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LOW-RANK COAL STUDY

NATIONAL NEEDS FOR RESOURCE DEVELOPMENT

MASTER

EXECUTIVE SUMMARY

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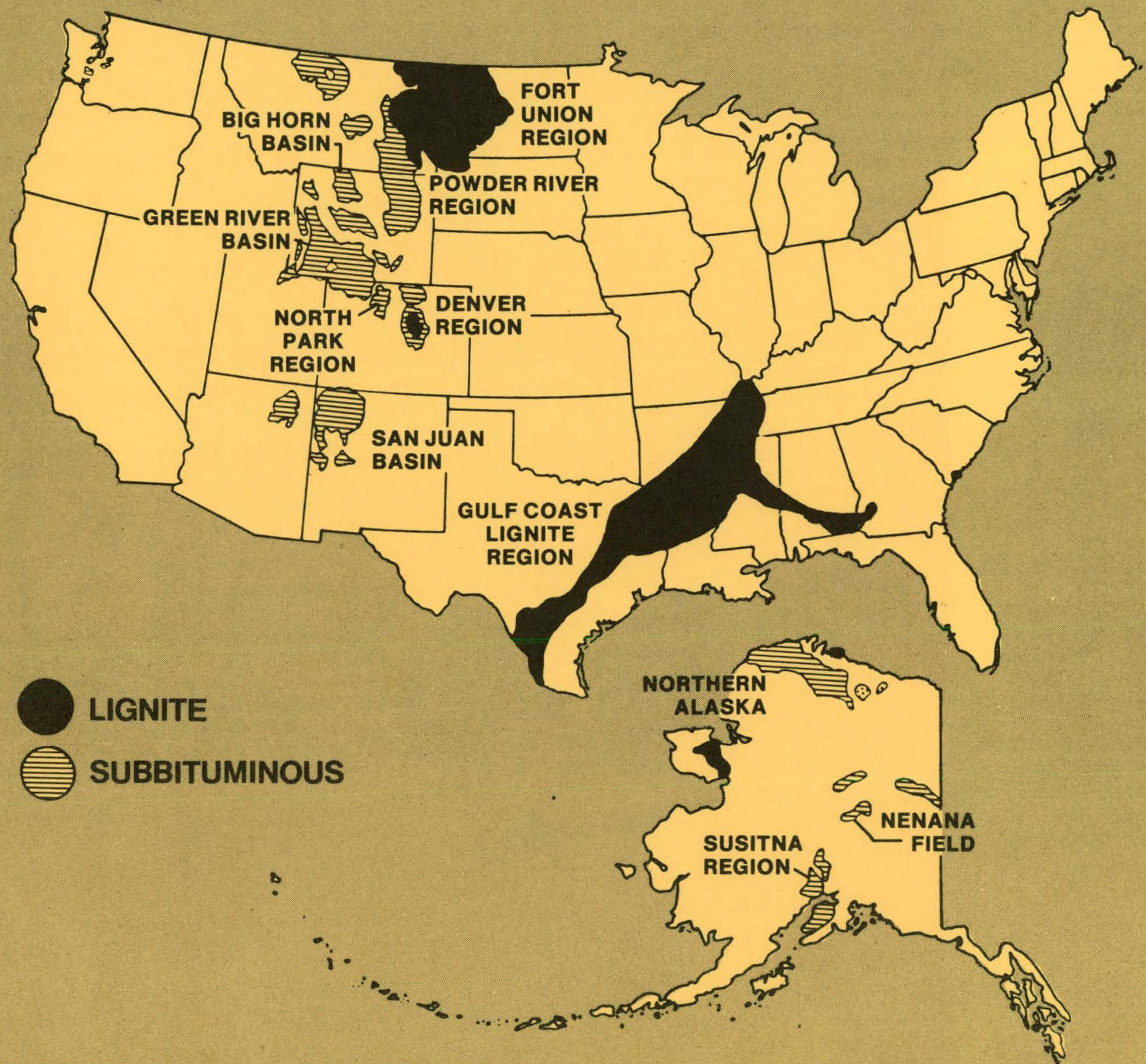

The United States has over 1 trillion tons of identified low-rank coal resources; the strippable reserve base exceeds 100 billion tons. Major lignite deposits exist in the Fort Union Region and the Gulf Coast Region. The largest subbituminous coal deposits are in the Powder River Region, the San Juan Basin, and Northern Alaska.

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DOE/FC/10066-T1(Vol.1)
Distribution Categories UC-88 and UC-90

LOW-RANK COAL STUDY
National Needs for Resource Development

Volume 1 - Executive Summary

Date Published - November 1980

Work Performed for DOE
Under Contract No. DE-AC18-79FC10066

Energy Resources Co., Inc.
Walnut Creek, California

HIGHLIGHTS

The U.S. energy economy must undergo fundamental changes if it is to provide a renewed foundation for national security and economic progress. In the immediate future, coal must play a much greater role than it does today. Development of low-rank coal resources in the west and gulf coast regions is key to achieving this goal.

This "Low-Rank Coal Study" was initiated in 1979 by the Grand Forks Energy Technology Center to contribute to the development of subbituminous coal, lignite and peat. Factors considered to be critical at the beginning of the study were:

- The huge unexploited resources of economically recoverable low-rank coals
- Substantial barriers to rapid and orderly development of these resources - including technical, environmental, policy, and market problems
- Lack of attention in many existing coal R&D programs to the unique and specific problems of low-rank coals

The production and use of low-rank coals for electric power generation has increased tenfold in the last decade, and now totals over 150 million tons per year. Successful establishment of a synthetic fuels industry along with continued growth in power production could push the use of low-rank coal to 1 billion tons per year by the year 2000. It is essential that this growth occur in an environmentally acceptable manner.

This report documents the extent of the low-rank coal resources, their unique characteristics, and their problems. It explains the market forces behind the recent rapid growth in low-rank coal production, and outlines the course of possible future market developments. It examines regulatory and environmental concerns to see if they can be resolved in a way that will meet national and regional objectives. Finally, it shows how the solutions to these problems are related to key low-rank coal technology issues.

Based on this analysis, a national program is recommended for research, development, and demonstration of improved technologies for the environmentally acceptable use of low-rank coals. The plan recognizes that without improvements in operability and economics for the application of the following technologies to low-rank coals, the needed growth will not occur:

- Surface mining and advanced underground coal extraction methods

- Coal slurry pipelines

- Preparation, handling, and storage techniques - for both conventional and advanced transport and utilization systems

- Conventional combustion and environmental control technology

- Advanced combustion and conversion techniques, with emphasis on synthetic fuels

As part of the RD&D program, basic research studies on low-rank coal properties and behavior are strongly recommended. This work will pay off in a fundamental understanding of the technology, and in future innovative developments.

This program is designed as a national effort in which a large number of organizations must become involved. The Department of Energy, through the Grand Forks Energy Technology Center, will serve as a repository for the technical data base for low-rank coal development. But, it will take the whole spectrum of federal, state and local agencies, together with private energy production and engineering companies to make the proposed program a reality.

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PREFACE

This is volume one of a six-volume "Low-Rank Coal Study." Overall, the report presents a comprehensive analysis of the technical, environmental, and economic constraints to expanded development of U.S. lignite, subbituminous coal, and peat resources. The primary objective of the study was to propose a comprehensive national research, development, and demonstration (RD&D) program focusing on technology development for enhanced utilization of these resources. The report is organized as follows:[a]

- Volume 1 - Executive Summary
- Volume 2 - Resource Characterization
- Volume 3 - Technology Evaluation
- Volume 4 - Regulatory, Environmental, and Market Analyses
- Volume 5 - RD&D Program Evaluation
- Volume 6 - Peat

This study was directed by the Grand Forks Energy Technology Center (GFETC), which has the lead mission within the Department of Energy for technology "applications for low-rank coals." G. H. Gronhovd (Director) and E.A. Sondreal (Deputy Director) of GFETC provided technical direction and review of all aspects of the study. The work was performed by Energy Resources Company, Inc. (ERCO) under a contract initiated on May 16, 1979, and completed on September 30, 1980. The study approach is summarized in Table P-1, which shows the eight major contract tasks and the approximate percentage allocation of funds to each. The study schedule is summarized on Figure P-1.

Because of the scope and complexity of the effort, GFETC enlisted a task force of recognized experts on the technical and regional issues germane to the study. These individuals are listed in Table P-2; their contributions to the quality and direction of the study were highly significant. The task force met with the study team at four critical points to review interim results and to lead working groups which established the emphasis, priorities, and methodologies for the analysis. Primarily through the efforts of the task force members, useful data inputs and critiques of working draft materials were received from a number of organizations as the study progressed.

Individual contacts and contributions made during the course of the study are too numerous to list. The following (in addition to the task force members) contributed significantly to the review of part or all of the document: G.H. Gronhovd, E.A. Sondreal, W.G. Willson, and H.H. Schobert of GFETC; W.R. Kube of the University of North Dakota and GFETC; S. Alpert, K. Clifford, S. Ehrlich, T. Lund, C. Aulisio, D. Giovanni, and R. Wolk of the Electric Power Research Institute; W. McCurdy, S. Freedman, L. Miller, M. Kopstein, L. Ludwig, E. Burwell, W. Schmidt, M.N. Rosenthal, J. Nardella, and J. Turner of DOE; W.R. Kaiser of the University of Texas at Austin; and P. Averitt (retired) of the U.S. Geological Survey.

[a] Volumes 2 through 5 address lignite and subbituminous coal; Volume 6 addresses peat; and Volume 1 summarizes the conclusions and recommendations of the total study.

