figure 7. Emission Fates For Coal Conversion Process

SOURCE: Reference 3

TABLE 2
CHEMICAL ANALYSIS OF SELECTED BOTTOM ASHES (%)^a

<u>Source</u>	<u>SiO₂</u>	<u>Al₂O₃</u>	<u>Fe₂O₂</u>	<u>CaO</u>	<u>MgO</u>	<u>Na₂O</u>	<u>K₂O</u>
Kammer	48.9	21.9	14.3	1.4	5.2	0.7	0.1
Kanawha River	53.6	28.3	5.8	0.4	4.2	1.0	0.3
Mitchell	45.9	25.1	14.3	1.4	5.2	0.7	0.3
Muskingham	47.1	28.3	10.7	0.4	5.2	0.8	0.4
Willow Island	53.6	22.7	10.3	1.4	5.2	1.2	0.1
Typical limits ^b	20-60	10-35	5-35	1-20	0.3-4	1-4	1-4

^a No SO₃ detected.

^b From Melvig, W. A., and Gibson, F. H. 1956. Analysis of ash from United States coals. Bu. Mines Bull. 567.

SOURCE: Reference 3

TABLE 3
CHEMICAL ANALYSIS OF FLY ASH (%)

<u>Chemical Components</u>	<u>Subbituminous Coal</u>	<u>Bituminous Coal</u>
SiO ₂	50.50	43.5 - 57.0
Al ₂ O ₃	33.70	18.0 - 28.0
Fe ₂ O ₃	6.85	7.9 - 16.0
CaO	2.80	4.0 - 10.0
MgO	1.50	1.0 - 5.5
SO ₃	0.75	0.9 - 3.3
Combustion Losses	2.85	(Na ₂ O + K ₂ O)

SOURCE: Reference 3

TRW has compiled an environmental assessment data base for various high-BTU gasification technologies (Reference 4). As part of this effort, elemental analyses of samples of ashes and chars were performed. The results, according to coal type, for the 800 ton per day South African Coal, Oil, and Gas Corporation (SASOL) Lurgi plant are presented in Table 4.

Shaw and Magee have calculated waste stream compositions for a hypothetical 250 MM scfd Lurgi synthetic natural gas plant using a subbituminous coal (Reference 5). Their results indicate that 314,000 lb/hour of ash are produced from the oxygen gasifier, and 80,200 lb/hour from the air gasifier. The sulfur content of the ash in this plant is 0.05% on a dry weight basis. Demineralizer blowdown water is mixed with the two sources of ash, resulting in 466,700 lb/hour of wet ash which is disposed of in the mine.

The Wesco Coal Gasification (Lurgi) Complex is expected to produce a total of 2,806,700 tons of bottom ash from (1) the coal fired boilers and, (2) fly ash collected by the precipitators (Reference 3).

Magee, Jahnig and Shaw have evaluated pollution control measures for a hypothetical 290 MM scfd Koppers-Totzek plant using a bituminous coal (Reference 6). They estimated that 640 tons per day of wet slag (9% water) will be produced by gasification. This substance is similar to blast furnace slag, but lower in sulfur content. Dust and leachable material contained in the slag stream should be minimized since the slag stream has been melted. However, odor and sulfur release may pose problems.

Trace amounts of a very large number of elements appear in ash. Table 5 lists 65 elements that have been found in coal. Maximum, minimum, and average concentrations of various trace elements present in coal ashes from anthracite and subbituminous coals are given in Table 6.

Griffin, R. A., et al, has conducted a study on the solubility and toxicity of potential pollutants in solid coal wastes (Reference 10). As part of this study, the chemical composition of Lurgi ash and slurry supernatant solutions of the ash at several pH's were investigated. These results are presented in Table 7. Of the approximately 60 chemical constituents measured in the raw Lurgi ash, only 16 were found to be in forms soluble enough to exceed recommended water quality levels in some samples at pH values between three and eight. Table 8 lists these 16 constituents. Nine constituents (B, Ca, Cd, K, Mn, NH_4 , Pb, SO_4 and Sb) exceeded the recommended levels in all Lurgi ash solutions over the pH range three to nine. The authors concluded that these nine constituents pose the highest potential pollution hazard.

Potential uses of ash from gasification processes include use as a soil stabilizer, concrete aggregate, paving material, fire-control, or proofing material, acoustical insulation, component of cement blocks, face brick, paving tile, and in the manufacture of tana grass.

Char is the solid residue remaining after the removal of moisture and volatile matter from coal. If carbon removal during the gasification process is incomplete, char will be produced (e.g., Synthane Process). Providing that there is sufficiently high carbon content, char can be a valuable source of energy for either the originator or another industry. Potential uses of char are for gasifier feedstock, utility fuel production, or

TABLE 4

PROPERTIES OF LURGI ASH - FROM GASIFIER ASH HOPPER

<u>COAL NUMBER:</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
<u>Type/Origin</u>	<u>Montana Rose-</u> <u>bud Subbitu-</u> <u>minous A</u>	<u>Illinois #6</u> <u>High</u> <u>Volatile</u>	<u>Illinois #5</u> <u>Bituminous</u>	<u>Pittsburgh</u> <u>#8</u>	<u>South African</u> <u>Subbituminous</u>
Production Rate: kg/kg	0.097	0.090	0.087	0.077	0.313
Angle of Repose:	24°	33°	41°	43°	-
<u>Bulk Density</u>					
Poured: kg/Nm ³ (lb/ft ³)	918 (57.4)	762 (47.6)	990 (61.9)	(42.1)	-
Tapped: kg/Nm ³ (lb/ft ³)	1078 (67.4)	894 (55.9)	1190 (69.1)	(48.9)	-
<u>Ash Fusion Temp.</u>					
<u>Oxidizing:</u>					
I.F.: °C	1240	1350	1280	1340	-
H.P.: °C	1260	1365	1300	1360	-
F.P.: °C	1290	1390	1330	1380	-
<u>Reducing:</u>					
I.F.: °C	1165	1090	1030	1145	-
H.P.: °C	1175	1150	1060	1170	-
F.P.: °C	1210	1225	1070	1180	-
<u>Partial Analysis</u>					
Carbon: wt. %	6.5	3.2	2.0	7.6	-
SiO ₂ : wt. %	46.8	49.6	46.1	43.6	52
Al ₂ O ₃ : wt. %	17.7	20.5	18.1	20.7	28
Fe ₂ O ₃ : wt. %	11.2	17.2	19.7	15.0	5
CaO: wt. %	8.3	2.1	3.9	3.0	7
MgO: wt. %	3.9	1.0	0.7	0.7	1.7
Sulfur as SO ₃ : wt. %	1.7	1.3	0.6	0.8	0.2
Cl: wt. %	0.01	0.01	0.01	0.01	-

I.F. = initial deformation temperature.
H.P. = hemispherical point
F.P. = fluid point

SOURCE: Reference 4

TABLE 4 (continued)

COAL NUMBER:	1	2	3	4	5
Type/Origin	Montana Rosebud Subbituminous A	Illinois #6 High Volatile	Illinois #5 Bituminous	Pittsburgh #8	South African Subbituminous
Trace Elements+ (ppm)					
Be	-	14	20	-	-
Hg	-	.04	.016	-	-
Cd	-	< 0.3	< 0.3	-	-
Sb	-	0.2	19	-	-
Se	-	-	-	-	-
Mo	-	6	8	-	-
Co	-	.40	.38	-	-
Ni	-	456	462	-	-
Pb	-	96	200	-	-
As	-	0.1	0.3	-	-
Cr	-	750	592	-	-
Cu	-	239	273	-	-
B	-	622	673	-	-
Zn	-	469	1600	-	-
V	-	301	181	-	-
Mn	-	200	305	-	-
F	-	5	4.6	-	-

TABLE 5
A PARTIAL IDENTIFICATION OF TRACE
ELEMENTS IN COAL ASH

Aluminum	Gallium	Samarium
Antimony	Germanium	Scandium
Arsenic	Hafnium	Selenium
Barium	Holmium	Silicon
Beryllium	Indium	Silver
Bismuth	Iodine	Sodium
Boron	Iron	Strontium
Bromine	Lanthanum	Tantalum
Cadmium	Lead	Tellurium
Calcium	Lithium	Terbium
Carium	Lutetium	Thallium
Cesium	Magnesium	Thorium
Chlorine	Manganese	Tin
Chromium	Mercury	Titanium
Cobalt	Molybdenum	Tungsten
Copper	Neodymium	Uranium
Dysprosium	Nickel	Vanadium
Erbium	Niobium	Ytterbium
Europium	Potassium	Yttrium
Fluorine	Praseodymium	Zinc
Gadolinium	Rubidium	Zirconium

SOURCE: Reference 3

TABLE 6
RANGE IN AMOUNT OF TRACE ELEMENTS PRESENT IN COAL ASHES (PPM)

Element	Anthracites			Lignites and Subbituminous		
	Maximum	Minimum	Average (5) ^a	Maximum	Minimum	Average (13)
Ag	1	1	b	50	1	b
B	130	63	90	1,900	320	1,020
Ba	1,340	540	866	13,900	550	5,027
Be	11	6	9	28	1	6
Co	165	10	81(4)	310	11	45
Cr	395	210	304	140	11	54
Cu	540	96	405	3,020	58	655
Ga	71	30	42	30	10	23(12)
Ge	20	20	b	100	20	b
La	220	115	142	90	34	62
Mn	365	58	270	1,030	310	688
Ni	320	125	220	420	20	129(8)
Pb	120	41	81	165	20	60
Sc	82	50	61	58	2	18(10)
Sn	4,250	19	962	660	10	156
Sr	340	80	177	8,000	230	4,660
V	310	210	248	250	20	125
Y	120	70	106	120	21	51
Yb	12	5	8	10	2	4
Zn	350	155	b	320	50	b
Zr	1,200	370	688	490	100	245

^a Figures in parentheses indicate the number of samples used to compute average values.

^b Insufficient figures to compute an average value.

SOURCE: Reference 3

TABLE 7
CHEMICAL COMPOSITION OF LURGI ASH AND SLURRY SUPERNATANT
SOLUTIONS OF THE ASH FROM AN ILLINOIS NO. 6
COAL AT SEVERAL pH'S

Constituents	Chemical Composition of 10% Slurry Supernatant (mg/l)								Recom- mended Water Levels (mg/l)	Solid Ash Content (mg/kg)	
	Air Atmosphere				Argon Atmosphere						
	pH	7.55 ^a	5.10	3.82	2.68	8.82 ^a	7.20	5.35			3.79
Ag	-	-	-	-	-	-	-	-	.05	<.4	
Al	ND ^b	2	14	132	ND	ND	ND	92	.1	108,121	
Au	-	-	-	-	-	-	-	-	-	.001	
As	ND	ND	ND	ND	ND	ND	ND	ND	.1	3	
B	4.0	4.5	4.5	5.5	4.5	3.0	4.5	8.0	.75	355	
Ba	ND	ND	ND	ND	ND	ND	ND	ND	1.0	950	
Be	ND	ND	.01	.03	ND	ND	ND	.01	.1	12	
Br	-	-	-	-	-	-	-	-	-	<1.0	
Ca	290	480	400	570	440	370	430	500	50	16,652	
Cd	.02	.03	.03	.06	.01	ND	.02	.05	.01	<1.6	
Ce	-	-	-	-	-	-	-	-	-	140	
Cl	ND	ND	ND	ND	ND	ND	ND	ND	250	100	
COD ^c	2	2	2	81	2	2	16	140	50	-	
MCE ^d	28	28	0	23	10	3	6	4	-	-	
Cr	ND	.02	.05	.12	.01	.01	.06	.16	.05	212	
Co	ND	.05	.08	.19	ND	ND	ND	.17	.05	34	
Cu	.01	.02	.13	.73	.01	.05	.01	.05	.2	57	
Cs	-	-	-	-	-	-	-	-	-	11	
Eu	-	-	-	-	-	-	-	-	-	1.9	

- a. Natural pH of supernatant.
- b. Not detectable.
- c. Chemical oxygen demand.
- d. Methylene chloride extractable.
- e. For low Na diet; 250 ppm for taste.

TABLE 7 (continued)

[illegible]

TABLE 7 (continued)

Constituents	Chemical Composition of 10% Slurry Supernatant (mg/l)								Recommended Water Levels (mg/l)	Solid Ash Content (mg/kg)
	Air Atmosphere				Argon Atmosphere					
Tl	ND	ND	ND	ND	ND	ND	ND	ND	-	4.6
U	-	-	-	-	-	-	-	-	-	17
V	-	-	-	-	-	-	-	-	0.1	184
W	-	-	-	-	-	-	-	-	-	1.5
Yb	-	-	-	-	-	-	-	-	-	2.9
Zn	.12	5.5	12	17	.01	.11	6.5	20	.2	400
Zr	-	-	-	-	-	-	-	-	-	170
EC (mnhos/cm)	1.17	1.50	1.95	5.60	1.20	1.39	1.80	5.20	18	-
Eb (electrode mv)	+223	+246	+407	+349	+109	+161	+102	+243	-	-

SOURCE: Reference 10.

TABLE 8
ELEMENTS EXCEEDING RECOMMENDED WATER QUALITY LEVELS

Constituent	Lurgi Ash Solubility	
	pH 3 (mg/l)	pH 8 (mg/l)
Al	132	0.5
B ^a	5.5	4.0
Ca ^a	570	290
Cd ^a	0.06	0.02
Cr	0.12	0.02
Co	0.19	0.10
Cu	0.75	0.01
F	-	-
Fe	560	0.06
K ^a	26	42
Mn ^a	3.80	0.45
NH ₄ ^a	11	17
Pb ^a	0.20	0.10
SO ₄ ^a	338	820
Sb ^a	0.60	0.20
Zn	17.00	0.12

^a Highest pollution potential

SOURCE: Reference 10

as a hydrogen source. Depending on the process steps, coal gasification can produce net char amounts ranging between 10 and 55% of the coal feed weight (Reference 3). A single conversion plant could produce as much as 4 to 5 million tons per year of char. Char which is used as a fuel may be a potential problem source of pollution due to sulfur dioxide emissions.

The characteristics of the char are a function of the coal feed, coal characteristics (ash, sulfur), and method of treatment (severity, temperature, reaction atmosphere). Table 9 provides a comparison of the ultimate and proximate analysis of chars obtained from the Synthane gasification process with the coals from which they are derived. As can be seen from Table 9, chars differ significantly in ash, sulfur and volatile matter content. There is a considerable reduction in the total sulfur in char compared to the original coal.

Other than in-plant use, the primary market for char is as a combustion source for power plants. Key factors determining the value of char as boiler fuel are volatile matter content, porosity, grindability, and ash content. Treatment of the residual sulfur content in the char will be required if used as a fuel. For example, the Synthane utility boiler, when combusting 4,350 tons of char per day, would emit 10,900 lb of sulfur dioxide per hour. Char desulfurization processes, similar to coal desulfurization processes, may be an effective solution to reduce sulfur dioxide emissions. Traditional methods of removing sulfur during or after coal combustion (Lime Scrubbing, Limestone Injection, etc.) may also be useful for chars (Reference 3).

In addition, some chars have demonstrated significant adsorption properties - superior to that shown by commercial activated carbons. Thus, chars may have value in sewage treatment or in the removal of sulfur dioxide from fuel gases.

Trace Elements. The fates of trace elements in coal conversion are not well known. The distribution of trace metals is governed by the process operating conditions and the interaction of coal constituents. Potential pathways for trace elements within gasification processes are: (1) adsorption on particulate matter, (2) incorporation in condensates, (3) inclusion in by-products, (4) inclusion in final products, and (5) emission as fugitive pollutants. The bulk of elements are anticipated to be present in the solid by-products such as ashes, chars and filter cakes (Reference 3). However, other by-products such as tars are likely to contain minor amounts of trace elements. The fate of trace elements through coal conversion may be different from that experienced by coal combustion since gasification occurs in reducing atmospheres, while combustion utilizes oxidation. Gasification processes may result in the formation of more volatile compounds (such as hydrides, carbonyls) than the oxidized compounds produced by combustion (Reference 3).

Trace element concentrations of the coal and ash generated by Lurgi gasification are compared in Table 10. Based on the above information, a Lurgi coal gasification plant processing 20,000 tons of coal per day may produce the following amounts of trace elements (Reference 3):

TABLE 9
REPRESENTATIVE ANALYSES OF COALS AND CHARS (WT. %)

<u>Component</u>	<u>Illinois Number 6</u>	<u>Western Kentucky</u>	<u>Wyoming Subbituminous</u>	<u>North Dakota Lignite</u>	<u>Pittsburgh Seam</u>
<u>Coals</u>					
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
Oxygen	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
<u>Chars</u>					
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: Reference 3.