Figure P-1

Low-Rank Coal Study Schedule

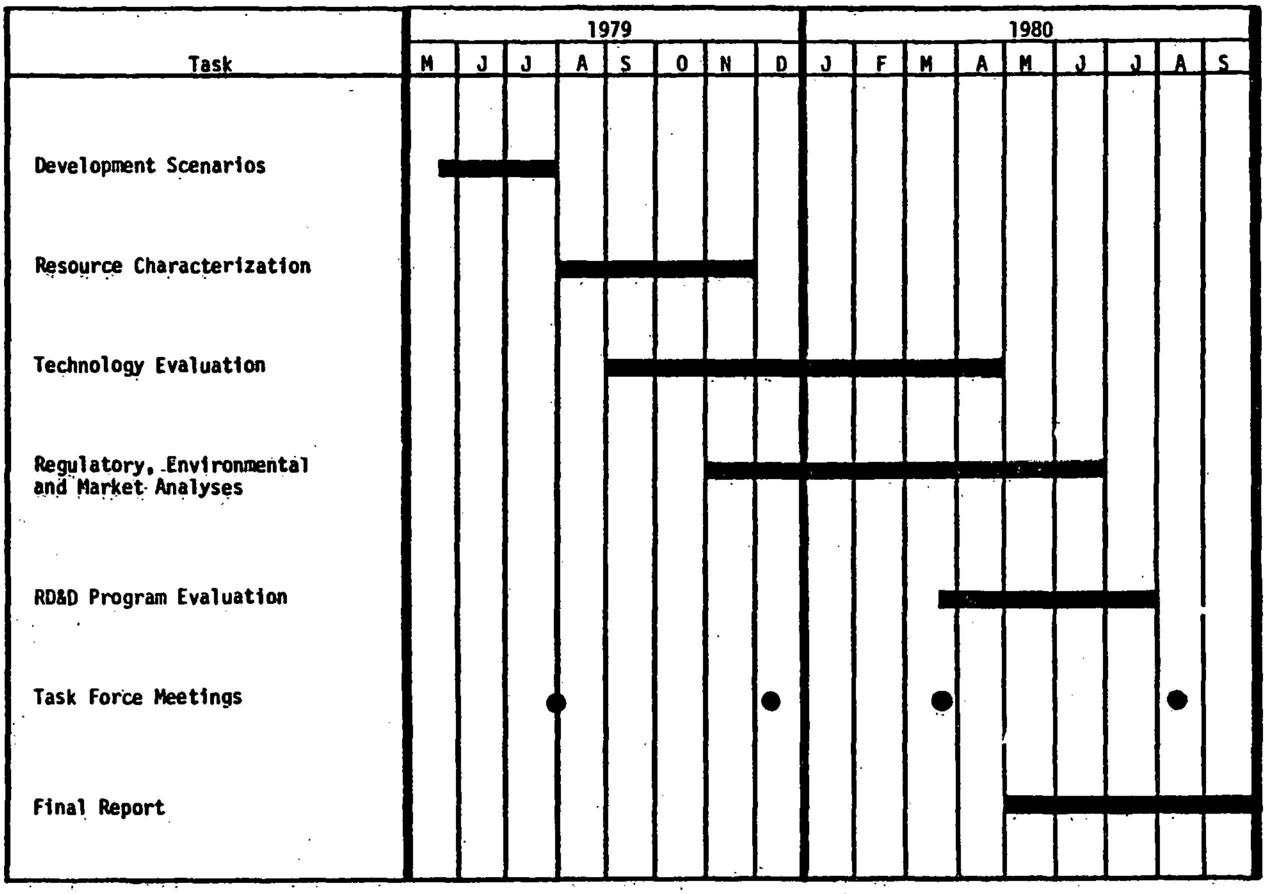


Table P-1

Major Tasks in the Low-Rank Coal Study

1. Low-Rank Coal Development Scenarios (6%)
   - 1.1 Literature Review
   - 1.2 Technology Definitions
   - 1.3 Regulatory/Environmental/Market Definitions
   - 1.4 Low-Rank Coal Data Base
2. Resource Characterization (8%)
   - 2.1 Occurrence
   - 2.2 Properties/Characteristics
   - 2.3 Classification
3. Technology Evaluation (42%)
   - 3.1 Extraction
   - 3.2 Transportation Systems
   - 3.3 Preparation, Handling, and Storage
   - 3.4 Processing and Utilization
   - 3.5 Environmental Control Technology
4. Regulatory Requirements/Constraints (4%)
   - 4.1 Definition
   - 4.2 Roadmap
   - 4.3 Effects on Development
5. Environmental Impact Analysis (3%)
   - 5.1 Land Use/Reclamation
   - 5.2 Air Quality
   - 5.3 Water Quality
   - 5.4 Ecological Effects
   - 5.5 Socio-Economic Effects
6. Market Analysis (6%)
   - 6.1 Existing Markets and Penetrations
   - 6.2 Potential Markets
7. RD&D Program Evaluation (11%)
   - 7.1 Definition and Priorities
   - 7.2 Review of Current RD&D Programs
   - 7.3 Cost and Impact Analysis
8. Task Force Utilization (20%)
   - 8.1 Development Scenarios Evaluation
   - 8.2 Technical Analysis Evaluation
   - 8.3 RD&D Program Definition
   - 8.4 RD&D Program Impacts and Recommendations

Table P-2

Low-Rank Coal Study
Task Force Participants

Participant	Affiliation
1. Dr. Martin A. Elliott Houston, Texas	Consultant, Texas Eastern Gas Transmission Co.
2. Professor George R. Hill Salt Lake City, Utah	University of Utah Department of Chemical Engineering
3. Mr. James Jonakin Birmingham, Alabama	Consulting Engineer (Retired from Combustion Engineering, Inc.)
4. Mr. Paul W. Crutchfield and Mr. David J. Beecy Washington, D.C.	U.S. Department of Energy Office of Policy and Planning
5. Professor Donald E. Severson Grand Forks, North Dakota	University of North Dakota Department of Chemical Engineering
6. Mr. David M. White Austin, Texas	Texas Energy and Natural Resources Advisory Council
7. Mr. Kurt Yeager and Dr. Charles R. McGowin Palo Alto, California	Electric Power Research Institute

The ERCO Program Manager on this effort was Dr. John Kotowski. Mr. George Wiltsee was the Assistant Program Manager and Technical Director. Other ERCO personnel who provided major contributions to the effort include Paul Goodson, Randall Smith, Wayne Simmons, Barbara Acker, Jeffrey Feerer, Timothy Buscheck, and Myron Burr. In addition, special thanks should be extended to Lydia Felix and Jennifer Spinello of the administrative staff for their support and assistance in the preparation of this report.

ABSTRACT

The findings and recommendations of a comprehensive "Low-Rank Coal Study" are presented. The factors analyzed include the occurrence and properties of low-rank coals; technologies for their use; existing and potential markets and economics; regulatory and environmental issues; and RD&D program recommendations. A similar but less detailed review of the potential development of U.S. peat resources for energy use was also included.

Major low-rank coal deposits in the United States include Fort Union Region and Gulf Region lignite, and the Powder River Region, San Juan Basin, and Northern Alaskan subbituminous coal. These coals are distinguished from eastern bituminous coal by lower heating value, higher moisture content, physical properties, generally lower sulfur content and a predominance of alkaline rather than acidic ash components. These and other properties of low-rank coal affect the technologies for their extraction, preparation, direct use, and conversion, and justify a separate focus on low-rank coals in the national RD&D efforts.

The overall emphasis of the recommended RD&D program is on exploratory, technology, and engineering development efforts which make systematic use of the knowledge and understanding gained from basic and applied research on low-rank coals. Priority-ranked RD&D projects specific to low-rank coals are listed in all major technology areas: extraction; transportation; preparation, handling, and storage; conventional combustion and environmental control technology; fluidized bed combustion; gasification; liquefaction; and pyrolysis. Basic coal science investigations for low-rank coals are also recommended.

1. EXECUTIVE SUMMARY

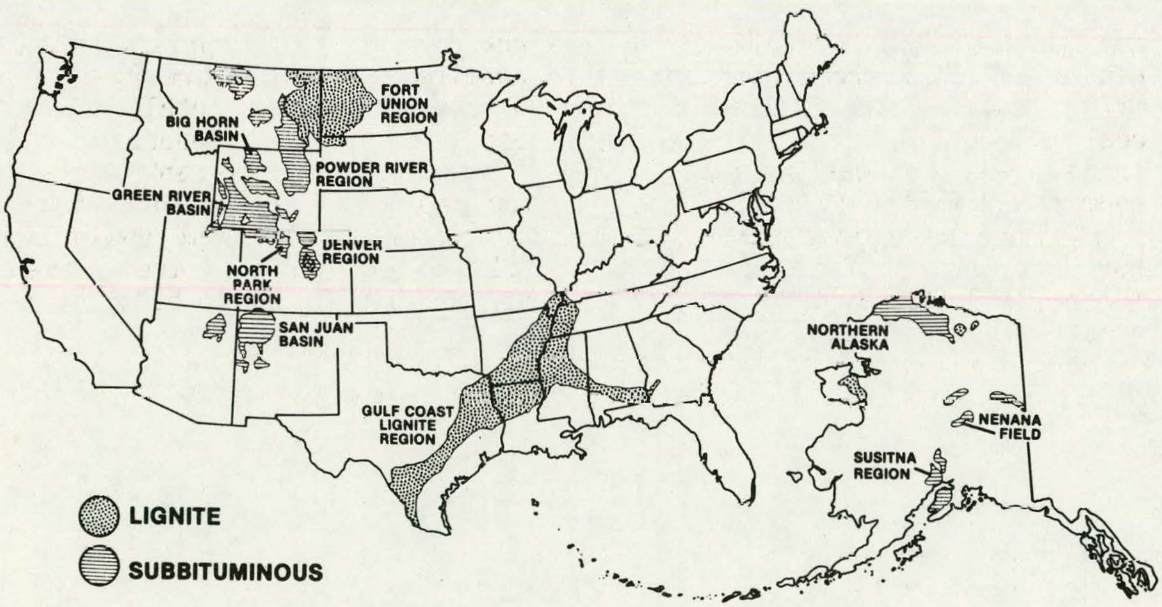
1.1 INTRODUCTION

Low-rank coals -- lignite and subbituminous -- are those which have been subjected to the least amount of metamorphic change during the coal-forming process. As such, they retain greater fractions of moisture and volatile matter from the original peat material, and contain less fixed carbon, than the high-rank coals -- bituminous and anthracite. The primary measure used to classify the lower ranks of coal is heating value. Lignite is defined (in this country, by the American Society for Testing and Materials) as coal with a heating value less than 8,300 Btu/lb, on a moist, mineral-matter-free basis (m,mmf). Subbituminous coal ranges in heating value from 8,300 to 11,500 Btu/lb (m,mmf). By comparison, bituminous coal and anthracite range from 10,500 to over 15,000 Btu/lb (m,mmf). Other important characteristics distinguish the low-rank coals from high-rank coals, as will be discussed in following sections of this report.

Low-rank coals represent a major, and largely untapped, energy resource for this country. Very extensive deposits of lignite and subbituminous coal exist in the western states, the Gulf coast, and Alaska, as shown on Figure 1. Major deposits of low-rank coal are also found in many other countries, most notably the USSR, Australia, Canada, and the central and eastern European nations. Worldwide coal statistics indicate that low-rank coals account for roughly one-third of the total resource and current production tonnages.

Figure 1

Low-Rank Coal Regions of the United States



This report recommends a comprehensive national research, development, and demonstration (RD&D) program to enhance the development of low-rank coals. The major conclusion of this study is that the unique properties of these coals affect the technologies for their extraction, preparation, direct use, and conversion and justify a separate focus on low-rank coals in the national RD&D efforts.

Why are the recommendations produced from this study important now? The timing appears critical for several reasons:

1. Large quantities of economically recoverable reserves make coal one of the few indigenous energy sources capable of relieving our overdependence on imported oil during the next 20 years.

2. Expanding the use of coal rapidly enough to make a difference (e.g., tripling by the year 2000) will necessarily require that much of the new production come from western low-rank coal areas.