TABLE 10

LURGI GASIFICATION: TRACE ELEMENT CONCENTRATIONS (PPM) IN ILLINOIS
COAL AND IN THE UNQUENCHED GASIFIER ASH OBTAINED

Reference:	Illinois Number 5 Coal				Ash			
	Peabody ^a	Argonne ^b			Peabody ^a	Argonne ^b		
Element								
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 ⁴)		1.3	±	0.1 (AA)		15	±	2 (AA)
Hg	0.20	0.17	±	0.02	0.01	0.016	±	0.002
K (x10 ³)		1.3	±	0.1 (AA)		14	±	1 (AA)
La		3.6	±	0.5 (A)		42	±	4 (AA)
Li	5.5				54			

- A. The precision of the Peabody results is estimated to be +10% in all cases.
- B. 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.
- C. Not representative of seam; contamination suspected.

SOURCE: Reference 3.

TABLE 10 (continued)

	Illinois Number 5 Coal					Ash				
Reference:	Peabody ^a		Argonne ^b			Peabody ^a		Argonne ^b		
Element										
Mn	21	23	± 2	(AA)		338	305	± 30	(AA)	
Mo	7					8				
Na (x10 ²)		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				(C)
V	21					181				
Yb							11	± 2	(B)	
Zn (x10 ²)	1.82	2.4	± 1.2	(B)		15.8	16	± 2	(A)	

	Illinois Number 6 Coal				Ash			
Reference:	Peabody ^a	Argonne ^b			Peabody ^a	Argonne ^b		
Element								
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)
En		0.2	± 0.1	(B)				
F	79	79	± 16			5.2	± 1.0	

TABLE 10 (continued)

	Illinois Number 5 Coal					Ash				
Reference:	Peabody ^a	Argonne ^b				Peabody ^a	Argonne ^b			
Element										
Fe (x10 ³)	1.00 ^c	1.2	±	0.1	(AA)	0.04	13	±	1	(AA)
Hg		1.18	±	0.12			0.007	±	0.001	
K (x10 ³)		1.5	±	0.1	(AA)		16	±	2	(AA)
La	9.2	3.9	±	0.4	(AA)	74	40	±	20	(B)
Li										
Mn	20	18.6	±	1.9	(AA)	243	156	±	16	(AA)
Mo	7					6				
Na (x10 ²)		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 ²)	0.43				(C)	4.69				(C)

<u>Element</u>	<u>Amount (lb/hr)</u>
Arsenic	1 - 2
Beryllium	75 - 80
Fluorine	10 - 20
Lead	750 - 2700
Vanadium	600 - 750

It should be remembered that these figures are only valid for the particular coal and ash samples analyzed in this study. The raw product gas stream is expected to contain trace elements lost in the conversion from coal to ash. Higher values of elements present in ash than in coal may be attributable to contamination or wear of equipment surfaces.

The potential of gasification ash for leaching trace elements 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 gasification reactions). Ash leachates (calcium chloride, magnesium sulfate, fluorides) may be an important source of trace metal environmental pollution. However, existing information concerning the environmental destiny of ash leachates is insufficient to make a definitive assessment of their role as potential environmental contaminants.

Ash can serve as absorption media for polynuclear aromatic hydrocarbons. Consequently, fugitive ash emissions may be environmentally significant. In fact, particulate matter (especially soot) may be solely responsible for the presence of polycyclic organic matter in the atmosphere (Reference 3).

Cyclones, electrostatic precipitators, or wet scrubbers can be used to remove much of the fly ash or particulate matter in the fuel gas before undergoing acid gas cleanup. During stack gas and product gas cleaning, elements adsorbed on particulate matter may be removed by electrostatic precipitators or cyclones. Table 11 presents trace elements that may appear in the hot gases leaving the gasifier.

Despite the potential differences between trace elements produced by coal gasification and coal combustion, data on trace elements in power plant flue gas may provide valuable insight on the distribution of trace elements in various gasification process streams. A study of the pathways of 37 trace elements was performed at the TVA Allen Steam Plant (Reference 3). The results indicated that the majority of the mercury, and probably most of the chlorine and bromine, and some of the selenium were emitted as gases. Heavier concentrations of arsenic, cadmium, copper, gallium, molybdenum, lead, antimony, selenium, and zinc were reported in the fly ash than in the slag, and primarily in the fly ash emitted from the stack as opposed to that collected by the precipitator. Aluminum, barium, calcium, cerium, cobalt, europium, iron, hafnium, potassium, lanthanum, magnesium, manganese, rubidium, scandium, silicon, samarium, strontium, tantalum, thorium, and titanium were detected in the slag and in collected and discharged fly ash.

The fate of trace elements in the various conversion process streams requires additional study before actual control measures can be determined.

TABLE 11
EXAMPLE OF TRACE ELEMENTS THAT MAY APPEAR IN
GAS DURING GAS CLEANING

<u>Element</u>	<u>Possible ppm in coal^a</u>	<u>Percent volatile for example^b</u>	<u>In gas^c (lb/day)</u>
Chlorine	1500	90+	32,400
Mercury	0.2	90+	5
Selenium	2.2	74	39
Arsenic	31	65	484
Lead	7.7	63	116
Cadmium	0.14	62	2
Antimony	0.15	33	1
Vanadium	35	30	252
Nickel	14	24	81
Beryllium	2	18	9
Zinc	44	(10)	106
Boron	165	(10)	396
Fluorine	85	(10)	204
Titanium	340	(10)	816
Chromium	22	Nil	Nil

^a Mainly based on Pittsburgh seam coal (Kalfadelis and Magee 1974).

^b Mainly based on lower-temperature gasifier (Attari 1973) and indicated at 10% for zinc, boron, and fluorine in absence of data.

^c For 12,000 tons of coal feed per day.

SOURCE: Reference 3

This area is of particular concern since hazardous elements may possibly be concentrated in a process area and then enter the environment at a concentration greater than that of the original coal.

Pretreatment Operations. Coal is stockpiled, cleaned, dried, and crushed in the preparatory stages of coal conversion. Emissions during this phase are characteristic of those from other large coal-using industries such as power plants. Consequently, pollutants produced by coal preparation operations are well documented, and effective control and treatment technology is available.

Dusting and runoff from the coal storage area may be environmentally significant. The concentration of matter from the coal that appears in runoff is affected by the composition of the coal, the surface area of the pile, and the amount of rainfall. In general, metal sulfate and sulfuric acid are produced from the reaction of coal minerals with rainwater and oxygen. The acid can, in turn, dissolve many other complex sulfides, sulfates and sulfites, releasing some or all of the following metals: aluminum, zinc, copper, cadmium, beryllium, nickel, chromium, vanadium, silver, and lead (Reference 3). Analyses of drainage from two industrial coal piles is provided in Table 12.

Extraneous mineral matter and other debris are generated from physical coal grinding and cleaning operations. In addition, coal washing generates 12 to 25 pounds of solid waste per 100 pounds of clean coal (Reference 3). Cyclone separators, bag filters, negative pressure grinders, wet scrubbers or electrostatic precipitators may be used to control coal dusts and fines from the drying and grinding operations. Table 13 presents yearly estimated emissions for the Wesco Coal Gasification (Lurgi) Plant. Controlled particulate emissions amount to 290.1 tons per year, but emissions could amount to as much as 152,000 tons per year without pollution control.

Potential disposal options include use of coal fines for minefill, manufacture of briquettes for the Lurgi process, use as power plant or utility feed, recycling for gasification or liquefaction, or resale.

B. Spent Catalysts

Many types of catalysts are used in coal conversion technologies (Table 14). The role of catalysts in gasification processes is as chemical reactants or purification solvents. Catalysts are required for the shift conversion and methanation processes. Eventually, catalysts become deactivated and require regeneration or disposal. Proposed commercial SNG facilities in the United States assume a catalyst life of 6 months to 2 years (Reference 4). Regeneration is usually accomplished by return to the manufacturer, while disposal often entails return to the mine with the ash. In addition to bulk spent catalyst, dusts may be generated by abrasion and escape into the ash, or be incorporated into product streams as extremely fine particulate matter. Such dusts may be collected in the air pollution control systems.

TABLE 12
ANALYSES OF DRAINAGE FROM TWO INDUSTRIAL COAL PILES

Constituent	Concentration (mg/liter)	
	Coal Pile 1	Coal Pile 2
Total acidity (as CaCO_3)	1,700	270
Calcium	240	350
Chemical oxygen demand	9	ND
Chloride	0	ND
Conductance, mho/cm	2,400	2,100
Total dissolved solids	3,200	1,500
Hardness (as CaCO_3)	600	980
Magnesium	1.2	0.023
pH	2.9	2.9
Potassium	ND	0.5
Silica (dissolved)	91	ND
Sodium	ND	4.1
Sulfate	2,600	ND
Total suspended solids	550	810
Turbidity (Jackson turbidity units)	300	ND
Aluminum	190	ND
Arsenic	0.01	0.009
Barium	ND	0.1
Beryllium	ND	< 0.01
Cadmium	< 0.001	< 0.006
Chromium	< 0.005	< 0.005
Copper	0.56	0.18
Iron	510	830
Lead	< 0.01	0.023
Manganese	27	110
Mercury	< 0.0002	0.027
Nickel	1.7	0.32
Selenium	0.03	0.003
Titanium	< 1	ND
Zinc	3.7	1.0

ND = No data

SOURCE: Reference 7

TABLE 13

YEARLY ESTIMATED EMISSIONS (TONS/YEAR) FROM WESCO COAL GASIFICATION
(LURGI) PLANT WITH POLLUTION CONTROL^a

Item	Pollution Control	SO ₂	Particu- lates	CO ₂	H ₂ S
Coal Lock Fan	Wet Cyclone		0.4		
Ash Lock Fan	Wet Cyclone		0.8		
Local Vent ^b	None	7.8			Trace
Flare ^b	None	20.7			
Coal Feed Bin	Baghouse		3.9		
Coal Lock	None			24	Trace
Boiler Feed Bin	Baghouse		1.0		
Steam Boilers	Hot Electrostatic Preci- pitator and Scrubber	2145	272		
Steam Superheater	None	133	6.4		
Coal Handling	Dust Suppression		Trace		
Claus Sulphur Plant	Incineration and Scrubber	480			
Stretford Plant	Incineration and Scrubber	63			
Gas Liquor Expansion Gas	Incineration and Scrubber	126			
Limestone Handling	Baghouse		5.6		
Gas Liquor Vent Gas	Incineration and Scrubber	66			
Rectisol Vent Gas	Incineration	140			
Shift Catalyst Regeneration ^a	Scrubber	7.3			
Recovered Hydrocarbons	Incineration and Scrubber	73			
TOTAL:		3261.8	290.1	24	Trace

a. Based on 7970 hr./year of full-capacity operation (NB. -- 24 hr./day x 365 days/yr. = 8760 hr./yr.).

b. During startup after periodic shutdowns.

c. During catalyst regeneration only.

SOURCE: Reference 3.

TABLE 14
CONVERSION CATALYSTS

<u>Catalysts</u>	<u>Use</u>
Activated carbon	Purification
Iron oxide	Purification
Methanol	Purification
Propylene carbonate	Purification
Sodium carbonate	Purification
Potassium carbonate	Purification
<u>Amines</u>	
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

TABLE 14 (continued)

Catalysts	Use
K_3AsO_3	Liquefaction
Tungsten	Liquefaction
Zinc chloride	Liquefaction
Sodium sulfite	Purification
Co-Mo/ $SiO_2-Al_2O_3$	Liquefaction
Sulfoxide	Sulfur recovery
Chelated iron salt	Sulfur recovery
Nickel-tungsten	Liquefaction (hydrotreating)
Ruthenium	Methanation

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 severity are factors which determine the rate of catalyst deactivation.

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 (Reference 4). Spark-source mass spectrometry analysis indicates that many of the elements present in the original coal are contained on used catalyst surfaces. The spent catalysts from both shift conversion and methanation operations are highly sulfided and contain coal-derived trace elements (e.g., arsenic, cadmium), elemental carbon and highly polymeric organic materials (Reference 4).

Unintentional loss of desulfurization or hydrogenation catalysts may pose environmental problems. The losses of these elements from catalysts would increase their concentrations in the ash.

C. Inorganic Solids and Sludges

The major sources of inorganic solids and sludges from coal gasification facilities include: (1) sludges from SO_2 emission control process, (2) solids (e.g., spent methanation catalyst) and bottom sludges from acid gas treatment processes, (3) sludges from chemical treatment of the wastewaters, and (4) perhaps sulfur (Reference 4).

Potential effluents from coal gasification processes may contain various forms of sulfur: elemental sulfur, hydrogen sulfide, sulfur dioxide, carbonyl sulfide, carbon disulfide, mercaptans, thiophenes, and thiocyanate. Most of the organic sulfur in coal (approximately 90%) is converted to hydrogen sulfide during gasification. For example, sulfur compounds in the product gas stream of the El Paso Burnham I Coal Gasification Complex (Lurgi technology) are estimated to be 95% hydrogen sulfide, 2.4% carbonyl sulfide, 0.3% carbon disulfide, 2.0% mercaptans, and 0.3% thiophenes (Reference 3). Removal of the sulfur compounds from the gas streams prior to methanation (acid gas removal) is necessary to prevent fouling of the methanation catalysts or nonsulfur-resistant shift conversion catalysts. 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. From the environmental point of view, this form is the most compact and least objectionable.

In addition, tail gas treatment units must be included as part of the Claus technology units to reduce sulfur emissions. Unrecovered sulfur in Claus plant tail gas included 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 gasification facilities (Reference 3).

The removal of sulfur dioxide by means of scrubbers is accomplished by two general types of processes - throwaway and regenerable. The first scrubber process type refers to those flue gas desulfurization scrubbers which produce a solid waste stream that is not presently marketable and requires disposal. The most common example of a throwaway process is that of a lime/limestone scrubber which uses calcium salts to absorb SO_2 in solution.

Regenerable scrubber systems are those which, because of their specific chemical reactions, produce a marketable product of sulfur and regenerate the solvent which can be reused. Some common examples of regenerable processes are the Wellman-Lord Sulfite, Westvaco Activated Carbon, AI Aqueous Carbonate, and IFP Catalytic, all of which produce a usable sulfur product, such as solid elemental sulfur.

With the exception of the nature and levels of trace elements, sludges produced from sulfur dioxide emission control at gasification plants are anticipated to be similar to those generated in flue gas desulfurization of coal-fired and industrial boiler flue gas or Claus plant tail gas in refineries (Reference 4). At present, there is insufficient data concerning the composition of sludges from existing coal gasification plants. Consequently, data on utility generated scrubber sludge has been presented to gauge the potential environmental contaminants resulting from sulfur dioxide removal processes at coal gasification plants.

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 Table 15. The data reveal that the sludge compositions can be highly variable.

Landreth and Mahloch have identified sludge and elutriate composition of waste SO_2 sludges (Table 16) from the Double Alkali and limestone processes when using eastern and western coal, and from the lime process when using eastern coal (Reference 3). They found the primary sludge and elutriate components to be sulfur dioxide, chlorine, and calcium. Selenium, mercury, manganese, and arsenic were identified as the elutriate metals most frequently exceeding the water quality standards.

A study conducted in 1975 examined 18 trace elements in ponded ash and scrubber sludge (Reference 8). Of the 18 elements, Se, Br, Cr, and Ba exceeded either proposed sludge standards or standards for Public Water Supply intake. However, several elements almost always exceeded the standards set to date (Table 17). It should be noted that the concentrations of trace elements increases dramatically with the addition of flyash to the scrubber sludge. Also, the total number of trace contaminants increases when flyash is added.

Concentrations of trace elements in leachate from ponded scrubber sludges are the focus for the greatest concern about impacts from flue gas desulfurization processes. Those trace elements which reach the groundwater will contaminate a valuable resource. As can be seen in Table 18, "fixed" sludges examined in two studies Pb, Cd, and Hg concentrations in leachate

TABLE 15
CHEMICAL ANALYSIS OF LIME PROCESS SLUDGES ON
A DRY SOLID BASIS (%)

Component	Sample ^a					
	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	0.001	1.2	b
Total sulfur	7.2	18.9	18.1	20.0	10.9	22.9
SO ₂	12.1	33.0	32.9	29.2	10.8	45.8
SO ₃	2.9	5.9	4.8	13.6	13.6	c
CO ₂	3.2	6.7	2.3	7.1	2.2	1.0
Free carbon	b	b	b	2.8	0.14	c
SiO ₂	31.6	4.9	3.76	0.58	21.3	0.18
Al ₂ O ₃	18.3	3.4	1.71	1.21	11.3	0.39
Fe ₂ O ₃	4.3	0.6	0.86	0.39	5.6	0.29
Na ₂ O	b	b	b	0.35	0.76	0.09
K ₂ 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

^a A - power station prior to fly ash collections; B - power station after fly 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.

b Not determined.

c Not detected.