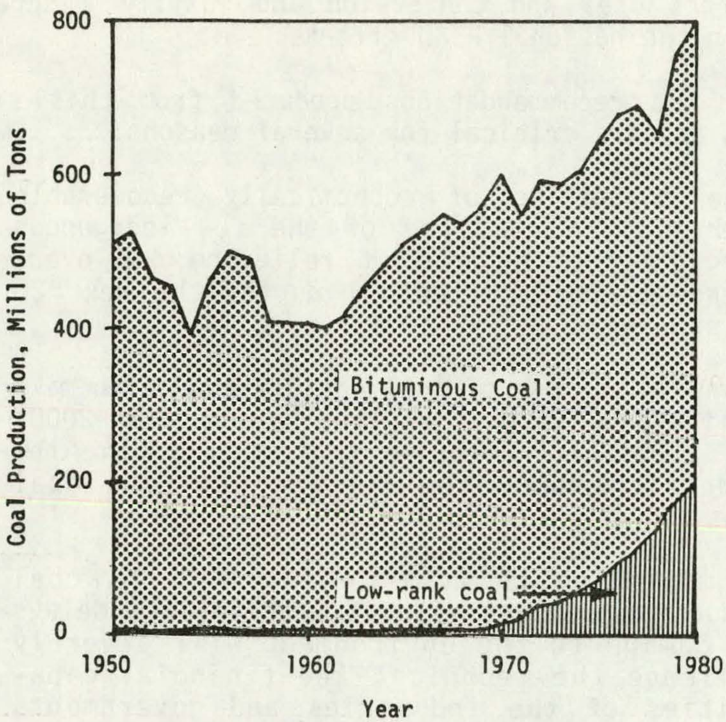
3. Accomplishing this kind of growth in coal production and use without unacceptable delays and damage to the environment will severely challenge the technical and financial capabilities of the industries and governments involved.

4. Very little attention has been paid to the special problems of low-rank coals in previous and existing national coal RD&D programs.

The lack of attention to low-rank coal is not surprising when U.S. historical coal production rates are examined, as in Figure 2. Prior to 1970, low-rank coals accounted for 1-2 percent of the total annual U.S. coal production . Utilization of these resources was important only in local areas and was at small scale. Production of low-rank coals mushroomed during the 1970's, accounting for nearly all of the growth in coal production achieved during that decade. In 1980, low-rank coals account for 24 percent of the total U.S. coal production, and are poised for further growth. By 1990, these coals may account for 40 to 50 percent of a greatly expanded total.

Figure 2

Historical U.S. Coal Production



Sections 1.2 through 1.6 below summarize the key findings and recommendations of the low-rank coal development analysis. All the information presented is explained, documented, and referenced in Volumes 2 through 5 of the report.

As an adjunct to the low-rank coal study, a similar but less detailed review of potential peat energy development in the U.S. was performed. The findings and recommendations of the peat analysis are summarized in Section 1.7 below. A separate volume contains the complete peat analysis and documentation.

1.2 OCCURRENCE AND PROPERTIES OF LOW-RANK COALS

The quantities of lignite and subbituminous coal in the U.S. are vast, as summarized in Table 1. Over 1 trillion tons of identified resources have been located and inferred by geologists. Over 100 billion tons occur close enough to the surface in favorable mining areas to be classified as the economically recoverable strippable reserve base. Another 108 billion tons of subbituminous coal are classified as the economically recoverable reserve base by underground mining. (It should be noted that these quantities are roughly comparable to the bituminous coal resources in the U.S.: 0.75 trillion tons of identified resources, 47 billion tons of strippable reserve base, and 182 billion tons of underground reserve base.)

Table 1

United States Low-Rank Coal:
Identified Resource and Reserve Base Estimates
(Billion Short Tons)

LIGNITE

Region	Identified Resources[a]	Strippable Reserve Base[b]
Fort Union	465.3	26.3
Gulf	68.3	11.6
Denver	10.0	2.9
Others	0.2	n.a.[c]
TOTAL	543.8	40.8

SUBBITUMINOUS COAL

Region	Identified Resources[a]	Strippable Reserve Base[b]	Underground Reserve Base[b]
Powder River	238.1	57.5	97.2
San Juan	50.6	5.5	0.9
Alaska	110.2	0.5	4.8
Others	147.2	4.4	4.8
TOTAL	546.1	67.9	107.7

Notes: [a]Identified resources include Demonstrated (measured and indicated) and inferred resources 2-1/2 feet or more thick to an overburden depth of 3000 feet.

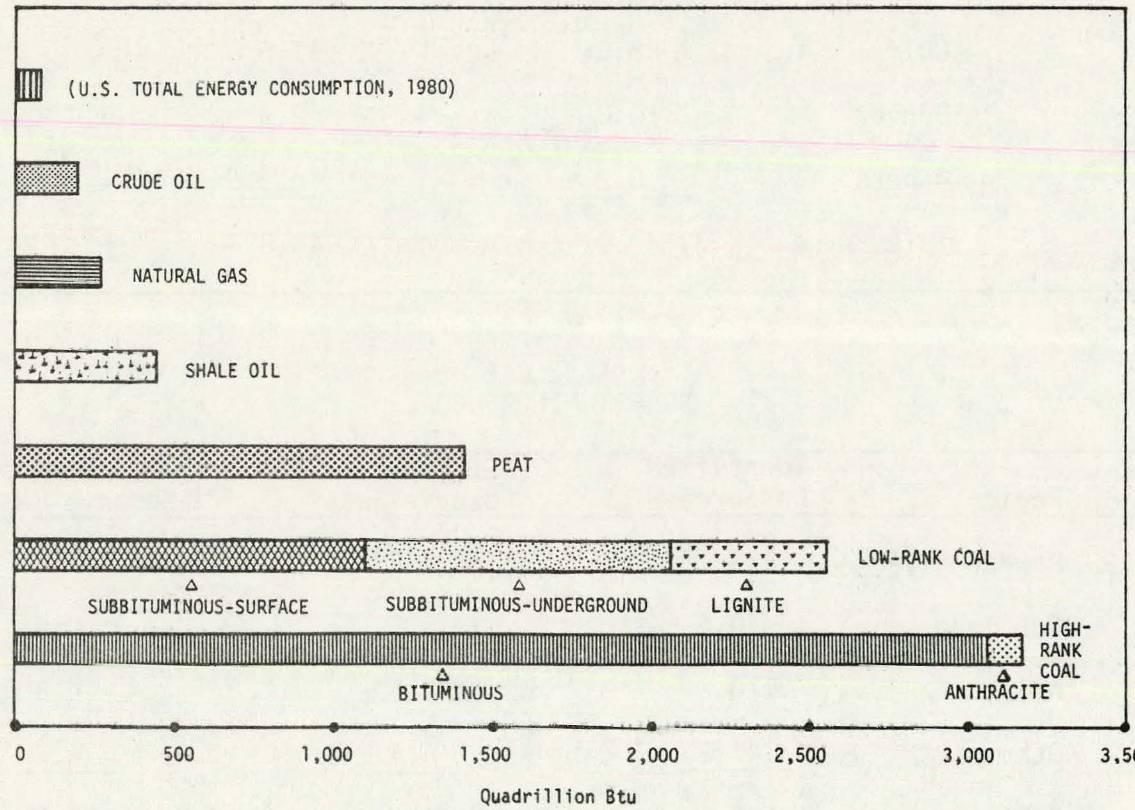
[b]The Reserve Base includes coal that is technically and economically minable at this time. Criteria for minimum seam thickness and maximum overburden thickness vary from state to state.

[c]Estimate not available.

When these reserve base quantities are multiplied by appropriate recovery factors (i.e., about 50 percent for underground mining and 90 percent for surface mining) and by average heating values, a comparison of recoverable reserves on a Btu basis can be made (see Figure 3). As indicated, the recoverable reserves of low-rank coals and peat together are greater than the reserves of high-rank coal; these in turn are vastly larger than our remaining reserves of oil and gas.

Figure 3

Recoverable Fossil Fuel Reserves in the United States



Figures 4 and 5 present a summary classification of the strippable reserve base quantities of lignite and subbituminous coal according to three important characteristics: thickness of the coal seams, sulfur content, and ash content of the coal. These generalized classifications serve to illustrate some of the favorable attributes of the U.S. low-rank coals.

Fig 'e 4

Classification of U.S. Lignite Strippable Reserve Base

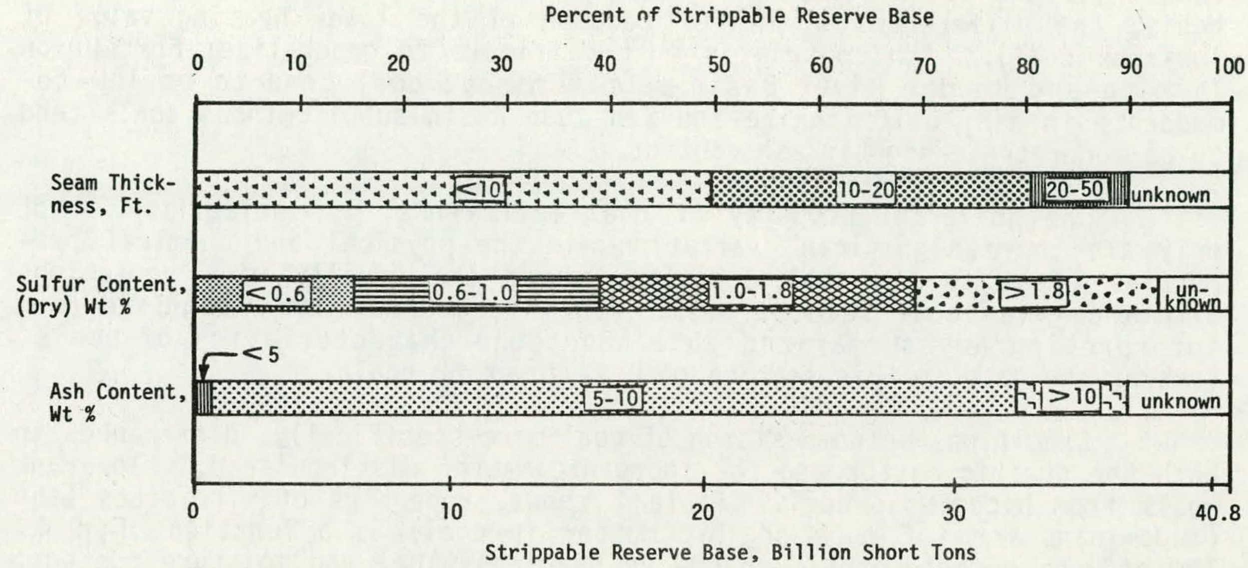
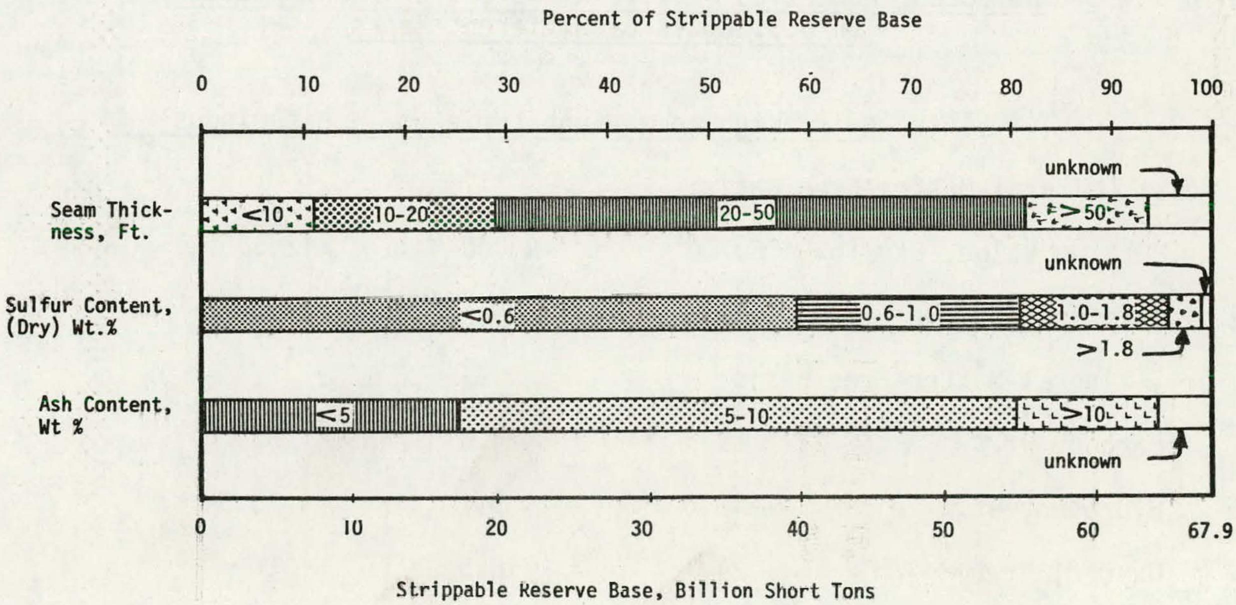