SOURCE: Reference 3

TABLE 16
CHEMICAL ANALYSIS OF FLUE GAS
DESULFURIZATION SLUDGES

Parameter	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: Reference 3

TABLE 17
TRACE ELEMENTS IN SLUDGE (WET LIMESTONE) IN PPM

Element	Concentration (range of 3 or more values)	Drinking Water Standard (mg/l)
As	4.0 - 33.0	0.05
Ba	20.0 - 500.0	1.00
B	41.8 - 211.)	1.00 (0.75 irrigation)
Cd	0.4 - 25.00	0.01 (0.005 irrigation)
Cr	1.6 - 17.00	0.05 (5.00 irrigation)
Cu	10.0 - 104.0	1.00 (0.20 irrigation)
Pb	1.0 - 290.0	0.05
Mn	36.0 - 340.0	none (0.05 taste & color)
Hg	0.1 - 6.000	0.002
Ni	13.0 - 75.20	none (0.50 irrigation)
Se	2.1 - 60.00	0.01
V	50.0 - 100.0	(10.00 irrigation)
Zn	13.9 - 2,050	

SOURCE: Reference 8

TABLE 18
TRACE ELEMENTS CONCENTRATIONS FROM "FIXED SLUDGE" LEACHATE

Element	Concentration Range (mg/l)	Drinking Water Standards (mg/l)
As	0.0080 - 0.05	0.05
Cd	0.0100 - 0.03	0.01
Cr	0.0200 - 0.05	0.05
Cu	0.0200 - 0.10	1.00
Pb	0.05	0.05
Mn	0.0200 - 0.05	0.05/taste & color
Hg	0.0015 - 0.006	0.002
Ni	0.015	none
Zn	0.010 - 0.02	5.00

SOURCE: Reference 8

exceeded Public Water Supply standards. The Electric Power Research Institute (EPRI) study of 1975 demonstrated that while sludge contained above-standard concentrations of trace elements, leachate compositions were significantly diminished for most elements except Ba, B, Cr and Se; pH was also found to be higher than allowable in several instances (Reference 8). Table 19 contains results of leachate monitoring and can be compared with Table 18 for "fixed" sludge leachate.

Figure 8 illustrates disposal options for the ash and sludge combination wastes from wet lime-limestone scrubbing. The most promising option appears to be use as a mineral aggregate or pozzolanic base.

Acid Gas Removal. 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) absorption on solids. Depending on the nature of the acid gas and the acid gas treatment process utilized, a sorbent blowdown containing a high concentration of solids (including possibly some organics) may be generated (Reference 4). A sludge requiring disposal may be produced by treatment of this stream. Coal-derived particulate matter, sorbent, and sorbent degradation products would most likely be contained in such a sludge (Reference 4).

Wastewater. Large quantities of water are used in many parts of the conversion process - in the pretreatment of coal, as feed for the conversion process, and finally for cooling or quenching. Water treating chemicals are used to demineralize and clarify most water supplies. For example, the Lurgi process requires the disposal of approximately 2 tons of water treating chemicals per hour (Reference 3), of which 1,000 lb/hr. are involved with demineralization (caustics, sulfuric acid, and resins).

The washing of coal requires large volumes of water. Settling ponds are used for the removal of fines from coal washing wastewaters. Leaching or seepage from the settling ponds is a potential source of environmental pollution and must be controlled. There are three major sources of process wastewaters from coal conversion processes: (1) when gases are scrubbed to remove soluble contaminants, quenched to control operating temperatures, compressed, or dehydrated, (2) when steam used in the unit cools and condenses or is reformed during methanation, and (3) when slags and ashes are quenched for slurry removal (Reference 3). The contaminant content of the wastewater is dependent on the characteristics of the feed coal, the type and severity of the conversion process steps, and the nature of the upstream subsidiary treatments. The exact chemical make-up of process water, which is the primary source of water contaminants, is expected to be quite similar to the ammonia liquor produced in coking industries.

The gas liquor 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. Concentration of soluble salts as high as 300 ppm may accumulate in aqueous streams (Reference 3).

Gas scrubbing can collect water soluble hydrogen sulfide and carbonyl sulfide, especially if ammonia is present. Ammonia, cyanide, and thiocyanates may also enter the gas liquor during gas scrubbing. In addition, phenols, cresols and water soluble aromatic compounds may be carried into the water from the gasification units.

TABLE 19
ELEMENTAL COMPOSITION OF SCRUBBER SLUDGE LEACHATE

Element	Standard	Max. (mg/l)	Min.	Standard 10X	Exceeded 1X
As	0.05	0.130 0.300	0.0010 0.0080	no	yes
Ba	1.00	2.000	0.0020	no	yes
B	1.00 0.75/irr.	40.000	0.2200	yes	yes
Cd	0.01	0.047	0.0005	no	yes
Cr	0.05	0.011 0.250	0.0010	no	yes
Cu	1.00	0.560	0.0020	no	yes
Pb	0.05	0.040	0.0030	no	no
Hg	0.002	0.070 0.003	0.0004	yes	yes
Ni	0.50/irr.	0.050	0.0150	no	no
Se	0.01	0.540	0.0005	yes	yes
V	--	0.200	0.1000	--	--
Zn	5.00	4.200	0.0100	no	no

SOURCE: Reference 8

Figure 8. SLUDGE DISPOSAL SCHEMES FOR A SINGLE-SCRUBBER SYSTEM.

Source: Reference 3

The composition of five water streams within the commercial Koppers-Totzek gasification plant is shown in Table 20. It should be noted that due to the high gasification temperature, phenols, pyridines, and other organics are not found.

A comparison of the gasifier condensate from the Synthane process (laboratory scale) when using various coals with a coking plant weak ammonia liquor is shown in Table 21.

As evidenced in Table 22, the by-product water from the Synthane process and the waste ammonia liquor for coking plants are very similar. Consequently, water treatment methods used for other industries, especially coking, should be applicable to coal gasification facilities.

Concentration of volatile trace elements may result from recycling of the sour water from the gasifier scrubbing and shift condensates and may necessitate recovery or treatment of this stream.

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 particulates from process wastewaters. The sludge produced from such chemical treatments may contain precipitated inorganics (e.g., ferric and aluminum hydrolysis products, and other metal hydroxides, calcium carbonate, etc.) and inorganic and organic particulate matter removed from the wastewater (Reference 3).

Commercial gasification facilities are likely to produce elemental sulfur as a by-product. The degree of purity of the by-product sulfur is dependent on the composition of the feed gas and the sulfur recovery process. Factors which determine the potential market value of the recovered sulfur are sulfur purity, location of the plant, and existing market conditions. If the recovered sulfur is not marketable, it will constitute a solid waste requiring disposal. Potential contaminants in the by-product sulfur include elemental carbon, vanadium, and arsenic (Reference 3).

D. Tar and Oil Sludges

The treatment of wastewaters in coal gasification plants is expected to be similar to that used in petroleum refineries and petrochemical plants (Reference 3). Basically, water treatment technologies for petroleum refineries are classified as primary, secondary, or tertiary. Gross removal of materials is accomplished by the primary treatment. Secondary treatment produces reasonably clean effluents, and tertiary treatment methods are for the removal of selected materials to environmentally acceptable levels. In order to facilitate the treatment process, wastewaters are usually segregated in some manner such as oil water, high solids, clean water, sour water, or very hazardous wastes.

One of the major categories of solid waste from coal gasification operations is tar and oil sludges. The treatment of oily wastewaters by gravity separation and/or flotation and by emulsion breaking results in the

TABLE 20

KOPPERS-TOTZEK COAL GASIFICATION WATER ANALYSES: KUTAHYA, TURKEY

Component	Amount (mg/liter) ^a at Sample Location ^b				
	I	II	III	IV	V
pH ^a	8.8	8.8	8.9	8.8	8.9
CaO	78	101	78	135	179
MgO	97	161	194	145	113
Na	17.5	17.5	17.5	17.5	17.5
K	5.6	8.8	10.0	8.0	8.0
Zn	0.01	0.03	0.02	0.02	0.02
Fe	0.05	0.22	1.95	0.20	0.64
NH ₄	0.32	157	184	137	122
NO ₂	0.02	0.13	4.47	0.24	4.37
NO ₃	58.2	3.32	13.7	24.7	22.9
PO ₄ Total	1.89	0.81	1.21	0.81	2.70
Cl ⁴	18	85	96	57	46
SO ₄	42	216	155	255	109
CN ⁴	0.26	0.52	12.5	1.4	14.0
H ₂ S ^c					
KMnO ₄ Consumed	8	9	400	11	145
Chemical Oxygen Demand	14	18	128	16	63
SiO ₂	14.8	16.0	14.8	19.8	42.6
Suspended Solids	14	4612	5084	3072	50
Cu	0.01	0.01	0.01	0.01	0.06

^a All measurements in mg/liter except for pH.