Figure 5

Classification of U.S. Subbituminous Coal Strippable Reserve Base



Many of the low-rank coal seams (particularly subbituminous) are thick in comparison to eastern bituminous coal seams. The low-rank coals are generally low in sulfur content compared to eastern bituminous coal (less than 1 percent sulfur compared to 2-5 percent on a weight basis; on a Btu basis, the difference is smaller because of the lower heating value of low-rank coal). Ash content is more difficult to generalize: Fort Union lignite and Powder River Basin subbituminous coal tend to be low-to-moderate in ash; Gulf lignite and San Juan Basin subbituminous coals tend to be moderate-to-high in ash content.

One universal property of coal (all ranks) is variability. Not only are there significant variations in the physical and chemical properties of different coal deposits; there are usually wide variations within a given coal seam as well. This fact should be recognized when interpreting any summarized data about the characteristics of coals, such as the data in this section on U.S. low-rank coals.

Examining the composition of coal more specifically, differences in both the organic matter and the inorganic matter distinguish U.S. low-rank coals from bituminous coal. Table 2 shows properties of vitrinites (the predominant form of pure organic matter in coal) as a function of rank. The effects of metamorphic change on heating value, and moisture content, as well as on the carbon/oxygen ratio, are evident.

Table 2

Selected Properties of Vitrinites (Pure Organic Matter) In U.S. Coals of Different Ranks

	Lignite	Subbituminous	Bituminous
Moist, Mineral-Matter-Free Basis:			
Heating Value, Btu/lb	6,700	9,000	12,500
Moisture, Wt.%	35	25	<10
Dry, Mineral-Matter-Free Basis:			
Carbon, Wt.%	69	74.6	83
Hydrogen, Wt.%	5.0	5.1	5.5
Oxygen, Wt.%	24	18.5	10

The low heating values of low-rank coals affect the costs (per Btu) of extraction, transportation, combustion, and conversion processes. The high oxygen content tends to be present in functional forms such as hydroxyl and carboxyl groups; these are generally much lower or absent in bituminous coal. Hydroxyl groups are believed to be a major cause of the very high reactivity of low-rank coals. The carboxyl groups tend to occur in salt form; protons have been replaced by metal cations such as calcium and sodium, leading to an important form of "inherent mineral matter" in low-rank coals.

The moisture content in low-rank coals is partly trapped in pores and capillaries, and partly bound in the molecular structure. Application of heat is the only practical means for removing this inherent moisture. Depending on the drying method employed, the resulting changes in the coal structure and physical/chemical properties can be very significant. When exposed to the air, the surface of low-rank coal dries and slacks, producing dust which can cause fugitive emissions problems.

The properties of inorganic matter (ash-forming minerals) in U.S. low-rank coals are in many respects unique, and are at least as important as the organic matter in affecting combustion and conversion technologies. Table 3 presents average chemical compositions of ash samples from lignite, subbituminous, and bituminous coals.

Table 3

Average Ash Compositions From U.S. Coals of Different Ranks (Weight Percent of SO_3 - Free Ash)

		Lignite	Subbituminous	Bituminous
Acidic Components	SiO_2	24.9	39.4	48.1
	Al_2O_3	14.1	21.1	24.9
	Fe_2O_3	11.5	10.1	14.9
	TiO_2	0.5	0.8	1.1
	P_2O_5	0.4	0.4	--
Alkali Components	CaO	31.2	20.1	6.6
	MgO	8.7	5.6	1.7
	Na_2O	8.2	2.1	1.2
	K_2O	0.5	0.3	1.5

One important difference is the much higher proportion of alkali elements in the ash from low-rank coals. These components (particularly sodium) alter the melting behavior of ash and lead to unique boiler fouling and slagging problems. Alkaline ash reacts with sulfur compounds, a property that can be used to reduce SO_2 control costs in wet scrubbing of flue gas, as well as in fluidized bed combustion. Fly ash from low-rank coals often has high electrical resistivity, making it difficult to collect in electrostatic precipitators.

The alkali elements in low-rank coals are believed to have catalytic properties, speeding up gasification and possibly liquefaction reactions. The alkaline mineral matter in low-rank coals tends to be largely inseparable from the organic matter by standard coal washing (float/sink) techniques.

These comments, and Table 3, are generally more applicable to the northern low-rank coals (Fort Union lignite and Powder River Region subbituminous coal) than to those farther south (such as San Juan Region subbituminous coal and Gulf lignite). Occurrences of high-silica ash and largely extraneous (separable) mineral matter are relatively common in the latter regions.

Fort Union Region Lignite

The Fort Union Region has been referred to as the largest coal basin on earth. Very large strippable lignite deposits are found in western North Dakota and eastern Montana. The seams are moderately thick, and stripping ratios are very favorable in areas currently being mined. The lignite is primarily used as boiler fuel by minemouth utility plants, and by industrial and institutional steam plants. Many of these boilers experience severe ash fouling on the convection section tubes, due to the prevalence of high sodium contents in much of the Fort Union Region lignite ash.

Table 4 presents average analyses of lignite samples from mines in the region. As an indication of the variability of these sample analyses, moisture content ranged from 32.5 to 43.6 percent; ash content ranged from 3.2 to 12.1 percent; and the lignite heating value ranged from 5880 to 7580 Btu/lb.

Table 4

Average Analyses of Fort Union Region
Lignite Mine Samples
(212 Sample Locations)

Proximate Analysis, Wt.% (As Received)		Ultimate Analysis, Wt.% (Dry, Mineral-Matter-Free)	
Moisture	37.2	Hydrogen	4.9
Volatile Matter	26.3	Carbon	71.9
Fixed Carbon	30.3	Nitrogen	1.1
Ash	6.2	Oxygen	21.0
		Sulfur	1.1

Heating Value, Btu/lb 6,820

Gulf Lignite

Lignite deposits in the Gulf Region occur primarily in Texas, Louisiana, Arkansas, Mississippi, and Alabama. The largest present commercial deposits are found in sediments of the Wilcox Group with thin overburden. Seams are quite irregular in thickness, and generally less than 10 feet thick. Some of the Texas deposits have very favorable mining and reclamation conditions, and are being rapidly exploited by utility companies to feed minemouth electric power plants. Most of these plants have not experienced the severe ash fouling problems associated with high-sodium Fort Union lignite. However, the ash content of the Gulf lignite is generally higher than the Fort Union lignite, and in some plants the ash is quite abrasive due to high silica levels.

Table 5 presents average analyses of Gulf lignite samples, representing a composite from all of the states mentioned above. The average properties shown represent somewhat poorer quality lignite than is currently being mined by utilities in Texas. As a general rule, the quality of Gulf lignite improves in moving from east to west. For example, lignite samples from Alabama average about 4,600 Btu/lb; from Arkansas, about 5,000 Btu/lb; and from Texas' Wilcox Formation, over 7,000 Btu/lb.

Table 5

Average Analyses of Gulf Lignite Samples
(495 samples)

Proximate Analysis, Wt.% (As Received)		Ultimate Analysis, Wt.% (Dry, Mineral-Matter-Free)	
Moisture	30.8	Hydrogen	6.1
Volatile Matter	30.8	Carbon	62.1
Fixed Carbon	24.9	Nitrogen	1.1
Ash	13.5	Oxygen	28.8
		Sulfur	1.9

Heating Value, Btu/lb 5,803

Powder River Region Subbituminous Coal

The Powder River Region lies just to the southwest of the Fort Union Region, in the states of Montana and Wyoming. The Wyoming portion of the region contains the thickest coal seams in the U.S., with some seams averaging 70 feet in thickness. The largest-producing coal mines in the country are also found in this region.

The subbituminous coal in the Powder River Region is generally of high quality, and is particularly valued for its low sulfur content. A large portion of the coal produced in this region is transported to midwestern and south central utilities for use as "compliance" coal in meeting SO_2 emissions standards.

Table 6 presents average analyses of subbituminous coal mine samples from the Powder River Region. Variability of the coal properties is wide, as in other regions: moisture content of the samples ranged from 20 to 31 percent; ash content, from 3 to 16 percent; heating value, from 7,360 to 9,610 Btu/lb; and sulfur content ranged from 0.1 to 3.5 percent.

Table 6

Average Analyses of Powder River Region Subbituminous Coal Mine Samples (79 sample locations)

Proximate Analysis, Wt.% (As Received)		Ultimate Analysis, Wt.% (Dry, Mineral-Matter-Free)	
Moisture	25.4	Hydrogen	5.1
Volatile Matter	29.6	Carbon	75.6
Fixed Carbon	38.7	Nitrogen	1.2
Ash	6.3	Oxygen	17.3
		Sulfur	0.8
Heating Value, Btu/lb	8,820		

San Juan Basin Subbituminous Coal

The San Juan Basin in New Mexico and Colorado contains both subbituminous and bituminous coal. The low-rank coal is near the top of the heating value range for subbituminous coal. Samples range in heating value from 8,900 to 11,900 Btu/lb, and in moisture content from 10 to 20 percent. Ash content of the coal is generally greater than 10 percent; the ash tends to be relatively low in alkali elements compared to other low-rank coals. Table 7 presents average analyses of subbituminous coal samples from the San Juan Basin.