^b I - cooling water to slag quench tank (stream 5); II - water from slag quench tank (stream 14); III - wash water from gas cooler (stream 17); IV - total water to clarifier; V - water out of clarifier.

^c Not detected.

SOURCE: Reference 3

TABLE 21
BY-PRODUCT WATER ANALYSIS FROM SYNTHANE GASIFICATION
OF VARIOUS COALS (IN MG/LITER^a)

<u>Component</u>	<u>Coke Plant</u>	<u>Illinois Number 6</u>	<u>Wyoming Subbituminous</u>	<u>Illinois Char</u>	<u>North Dakota Lignite</u>	<u>Western Kentucky</u>	<u>Pittsburgh Seam</u>
pH	9	8.6	8.7	7.9	9.2	8.9	9.3
Suspended Solids	50	600	140	24	64	55	23
Phenol	2,000	2,600	6,000	200	6,600	3,700	1,700
Chemical Oxygen Demand	7,000	15,000	43,000	1,700	38,000	19,000	19,000
Thiocyanate	1,000	152	23	21	22	200	188
Cyanide	100	0.6	0.23	0.1	0.1	0.5	0.6
NH ₃	5,000	8,100 ^b	9,520	2,500	7,200	10,000	11,000
Chloride		500		31			
Carbonate		6,000 ^c					
Bicarbonate		11,000 ^c					
Total Sulfur		1,400 ^d					

a. Except for pH.

b. 85% free NH₃

c. Not from same analysis.

d. S²⁻ = 400; SO₃²⁻ = 1,400; S₂O₃ = 1,000.

SOURCE: Reference 3.

TABLE 22
COMPOSITION OF WASTEWATERS (IN MG/LITER^a)

Pollutant	Coke plant waste ammonia liquor	Synthane process by-product water
pH	8.3 - 9.1	7.9 - 9.3
Chemical oxygen demand	2,500 - 10,000	1,700 - 43,000
Ammonia	1,800 - 4,300	2,500 - 11,000
Cyanide	10 - 37	0.1 - 0.6
Thiocyanate	100 - 1,500	21 - 200
Phenols	410 - 2,400	200 - 6,600
Sulfide	0 - 50	b
Alkalinity (as CaCO ₃)	1,200 - 2,700	b
Specific conductance, mho/cm	11,000 - 32,000	b

^a Except for pH and specific conductance.

^b Not determined.

Source: Reference 3

production of tar and oily sludges. Tar and oil separators use the different specific gravities of tar, oil and water to effect separation. Oil organics are less dense than water, while tar organics are more dense than water. It should be noted that processes operating at higher temperatures, such as the Koppers-Totzek process, do not produce tar, oil, or phenols.

Tar and oily 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% oil have been reported in sludges from the API separators in petroleum refineries (Reference 4). The organic fraction of the sludge is expected to have characteristics similar to the bulk tars and oils in the gasifier. Furthermore, tar and oily sludge is likely to contain high levels of coal-derived organic and inorganic particulate matter since tars and oils are removed from the raw gas in a quenching operation (Reference 4).

Table 23 lists the major components of German high temperature conversion process coal tar. The highest reported concentrations are for naphthalene, phenanthrene, and fluoranthene. The use of combined gas chromatography-mass spectrometry for the analysis of product water from gasification has also indicated a high relative concentration of naphthalene and phenanthrene, in addition to fluorene and phenols. (Figure 9 and Table 24). Mass spectrometric analyses of water contaminants and benzene-soluble tar from the Synthane (laboratory-scale) gasification have also been performed (Table 25). The results detected high relative concentrations of acenaphthenes, 3-ring aromatics and naphthalenes.

Due to the high percentage of phenols present in the product water from coal gasification, recovery of phenol may be essential for pollution control and economical for some conversion processes. The SASOL (Lurgi technology) process utilizes a parallel, two stream Phenolsolvan process to reduce phenol concentration.

Studies of petrochemical industrial effluents (Reference 3) reported that the aqueous distillate from tar distillation and pyrolysis installations contained the highest concentrations of benzo (a) pyrene (BaP - up to 27 mg/liter) and benzo (a) anthracene (BaA- up to 2.8 mg/liter).

Although polycyclic aromatic hydrocarbons (PAH) have a low solubility in water, they may occur in the conversion aqueous streams in a dissolved state or adsorbed onto suspended particulate matter. Furthermore, the presence of surfactants may increase the solubility of PAH by a factor of 2 to 7 (Reference 3). The possible presence of PAH in the aqueous liquor of conversion processes is environmentally significant because of the potential health hazards they present. Consequently, PAH wastewater treatment may be an essential component of certain conversion processes.

E. Biosludge

The treatment of aqueous wastes by biological processes results in the formation of a "biosludge". The sludge is formed by the degradation of organics and the physical entrapment and settling of suspended particles.

TABLE 23
MAJOR COMPONENTS OF GERMAN HIGH-TEMPERATURE CONVERSION
PROCESS COAL TAR

Component	Boiling point (°C)	Melting point (°C)	Average Weight (percent)
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
Diphenylenoxide	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
m-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
Diphenylsulfide	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-Benzodiphenylenoxide	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
2,4-Intidine	158.4	-64.0	0.01

SOURCE: Reference 3

Figure 9. CONTAMINANTS IN PRODUCT WATER FROM COAL GASIFICATION: GAS CHROMATOGRAPHY-MASS SPECTROMETRY DATA

SOURCE: Reference 3

TABLE 24
CONTAMINANTS IN PRODUCT WATER: GASIFICATION OF
ILLINOIS NO. 6 COAL^a

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

^a Low-voltage mass spectrometry data.

N.A.: Not Available

SOURCE: Reference 3

TABLE 25
MASS SPECTROMETRIC ANALYSES OF WATER CONTAMINANTS AND
BENZENE-SOLUBLE TAR FROM SYNTHANE (LABORATORY-SCALE)
GASIFICATION (VOL %)

Structural type ^a	Pittsburg ^b	Illinois No. 6 ^b
Benzenes	1.9	2.1
Indenes	6.1 ^c	8.6 ^c
Indanes	2.1	1.9
Naphthalenes	16.5	11.6
Fluorenes	10.7	9.6
Acenaphthenes	15.8	13.5
3-Ring aromatics	14.8	13.8
Phenylnaphthalenes	7.6	9.8
4-Ring, peri-condensed	7.6	7.2
4-Ring, cata-condensed	4.1	4.0
Phenols	3.0	2.8
Naphthols	c	c
Indanols	0.7	0.9
Acenaphthenols	2.0	
Phenanthrols		2.7
Dibenzofurans	4.7	6.3
Dibenzothiophenes	2.4	3.5
Benzonaphthothiophenes		1.7
n-Heterocyclics	(8.8)	(10.8)
Average molecular weight	202	212

^a Includes alkyl derivatives.

^b Spectra indicate traces of 5-ring aromatics.

^c Includes any naphthol present (not resolved in these spectra).

^d Data on n-free basis since isotope corrections were estimated.

SOURCE: Reference 3

Biological oxidation units using trickling filters or activated sludge may be utilized for the treatment of residual contaminants (fugitive sulfur compounds, ammonia, phenols, cyanides, and thiocyanates, or amounts too small for cost-effective recovery). In biological treatment, contaminants in the wastewater are fed to active bacteria, which use the contaminant as food, and, in the process, generate less harmful by-products. Trickling filters distribute the waste over the surface of stones or other media in the bed on which bacteria are living. This action allows the bacteria to absorb the contaminants. Activated sludges utilize suspended bacteria in the tank. Separation of the biological floc suspensions is accomplished by settling. Some of the thickened sludge is recycled to the aeration tank or filter to intercept additional waste; the excessive sludge accumulation requires disposal. The pollutants are incorporated into the cellular material or sludge by the biological treatment processes. Biosludge often contains 80 to 90% water, thereby making disposal difficult (Reference 3). Sludges removed from final clarifiers typically contain 2 to 5% solids with the solids generally containing 50 to 70% "volatile" matter (Reference 4).