Table 7

Average Analyses of San Juan Basin Subbituminous Coal Samples (82 samples)

Proximate Analysis, Wt.% As Received		Ultimate Analysis, Wt.% (Dry, Mineral-Matter-Free)	
Moisture	12.8	Hydrogen	5.5
Volatile Matter	33.1	Carbon	77.6
Fixed Carbon	40.6	Nitrogen	1.4
Ash	13.5	Oxygen	14.3
		Sulfur	1.2
Heating Value, Btu/lb	10,020		

1.3 MARKETS AND ECONOMICS

During the past 60 years, the markets for coal in the United States have shifted substantially, while the total consumption has remained generally between 400 and 600 million tons/year. Railroad and residential/commercial direct use of coal -- two very large markets at one time -- have all but disappeared. Industry use has been relatively constant for the last 30 years, with about half being coking coal for metallurgical production -- a market reserved for high quality bituminous coal.

Electric Utilities

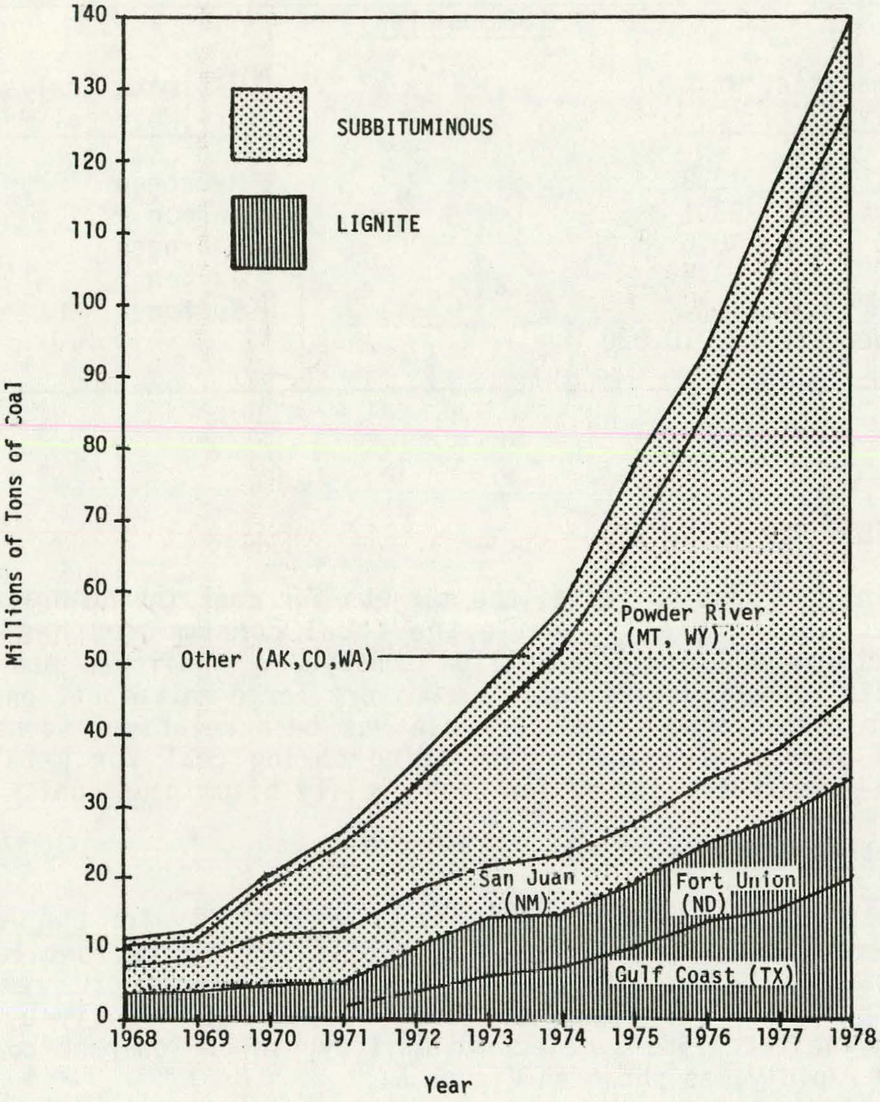
Electric utility use of coal has grown steadily for the last 30-40 years. Low-rank coals played a minor role in that market until the late 1960's, primarily because the low-rank coal resources are remote from industrial centers, and cheap oil and gas were abundantly available. Beginning in the late 1960's, electric utility use of low-rank coals began to grow very rapidly, as shown on Figure 6.

Why did this happen? Several technological and regulatory developments changed the relative economics of low-rank coal use by the electric utility industry:

1. Very large pulverized coal boilers, as well as extremely large strip mining machines, were adapted for low-rank coals. These allowed the industry to realize the economies of scale required to make low-rank coal use competitive.

Figure 6

Low-Rank Coal Production by Region, 1968-1978

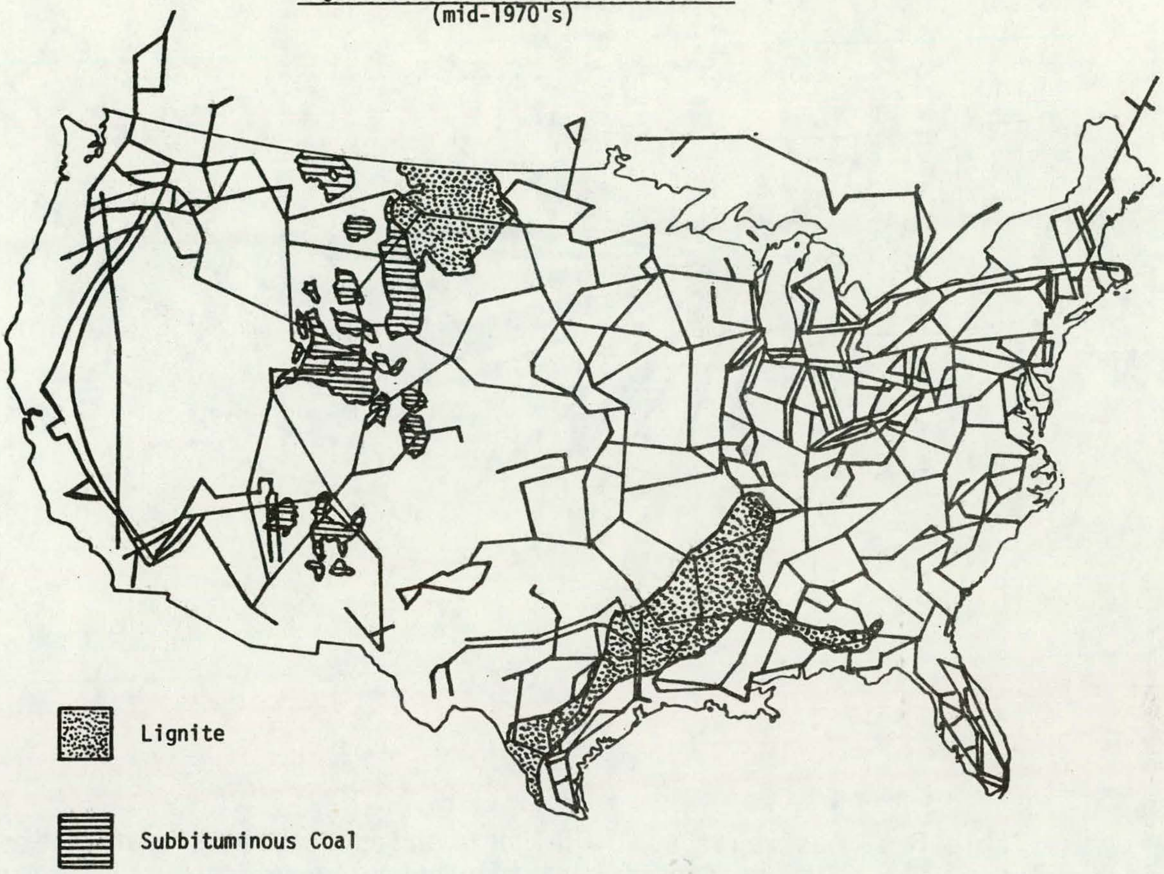


2. Electric power transmission systems and regional reliability councils developed to the point that vast regions of the U.S. became interconnected and interdependent in terms of power supply. Thus, minemouth power plants in the low-rank coal regions could penetrate large markets for the first time. (See Figure 7).

3. Limits were placed on emissions of SO_2 from coal-fired power plants in the early 1970's. This created a huge demand in the midwest for low-sulfur western coal, despite the high transport costs.

Figure 7

Major Electric Interties in the U.S.
(mid-1970's)



4. The price and long-term supply uncertainty of OPEC oil and domestic gas rose rapidly in the early 1970's. This created a strong incentive to switch from these fuels to coal for power generation, particularly in Texas.

In this dramatic growth process (generally 15-20 percent per year for low-rank coal overall), lignite has remained a regional fuel, used almost exclusively within the borders of the Fort Union and Gulf lignite regions. In contrast, subbituminous coal has penetrated markets far from the coal mines. About 18 percent of the Powder River Region subbituminous coal produced in 1978 was used in power plants in Montana and Wyoming. The remainder (65 million tons of "compliance" coal) was shipped by unit train to power plants in twenty other states.(see Figure 8). During the same year, about 92 percent of the San Juan Region subbituminous coal production was burned by utilities in New Mexico and Arizona; small amounts were shipped to Missouri and Texas.

Figure 8

Shipments of Powder River Region Subbituminous Coal to Electric Utilities, 1978

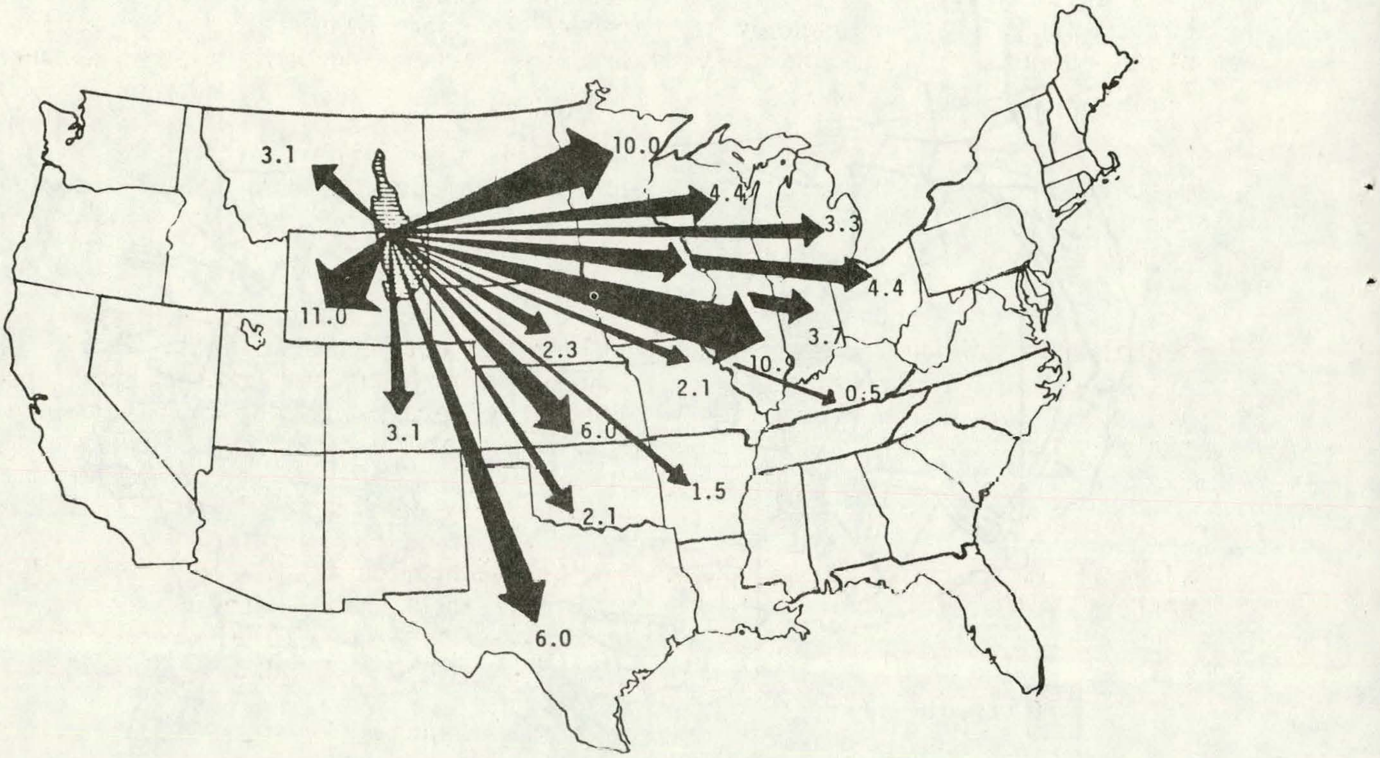


Table 8 summarizes fossil fuel deliveries to electric utilities in 1978. Two of the major reasons for rapid penetration of the utility market by low-rank coals are evident on the table: low delivered fuel cost compared to all alternatives, and low sulfur content compared to bituminous coal. The figures shown reflect national averages; substantial regional variations occur. For example, the cost (per Btu) of subbituminous coal at the minemouth is comparable to the value shown for lignite; depending on the distance shipped, transport costs can double or triple the delivered cost of subbituminous coal.

Table 8

Fossil Fuels Delivered to Electric Utilities, 1978

	Fuel Delivered			Average	
	10^{15} Btu	(1000 tons)	Average Btu Per Pound	Weight Percent Sulfur	Average Price ¢/10^6Btu
Oil	3.74		18,000	1.0	215.6
Gas	3.12		21,800	--	143.8
Coal:					
Bituminous	8.05	354,019	11,368	2.2	121.8
Subbituminous	1.66	90,519	9,169	0.57	79.1
Lignite	0.40	30,611	6,605	0.68	45.0

Table 9 shows in round numbers the cost incentive for midwestern utilities to use western low-sulfur coal rather than local high-sulfur coal plus scrubbers. (Tables 8 and 9 do not account for differences in the boiler plant costs caused by differences in coal properties. For a given steam output, boilers and pulverizers are larger and more expensive when low-rank coal is used.)

Without question, the electric utilities will continue to be the most important market for low-rank coals. Coal and nuclear power represent the only proven and domestically abundant options that can be relied upon to meet growing electricity demand during the next several decades.

The challenges will be: 1) to improve the reliability and environmental performance of conventional pulverized coal-fired plants, and 2) to introduce new technologies (e.g., gasification/combined cycle, fluidized bed combustion) that substantially improve overall conversion efficiency, environmental control capability, water consumption, and other such factors.

A key question affecting future utility demand for low-rank coal is whether the 1979 revised New Source Performance Standards for SO_2 emissions from new coal-fired power plants will negate the advantage that western low-sulfur coal has had in midwestern markets. The new standard requires scrubbers (or other sulfur removal systems) on all new plants, with a sliding scale of 70 to 90 percent removal (see Figure 9).

Low-sulfur coals will have a cost advantage in the FGD portion of new power plants due to the lower sulfur removal requirement. However, this advantage will be much less than it is for existing plants, and may or may not outweigh the long-distance delivery costs of western coal, plus the incremental costs of handling, storing, pulverizing, and burning low-rank coal.

Table 9

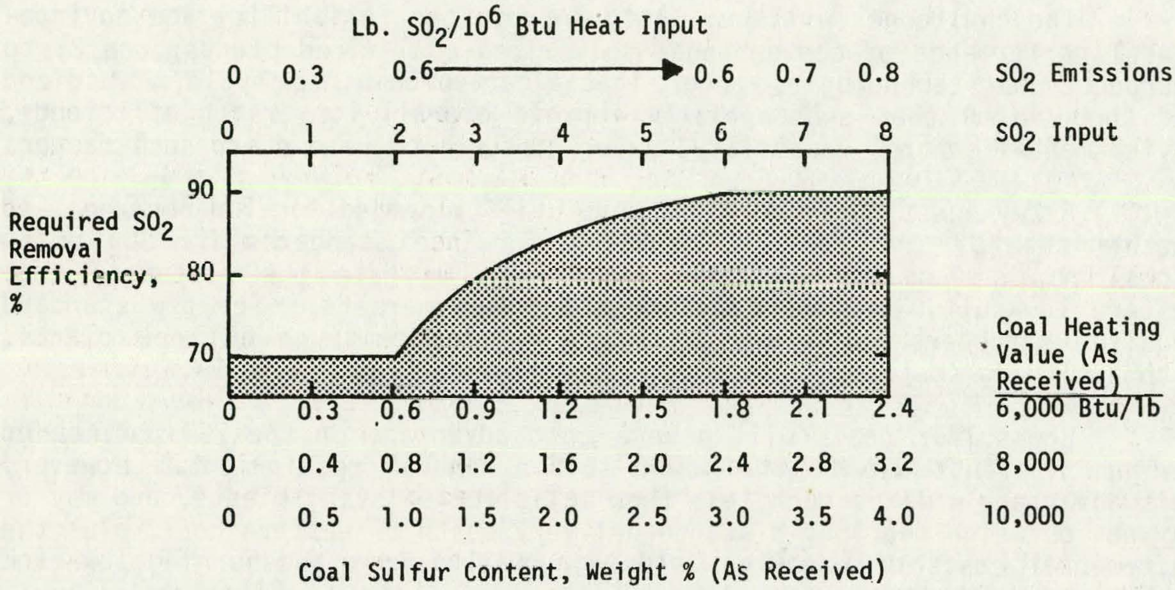
Cost of Low-Sulfur Coal Compared to Illinois Coal Plus Flue Gas Desulfurization (FGD), 1978

(¢/10^6Btu) (hypothetical plant, Illinois site)

	Low-Sulfur Western Coal	Illinois Bituminous Coal
Coal Cost, f.o.b. mine	40	80
Transport Cost (unit train, Decker, MT to Chicago, IL)	90	
FGD Levelized 30-yr cost	--	80-130
TOTAL	130	160-210

Figure 9

New Source Performance Standards for SO_2 Emissions from Electric Utility Steam Generators



Another critical factor affecting the future use of western low-sulfur coal in distant markets will be transportation costs. Deregulation of railroad ratemaking is proceeding. This is likely to result in even larger increases in coal transportation rates than have occurred recently. If coal slurry pipelines are built, this would tend to decrease rates.

In addition to the New Source Performance Standards, ambient air quality standards will constrain new power plant construction in areas where concentrations of pollutants are close to the established limits. Western North Dakota already has such a problem with respect to SO_2 concentrations.

Industrial Markets

Industrial markets for low-rank coal are currently very small, amounting to only about one percent of total production, or 1-2 million tons/year. This utilization is primarily in industrial or institutional boilers near the coal deposits. There is some use of subbituminous coal in the midwest and west by industrial companies, including some non-boiler applications such as cement plants.

The basic problem for low-rank coal in penetrating industrial markets is the inability to compete with oil and gas in most regions, even though the cost of the fuel (per Btu) is lower. An industrial-size coal-fired boiler (either stoker or pc) is about 3 times higher in capital cost than an oil- or gas-fired boiler.

Even in cases where the total calculated costs to produce a pound of steam from coal are comparable or slightly better than from oil or gas, many firms reject the coal option. Reasons most frequently cited are the uncertainties and difficulties in meeting environmental regulations, and the inconvenience of handling solid fuel. The cost incentive has to be strong before low-rank coal can penetrate this market.

For industrial areas distant from the low-rank coal deposits, a major impediment is the inability of relatively small coal consumers to achieve the economies of scale that utilities achieve. These economies apply to the whole extraction and delivery, utilization, and cleanup system. For example, single-car rail rates per ton of coal delivered are double (or more) the unit train rates negotiated by utilities.

Solving this problem would require the development of a "wholesaling" infrastructure for low-rank coal -- large, efficient delivery systems to industrial distribution centers. Options to consider would be: 1) central combustion facilities feeding a steam and power distribution network (a natural extension of electric utilities' current operations); and 2) central gasification facilities feeding syngas to individual boilers. One advantage of these options compared to individual direct use would be the convenience and economy of centralizing all important environmental control and disposal operations. Alternatively, minemouth coal conversion operations, combined with long-distance product transportation, might achieve similar economies of scale. In any of these cases, a prerequisite to raising the capital required for such projects would be the existence of a firm market for the products. Ensuring this steady, long-term demand in compact areas may require the development of new cooperative investment and financing approaches.

Calculations show that the one major industrial area where coal is currently cost-competitive with oil and gas for industrial-scale steam generation is the industrial midwest (i.e., Illinois, Michigan, Ohio). However, in the absence of SO_2 emission regulations for such plants, local bituminous coal has a cost advantage over western subbituminous coal in this market.

During the 1980's (and beyond), oil and gas prices will continue to rise faster than coal prices. As this occurs, the cost of steam from coal will eventually become competitive with steam from oil and gas in areas other than the midwest.

One high-potential growth area for industrial use of low-rank coal is the Gulf coast. By the mid-1980's it is projected that Gulf lignite will be competitive with oil and gas as conventional boiler fuel. And, if fluidized bed combustion technology proves out, the cost incentive to use Gulf lignite (as well as "imported" western coal) could be substantial. The huge petrochemical industry in the Gulf region also represents a very good potential market for low-rank coal (via synthesis gas) in the next 10-20 years.

Synthetic Fuel Markets

Coal-based synthetic fuels are expected to begin contributing to our energy supply in significant amounts starting in the 1990's. The electric utility industry may be a major customer, using coal-derived gas in highly efficient combined cycle plants, and coal liquids in existing oil-fired boilers and new peaking units. Once synthetic fuels pass the cost "crossover" point with respect to petroleum and natural gas, penetration of synthetic fuels into many of the markets now served by oil and gas could occur rapidly. The transportation and distribution infrastructures for oil and gas products from coal are in place.

Several characteristics of low-rank coals (e.g., high reactivity, low sulfur content, non-caking properties) make them generally favorable feedstocks for many of the coal conversion processes. This fact, coupled with the low extraction cost per Btu, indicates that low-rank coal could account for a very large portion of the eventual synfuels market.