Lagoons and stabilization basins are often used in biological treatment. In these facilities, the biological sludge which is produced, and the settleable material in the raw wastewater, settle to the bottom. The degradable material in the settled sludge undergoes aerobic and/or anaerobic decomposition. Periodic cleaning of the lagoons may be necessary to remove the settled sludge, depending on the nature and quantity of the solids in the raw wastewater and the lagoon design. Biosludges may contain higher concentrations of certain elements (e.g., heavy metals) and refractory organics than are present in the raw wastewater. Refinery-generated biosludge has been reported as having Cr and Zn concentrations of 540 and 200 mg/kg of dry sludge, respectively (Reference 4). Concentration of heavy metal in the biosludge is especially prevalent when anaerobic digestion is used for the stabilization and thickening of primary and secondary sludges. Certain disposal options for sludge such as fertilizer on agricultural soils may be eliminated due to the presence of high concentrations of undesirable elements in the sludge.

V. CRITICAL ANALYSIS OF IDENTIFIED SOLID WASTE STREAMS
WITH RESPECT TO SECTION 3001 OF RCRA

The proposed Section 3001 regulations (December 18, 1978) describe the set of criteria a waste generator must use to determine if a waste is hazardous, and thus subject to the more stringent hazardous waste regulations. The objective of this section is to provide a hazard assessment of solid waste streams generated at coal gasification facilities based on a comparison of each identified waste stream with the proposed hazardous waste criteria. The comparisons were made using the maximum concentrations found for all potentially hazardous waste constituents. Therefore, the results represent worst-case conditions and are not intended to reflect waste stream characteristics at the average coal gasification facility. The usefulness of the results extend only toward (1) identification of these waste streams likely to be listed as a hazardous waste, and (2) determination of future research needs.

Hazard Assessment

The Environmental Protection Agency (EPA) has developed eight categories which are used to determine if a waste is to be deemed hazardous: (1) ignitability, (2) corrosivity, (3) reactivity, (4) toxicity, (5) radioactivity, (6) infectiousness, (7) phytotoxicity, and (8) teratogenicity and mutagenicity. In the proposed regulations, EPA relies only on consideration of the first four characteristics because those are the only ones for which established test protocols are available. EPA has published an Advance Notice of Proposed Rulemaking that would, if promulgated, expand the characteristics to include radioactivity, unnatural genetic activity, bioaccumulation, and separate considerations of toxicity to aquatic organisms, terrestrial plants and humans. The following paragraphs outline the test criteria in the proposed regulations to determine ignitability, corrosivity, reactivity, and toxicity.

Ignitability. A waste which presents fire hazard due to being ignitable under routine waste disposal and storage conditions is hazardous according to the proposed ignitability criteria. These criteria identify a waste as ignitable if a representative sample of the waste:

1. is a liquid and has a flash point less than 60°C (140°F) as determined by specified protocol, or
2. is not a liquid and is liable to cause fires through friction, absorption of moisture, spontaneous chemical changes, or retained heat from manufacturing or processing, or when ignited burns so vigorously and persistently as to create a hazard during its management, or

3. is an ignitable or compressed gas as defined in the regulations, or
4. is an oxidizer as defined in the regulations.

Corrosivity. The corrosivity characteristic is designed to identify wastes which must be segregated from other wastes because of their ability to extract and solubilize toxic contaminants, especially heavy metals, from other wastes. According to the proposed regulations, a solid waste is corrosive if a representative sample of the waste:

1. is aqueous and has a pH less than or equal to 3 or greater than or equal to 12 as determined using specified protocol, or
2. corrodes steel (SAE 1020) at a rate greater than 0.250 inch per year at a test temperature of 130°F as determined using specified protocol.

Reactivity. A reactive waste presents a hazard because of instability or extreme reactivity. According to the proposed regulations, a solid waste is reactive if a representative sample of the waste:

1. is normally unstable and readily undergoes violent chemical change without detonating; reacts violently with water, forms potentially explosive mixtures with water, or generates toxic gases, vapors, or fumes when mixed with water; or is a cyanide or sulfide bearing waste which can generate toxic gases, vapors, or fumes when exposed to mild acidic or basic conditions, or
2. is capable of detonation or explosive reaction but requires a strong initiating source, or which must be heated under confinement before initiation can take place, or which reacts explosively with water, or
3. is readily capable of detonation or of explosive decomposition or reaction at normal temperatures and pressures, or
4. is a forbidden explosive or a Class A or B explosive as defined in the regulations.

Toxicity. The toxicity characteristic is intended to identify wastes which, if improperly disposed of, may release toxic materials in sufficient amounts to pose a substantial hazard to human health or the environment. Since the most likely pathways for exposures to waste contaminants are leaching to groundwater or surface runoff, the only aspect of toxicity currently proposed for control is chronic toxicity to humans. This toxicity characteristic is based upon an Extraction Procedure (EP), which is intended to model improper management by simulating the leaching action of rain and of groundwater in the acidic environment present in landfills or open dumps.

The extract resulting from the EP must undergo the toxicity tests specified in the regulations. According to the proposed regulations, a solid waste is toxic if the extract obtained from applying the EP to a representative sample of the waste has concentrations of a contaminant that exceed any of the following values:

<u>Contaminant</u>	<u>Extract level, milligrams per liter</u>
Arsenic	0.50
Barium	10.0
Cadmium	0.10
Chromium	0.50
Lead	0.50
Mercury	0.02
Selenium	0.10
Silver	0.50

The extract levels specified for the above substances equal ten times the EPA National Interim Primary Drinking Water Standards for these substances. These standards are being revised, and extract levels specified above will be changed to reflect revisions to these standards.

B. Comparison of Waste Streams With Hazardous Waste Criteria

Table 26 presents the preliminary results of the comparison of each waste stream with the proposed hazardous waste criteria. The criteria are listed in four categories (ignitable, corrosive, reactive and toxic) as they appear in the 3001 regulations. The five major waste streams are subdivided where appropriate to take into account differences in waste generating subsystems. Each waste stream was compared separately with each of the hazardous waste criteria, with the results indicated in the following manner:

- N (NO): The available information indicates that the waste is not hazardous according to this criteria.
- Y (YES): The available information indicates that components of the waste stream (at least worst-case values) exist in concentrations unacceptable according to this criteria.
- P (Possible): The available information indicates that concentrations of waste stream components approach values unacceptable according to this criteria.
- ? (Not Determinable): The available information is not sufficient to make a determination according to this criteria.

TABLE 26

PRELIMINARY COMPARISONS OF WORST-CASE WASTE STREAMS FROM COAL GASIFICATION
FACILITIES WITH PROPOSED HAZARDOUS WASTE CRITERIA

Hazardous Waste Criteria	GASIFICATION AND AIR POLLUTION CONTROL ASH		COAL PILE DRAINAGE	SPENT CATALYST	INORGANIC SOLIDS AND SLUDGES				TAR AND OIL SLUDGES	BIOSLUDGES
					SO ₂ REMOVAL		Waste Water Treatment			
					Scrubber Sludge	Sludge and Leachate		Acid Gas Removal		
A. IGNITABLE										
1. Flash point 60°C	N	N	N	N	N	N	N	N	N	N
2. Liable to cause fires through friction, ab- sorption of moisture, etc.	N	N	N	N	N	N	N	N	N	N
3. Compressed gas	N	N	N	N	N	N	N	N	N	N
4. Oxidizer	N	N	N	N	N	N	N	N	N	N
B. CORROSIVE										
1. pH 3 or 12	?	?	Y	P	P	P	Y	P	?	?
2. Corrosion rate 0.250 on steel	?	?	?	P	?	?	?	?	?	?
C. REACTIVE										
1. Undergoes violent chemical change; reacts violently with water, etc.	N	N	N	?	N	N	N	N	N	N
2. Capable of detona- tion but requires strong initiating source	N	N	N	N	N	N	N	N	N	N
3. Capable of detona- tion at normal temp- eratures and pressures	N	N	N	N	N	N	N	N	N	N
4. Forbidden, Class A or Class B explosives	N	N	N	N	N	N	N	N	N	N

TABLE 26 (Continued)

Hazardous Waste Criteria	<u>GASIFICATION AND AIR POLLUTION CONTROL ASH</u>		<u>COAL PILE DRAINAGE</u>	<u>SPENT CATALYST</u>	<u>INORGANIC SOLIDS AND SLUDGES</u>				<u>TAR AND OIL SLUDGES</u>	<u>BIOSLUDGES</u>
					<u>SO₂ REMOVAL</u>	<u>Scrubber Sludge</u>	<u>Sludge and Leachate</u>	<u>Acid Gas Removal</u>	<u>Waste Water Treatment</u>	
D. TOXIC										
1. EP extract exceeds applicable threshold values	P	P	P	P	P	P	P	P	P	P

Of the four categories of hazardous waste criteria, the toxic category has the greatest potential applicability to coal gasification waste streams, followed by the corrosive criteria. The reactive category may also be applicable in worst-case situations if potentially explosive gases such as hydrogen are produced from spent catalyst waste.