The first commercial SNG-from-coal plant in the U.S. is expected to be the Great Plains Gasification Associates project, which will use North Dakota lignite. Almost all of the SNG projects that have been proposed during recent years (most of which have been cancelled or deferred due to high costs and the regulatory climate) intended to utilize western low-rank coals.

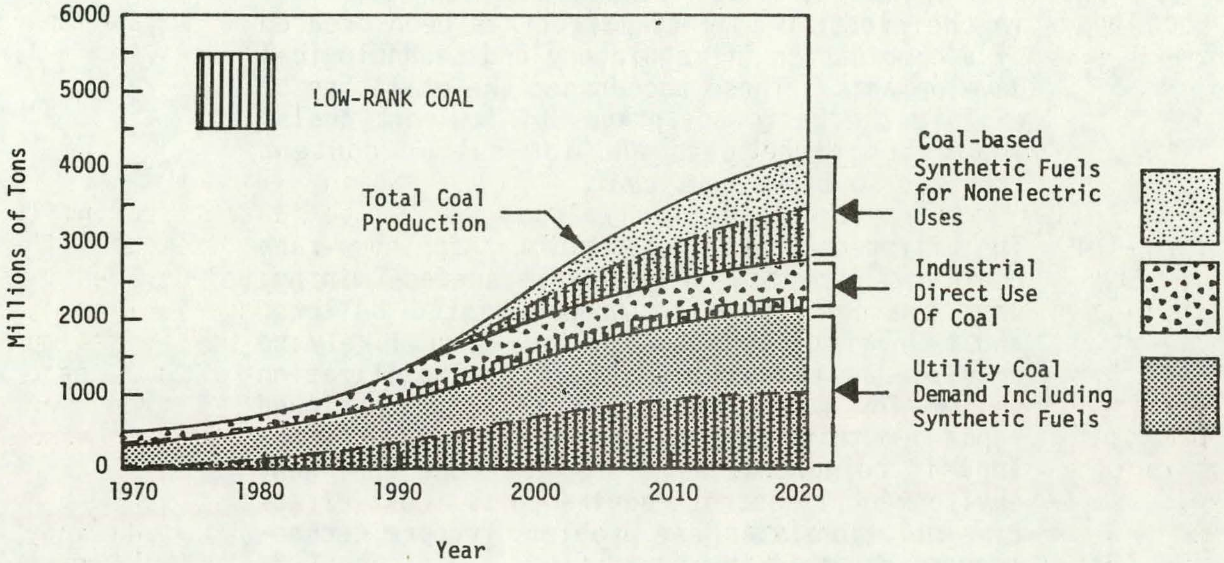
The prospects for commercial production of synthetic liquids from coal appear to be farther in the future than for SNG. In addition, the advantages of low-rank coals as feedstocks to direct liquefaction processes are not as obvious as the advantages in first-generation gasification processes. Preliminary economic tradeoff studies indicate that low-rank coals could be at least as attractive as bituminous coal for liquefaction, but these calculations are based on inadequate process data. The future market for low-rank coals as liquefaction feedstocks must be considered highly uncertain until more RD&D has been performed.

Summary

One scenario for the future use of coal -- derived from Air Electric Power Research Institute long-range planning study -- is shown on Figure 10. Other forecasts (by DOE, the National Coal Association, and others) are similar. (The low-rank coal share shown on the graph is an estimate produced in this study. It is not intended as a forecast, but rather as an indication of the potential for growth.)

Figure 10

A Future Scenario for the U.S. Coal Industry



Under this scenario, total U.S. coal production would triple by the year 2000 to about 2 billion tons/year. This is an average annual growth rate of 4.7 percent -- much higher than the historical rate.

The low-rank coal portion of the total could grow to the order of 50 percent, or 1 billion tons/year, by 2000. To achieve this production rate, low-rank coal use would have to continue growing much faster than total coal use, at a rate of approximately 8-10 percent per year for the next 20 years.

Major conclusions of the market analysis for low-rank coals are as follows:

1. Low-rank coal growth is mainly constrained by demand. Competing fuels have the edge in many markets. Low-rank coal mining capacity currently exceeds production by a substantial amount, and is projected to do so at least through the mid-1980's.

2. The primary demand constraints are caused by: a) the location of low-rank coal reserves far from major markets; b) the high cost per Btu of transporting low-rank coals over long distances; c) the costs and uncertainties of using coal due to environmental standards; and d) the lack of a coal distribution infrastructure for industry; and e) the high cost of converting oil-or-gas-fired equipment to coal.

3. In the recent past, demand for low-rank coal in the electric utility market has been created by a combination of regulatory and technological developments. These encouraged the utilities to exploit the basic advantages of low-rank coals: low extraction costs and low sulfur content compared to bituminous coal.

4. The first-generation technology for low-rank coal development -- large-scale surface mining, unit train transport, large pc-fired boilers, and major regional power grids -- is likely to continue as the major low-rank coal utilization system for some time. However, the continued rapid growth of this existing market and technology is being challenged by new, more stringent environmental control requirements. Cost-effective solutions to these problems require technology development.

5. Similar considerations will apply in the longer-range future. Even though the nation needs rapid coal development to reduce its dependence on imported oil, demand for coal-derived substitute fuels in major oil markets will be constrained. Product quality and cost, and environmental, health, and safety issues associated with synfuels could limit their marketability. Government policy initiatives and new waves of technology will be the keys to removing these constraints.

6. As coal use expands, supply-side constraints will also emerge. Impacts of greatly expanded surface mining and coal use in the arid and semi-arid west, water availability, and inadequate coal transportation capabilities are the major factors that could hold back continued growth. Cost-effective solutions to these problems also require technology development.

1.4 REGULATORY AND ENVIRONMENTAL ISSUES

All energy production, delivery, and utilization systems in the U.S. are being increasingly shaped by the actions of the federal government and state regulatory agencies. For example, implementation of the Fuel Use Act by the Department of Energy will have wide-ranging effects on the selection of fuels and boilers by utilities and industry. Currently the federal government is establishing the Synthetic Fuels Corporation to initiate the large-scale production of oil and gas substitutes.

Coal is inherently a dirty fuel. Each step in the sequence from extraction through utilization involves some environmental risk. These risks have come under increasing regulatory scrutiny -- a trend that can be expected to continue as coal use expands. Technology development is being forced; costs are being driven up.

In both of these areas -- government policies regulating production or use of fuels, and environmental standards -- the requirements represent moving targets to those who must comply. The uncertainty created in industry by constantly changing public policies tends to retard decision-making, and affects research and development needs.

Low-rank coals share many generic environmental/regulatory issues with all coal. There are also some unique considerations due to the location and properties of the coal. Table 10 summarizes the major issues of concern.

Much of the western low-rank coal is mined in areas that possess natural beauty but lack rainfall. In some areas of the west, water resource allocation decisions that will significantly affect coal development will be made only with great difficulty due to the many competing uses.

Reclamation is difficult in many of the arid low-rank coal-bearing regions, and its ultimate success may require many years to ascertain. At the other extreme, such as the current lignite mining area in Texas, revegetation occurs quickly with abundant rainfall. In this region, there is no need for segregation of topsoil during mining (as there is in most other areas) to aid in re-establishing ground cover.

Transportation of western subbituminous coal has been a regulatory issue since the mid-1970's due to the monopolistic position of some railroads, their pricing policies and merger applications, and their opposition to proposed slurry pipeline projects. Deregulation of rail rates is being considered in Congress. Higher rates would enable the railroads to improve and maintain unit train trackage, but would tend to depress demand for low-rank coal in the midwest and south. Conversely, lower transportation rates and additional competing capacity (i.e., slurry pipelines) would increase both demand and supply.

Federal and state air quality regulations are major technology-forcing issues for coal-fired power plants. The tightening of air emission standards for new boilers in the 1979 NSPS has sent low-rank coal-fired power plant designers back to the drawing boards to improve the control of SO_2, NO_x, and particulate emissions (see Table 11). Continued tighten-

Table 10

Environmental Issues in Low-Rank Coal Development

Air Quality

1. SO_x, NO_x, and particulate emissions from power plants and conversion plants.
2. Odors, hazardous trace organic emissions from conversion plants.
3. Fugitive dust from mining, preparation, storage piles, rail cars.
4. Visibility; ambient pollutant concentrations; acid rain; CO_2 buildup.

Water Quality

1. Leaching to aquifers from mined or gasified areas.
2. Liquid effluent disposal from conversion processes.
3. Water from slurry pipelines and coal preparation plants.

Water Quantity

1. Cooling water required for combustion and conversion plants.
2. Process water required for gasification plants.
3. Water required for slurry pipelines.

Land Productivity

1. Productivity of reclaimed mined land in arid and semi-arid regions of the West.

Solid Waste Disposal

1. Ash disposal from combustion and conversion processes.
2. Sludge disposal from wet and dry SO_2 scrubbers, and and coal preparation plants.
3. Mine spoil piles.

Land Use

1. Land out of agricultural production or other use during mining or underground coal gasification.
2. Plant site area required for combustion and conversion.

Noise

1. Combustion, conversion, mining, and transportation facilities.

Public Safety

1. Potential exposure to hazardous material in conversion plants and UCG.
2. Grade crossing hazards and derailments in rail transport.
3. Subsidence following underground mining and UCG.

Table 11

New Stationary Source Performance Standards
For Electric Utility Steam Generating Units, December 1971 and June 1979

Pollutant		December 1971 Standards	June 1979 Standards
SO_2:	Emission limit	1.2 lb/10^6 BTU	1.2 lb/10^6 BTU (based on a 30-day rolling average)
	Reduction in potential emissions		90% when emissions are 0.6 lb/10^6 BTU or greater 70% when emissions are less than 0.6 lb/10^6 BTU
Particulate Matter:	Emission limit	0.1 lb/10^6 BTU	0.03 lb/10^6 BTU
	Opacity of emission	20%	20% (based on a 6-minute average)
NO_x:	Emission limits		Based on a 30-day rolling average:
		(i) 0.70 lb/10^6 from the combustion of coals except lignite.	(i) 0.50 lb/10^6 BTU from the combustion of subbituminous coal, shale oil, or any solid, liquid, or gaseous fuel derived from coal.
		(ii) 0.80 lb/10^6 BTU from the combustion in a cyclone furnace of any fuel containing more than 25 percent, by weight, lignite which has been mined in North Dakota, or Montana.	(ii) 0.80 lb/10^6 BTU from combustion in a slag tap furnace of any fuel containing more than 25 percent, by weight, lignite which has been mined in N. Dakota, S. Dakota, or Montana.
		(iii) Combustion of a fuel containing more than 25 percent, by weight, coal refuse is exempt from the NO_x standards and monitoring requirements.	(iii) Combustion of a fuel containing more than 25 percent, by weight, coal refuse is exempt from the NO_x standards & monitoring requirements.
		(iv) 0.60 lb/10^6 BTU from the combustion of lignite except as stipulated in (ii) above.	(iv) 0.60 lb/10^6 BTU from the combustion of any solid fuel not specified in (i), (ii), or (iii) above.