Table 27 compares maximum concentrations of certain constituents found in the ash, slag and slurry produced from the gasifier to the toxic criteria. Several trace elements (Ba, Cd, Cr, Pb) are present in relatively high concentration in the ash and slag. The data used for assessing the hazard potential of the gasifier ash and slag according to the toxic criteria are based on samples from both the solid fraction and the wastes as a viscous fluid (slag) and not on an extract obtained by applying the extraction procedure as prescribed in the regulations. However, since the extraction procedure is designed to simulate leaching action and runoff under acidic conditions, it is likely that the EP extract will contain concentrations of heavy metals that exceed at least one of the toxic threshold values. The remaining four categories of solid waste were also classified as "possible" problem areas with regard to the toxic criteria. For example, spent catalysts from shift conversion and methanation contain coal-derived trace elements. Sludges produced from the other treatment processes such as SO₂ removal, acid gas treatment, and wastewater treatment may tend to concentrate certain trace elements which are present in relatively low concentrations in the raw waste streams.

Waste streams that are likely to have maximum pH values greater than or equal to 12 or minimum values less than or equal to 3 include coal pile drainage and probably acid gas removal wastes. Scrubber sludge and sludge pond leachate from utility operations have documented pH values that approach the corrosive criteria; however in the literature surveyed, no values were found that equaled or exceeded the criteria. It is possible that scrubber sludge and sludge pond leachate produced by coal gasification facilities will have pH values similar to those produced by utility operations since sulfur dioxide removal technologies developed for industries such as power plants may be applicable to coal gasification facilities. There were not sufficient data available on many of the remaining waste streams to make a determination on corrosivity based on the pH criteria. The second criteria under the corrosive category, corrosive rate on steel, is rarely included in industry or open literature characterizations of waste streams. In all probability, most of the coal gasification waste streams (with the possible exception of the acid gas removal stream) will not have a corrosion rate greater than 0.250 inches per year on steel. However, due to limited data, a determination of corrosivity based on this criteria cannot be made at this time.

EPA does plan to expand the characteristics of a hazardous waste to include radioactivity, unnatural genetic activity, bioaccumulation, and separate considerations of toxicity to aquatic organisms, terrestrial plants, and humans.

The EPRI report of 1978 investigated the potential presence of radioactive materials in power plant waste streams (Reference 8). Although there is a general lack of quantitative data concerning radionuclide concentration in power plant wastes, the report indicated that coal flyash and bottom ash

TABLE 27
COMPARISON OF LURGI PROCESS GASIFIER ASH AND SLAG
AND SLURRY TO TOXIC CRITERIA*

<u>Contaminant</u>	<u>Threshold Value (mg/l)</u>	<u>Ash (ppm)</u>	<u>Slag (ppm)**</u>	<u>10% Slurry*** Supernatant (mg/l)</u>
Arsenic	0.50	0.3	N.A.	N.A.
Barium	10.00	490 ± 250	1670	N.A.
Cadmium	0.10	20.3	1.2	0.06
Chromium	0.50	806 ± 81	240	0.16
Lead	0.50	200 ± 10	29	0.20
Mercury	0.02	0.02	N.A.	N.A.
Selenium	0.10	N.A.	2	N.A.
Silver	0.50	3.8	N.A.	N.A.

N.A.: Not available

* Maximum values used for comparative purposes.

** SOURCE: Reference 9

*** SOURCE: Reference 10

may be significant sources of radioactivity according to criteria specified in the draft Section 3001 regulations. Flyash collected by electrostatic precepitators was found to have worst-case radioactivity levels in excess of the standard. However, it is possible that incorporation of the flyash into the much larger volume of scrubber sludge would dilute the final concentration of radioactive material to a level that is no longer significant. Coal pile drainage wastes were also mentioned as possibly containing radioactive materials. Based on this information, gasifier ash and coal pile drainage wastes from coal gasification facilities may contain radioactive material. However, due to the lack of data concerning radionuclide concentrations in gasification waste streams, a determination of radioactivity based on the draft 3001 regulations is not possible at this time.

Based on our research, the waste stream likely to pose the greatest hazard potential is ash and char from the gasification operation and air pollution control (in part due to their large volumes), followed by inorganic solids and sludges from acid gas removal and air and water pollution control (scrubber sludge, acid gas removal sludge), followed by spent catalyst waste.

These conclusions are not meant to suggest that most coal gasification facilities or even a typical plants generate hazardous wastes. They indicate merely that several waste streams at coal gasification facilities may contain concentrations of corrosive, reactive or toxic pollutants high enough to be deemed hazardous according to Section 3001 criteria. Prediction of the number of coal gasification facilities generating "hazardous" wastes, and correlation of plant location, gasifier type, fuel burned, or BTU output with the generation of "hazardous" wastes were outside the scope of the present study and would require a more exhaustive literature search, a more detailed analysis of the available data, and direct sampling and testing of coal gasification plant waste streams.

VI. FUTURE RESEARCH NEEDS

Specific Areas

The study provides the basis for determining what areas require research. Some of the primary areas where research should be undertaken are:

1. Develop a broader data base on the origin, chemistry and ultimate pathways of waste stream constituents.
 - a. Undertake a detailed research effort to determine the nature and level of trace constituents present in solid waste streams at coal gasification facilities.
 - b. Conduct leaching tests to determine the types and amounts of trace elements that are leachable from the solid wastes under a variety of disposal schemes.
 - c. Analyze the statistical variability of the waste stream constituents and their interrelationship with other variables such as coal type, gasifier type, and operating conditions.
2. Analyze the various test procedures prescribed in the Section 3001 regulations (especially those for the toxic criteria) to determine whether the criteria predict a realistic assessment of hazard with respect to coal gasification plant waste streams.
 - a. Design and implement a program to determine the statistical characteristics of the 3001 Toxic Extractant Procedure. The program should include testing the repeatability of the procedure and the effect on the overall results of such variables as rate of acid addition or solids/liquids ratio of the original sample. All five major categories of waste streams covered in the report should be tested.
 - b. Design and implement a program to determine how the 3001 testing procedures compare with and/or represent what would or could be expected to occur under natural conditions.
3. Identify and investigate possible process changes or operating procedures that might reduce the quantity or hazard potential of coal gasification plant waste streams.

- a. Investigate the use of regenerable SO₂ air pollution control devices in light of the RCRA requirements.
 - b. Investigate the use of a series of flyash collection devices to reduce the disposal problems associated with potentially hazardous flyash size fractions.
4. Identify worst-case solid waste mismanagement practices at existing coal gasification plants and assess the level of hazard resulting from these practices (i.e., determine environmental fate of contaminants on a worst-case basis).
 - a. Determine what would be worst-case solid waste mismanagement for solid waste streams at coal gasification facilities.
 - b. Make on-site visits to existing coal gasification plants (mainly in Europe) to obtain data on current solid waste disposal practices. Special emphasis should be placed on investigating sites that have disposal practices close to the definition of worst-case.
 - c. Determine from field tests at these sites the actual environmental fate of potentially hazardous waste stream constituents (Radian Corporation is currently conducting this type of program for EPA at foreign gasification plants).
5. Evaluate the potential for recovery of saleable materials from coal gasification plant waste.
 - a. Identify those materials contained in coal gasification plant waste streams that have potential value.
 - b. Investigate the technological feasibility of recovering potentially valuable materials.
 - c. Determine the waste handling techniques that best preserve or enhance the value of recoverable materials.
 - d. Analyze the costs associated with materials recovery and assess the market value of the materials.
 - e. Evaluate the costs of waste disposal in compliance with RCRA regulations in order to determine the economic feasibility of materials recovery.

6. Identify disposal procedures that would allow future recovery of valuable materials should recovery become economically feasible (i.e., separating waste streams).
 - a. Evaluate separate disposal sites and practices for each waste stream with primary emphasis on ease of future recovery.
 - b. Perform a cost analysis or economic feasibility study to determine under what conditions it would be profitable to recover materials from coal gasification plant waste streams.
 - c. Evaluate the cost of receiving hazardous materials from the waste streams prior to disposal.

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