Notes: 1. These standards apply to electric utility steam generating units capable of combusting more than 73 megawatts heat input (250 million BTU/hour) of fossil fuel.

2. A major difference between the December 1971 and June 1979 NSPS is in compliance testing. The June 1979 NSPS require continuous stack monitoring and a 30-day rolling average for the SO_2 and NO_x emissions. The December 1971 required that emission monitoring only be performed at the beginning of plant operation and thereafter when the EPA deemed it necessary.

ing of some of these standards (i.e., NO_x) as well as development of new standards for hydrocarbons, trace elements and solid waste can be expected to force additional changes -- not only in add-on cleanup modules, but in the combustion units themselves. Ambient air quality standards and visibility rules may also add to technology requirements.

A major thrust in the recommended RD&D program for low-rank coal is to develop improved combustion environmental control technology (ECT). On one hand, it should be possible to take advantage of some of the unique properties of low-rank coal in meeting the standards (i.e., SO_2 removal by alkaline ash). On the other hand, certain aspects of ECT for low-rank coal (i.e., particulate capture and disposal) may present more difficult technical problems compared to bituminous coals.

Similar needs for focused research apply to the ECT requirements for low-rank coal gasification, liquefaction, and pyrolysis processes. The unique physical and chemical properties of the coal, as well as western location factors, create special problems and opportunities in controlling air, water, and solid emissions.

Nearly all recent studies of our national energy future and journal articles on Federal coal-related issues cite the need for expeditious new leasing programs for western coal. This is basically a "get on with it" versus "ban development and pollution" political issue. Similar (but global rather than national) concerns surround the acid rain and upper atmospheric CO_2 phenomena. Acid rain and CO_2 buildup are not unique to low-rank coals, nor to this country's policy agenda.

1.5 KEY LOW-RANK COAL TECHNOLOGY ISSUES

If low-rank coal use is to continue its rapid expansion, improvements are needed in existing technology to meet tightening standards and to enhance efficiency and reliability. There is also a need for new waves of technology which will allow coal to play the transition role expected of it in the next 40-50 years. These needs are driven by the market forces discussed earlier, as well as the environmental and regulatory requirements and constraints.

A thorough analysis of the technology currently applied (or potentially applicable) to low-rank coal development has been performed. Emphasis was placed on the unique physical and chemical properties of low-rank coals, and the effects or requirements imposed on technologies by these properties. The conclusion is that the key technical issues for low-rank coals are different from those for bituminous coal, and require a separate focus.

Figure 11 illustrates in shorthand form some of the important effects of low-rank coal properties on various technologies. When examined in conjunction with the specific needs for improvement of the technologies themselves, these effects generate a long list of key issues, which are summarized below. These issues, in turn, dictate the major elements of the recommended RD&D program for low-rank coals; these are presented in the next section.

Figure 11

Effects of Low-Rank Coal Properties on Technology
As Compared to Bituminous Coal

LOW-RANK COAL PROPERTIES	EXTRACTION: SURFACE MINING	EXTRACTION: RECLAMATION	EXTRACTION: UNDERGROUND MINING	EXTRACTION: UCG	TRANSPORT: RAIL AND BARGE	TRANSPORT: SLURRY PIPELINES	PREP, HANDLING & STORAGE: DRYING	PREP, HANDLING & STORAGE: CRUSHING AND PULVERIZATION	PREP, HANDLING & STORAGE: HANDLING AND STORAGE	DIRECT UTILIZATION AND CONVERSION: CONVENTIONAL COMBUSTION	DIRECT UTILIZATION AND CONVERSION: COMBUSTION ECT	DIRECT UTILIZATION AND CONVERSION: FBC	DIRECT UTILIZATION AND CONVERSION: GASIFICATION	DIRECT UTILIZATION AND CONVERSION: LIQUEFACTION	DIRECT UTILIZATION AND CONVERSION: PYROLYSIS	DIRECT UTILIZATION AND CONVERSION: MHD
OCCURRENCE	+	−	−	+	−	−					±					
PHYSICAL PROPERTIES					−	−	−	−	−				−			
HIGH MOISTURE CONTENT				?	−	−	−	−	−	−	+	−	±	−	−	−
LOW SULFUR CONTENT	+	+	+	+						+	±	+	+	±	+	+
HIGH ALKALI CONTENT				?		?				±	±	±	±	?		
HIGH REACTIVITY	−		−	+	−		−		−	+		+	+	±	+	
NON-CAKING PROPERTIES				+						+		+	+		+	

LEGEND:
(+) Generally positive effect on that technology
(−) Generally negative effect on that technology
(±) Either positive or negative effect, depending on circumstances
(?) Suspected to have an effect but not well characterized

Conventional combustion and associated environmental control technology is the area of most urgency. Pulverized coal-fired boiler technology is well-developed and has for the most part been adapted successfully to low-rank coals. Utilities in general need to improve the reliability and availability of boilers due to rising cost pressures.

One coal-specific issue affecting boiler reliability is ash fouling of boiler tubes. This problem is most severe with high-sodium lignite from the Fort Union Region. The costs of downtime in these boilers are being determined. A key question now is whether any of the proposed solutions -- such as revised boiler design, ion exchange removal of sodium, or injection of additives to the boiler -- are cost-effective.

In the area of sulfur emission control from power plant stacks, the combination of low sulfur content and high ash alkalinity frequently found in low-rank coals presents interesting opportunities. As a general strategy, it would be desirable to get away from conventional wet scrubbing with its many operating problems. Dry scrubbing offers lower capital costs and, potentially, better reliability. The higher reagent costs compared to wet scrubbing can be tolerated if the sulfur content of coal is sufficiently low . Field tests of the first commerical spray dryers in power plants, plus bench-scale research to develop improved sorbents or systems, should advance this technology.

Meeting New Source Performance Standards for SO_2, NO_x, and particulate emissions are not the only questions utilities will face in building new plants. Ambient air quality standards could force utilities to consider retrofitting existing plants to obtain SO_2 emission offsets. Different control options would apply to retrofit situations as compared to new plant designs; these need to be developed, taking advantage of the favorable low-rank coal properties.

The new particulate emissions standard of 0.03 lb/10^6 Btu is expected to present a major problem to utilities burning low-rank coals. Electrostatic precipitators have a difficult time collecting high-resistivity, fly ash from low-rank coals. Various techniques and devices have been proposed to improve ESP performance, but it is not clear yet if they can meet this standard. Alternatives to ESP's, such as fabric filters and various novel devices, have little or no experience on low-rank coal fly ash; basic data are needed. Special attention should be given to sampling, analyzing, and designing collection systems for very fine particulate matter.

Several aspects of NO_x emissions control from low-rank coal combustion may be unique: 1) conventional NO_x control techniques such as overfire air and low excess air could make ash fouling problems worse; and 2) dry sorbents used for SO_2 control may absorb some NO_x.

Disposal of solid wastes from power plants is an area where standards are currently evolving and data are needed. Specific questions about low-rank coal include: 1) leachability of high-sodium fly ash; 2) ash-alkali scrubber sludge fixation requirements; and 3) disposal methods for soluble (sodium-based) spent sorbents from spray dryers.

Trace elements and organic compounds can be emitted from coal-fired power plants. The nature of these emissions, and their fate and effects in the environment are not known. The unique compositions and forms of minerals in low-rank coals suggest that these compounds might be distributed differently in the effluents from low-rank coal plants. A basic problem in this area is the lack of adequate sampling and analytical procedures.

Technologies that are expected to be important to low-rank coal utilization in the future include fluidized bed combustion, gasification, liquefaction, and pyrolysis. In each of these technologies, there are specific concerns relating to the properties of low-rank coals.

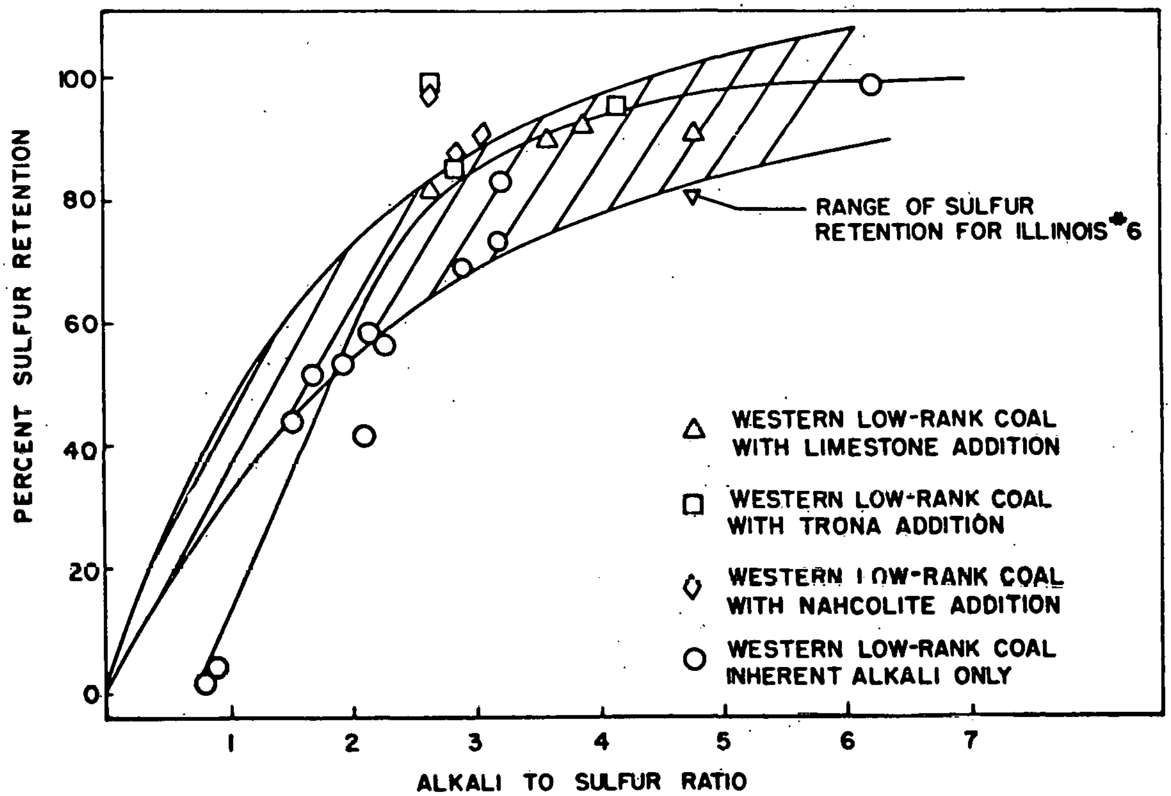
Fluidized bed combustion offers a number of potential advantages over conventional pulverized coal combustion. These include flexibility to handle widely varying fuels, capture of sulfur by limestone in the fluidized bed, high combustion efficiency, compact size, and lower NO_x emissions due to reduced combustion temperatures. Low-rank coals with high alkali-to-sulfur ratios offer a significant additional advantage: the ability to absorb sulfur on the alkaline ash and meet emissions standards with little or no added limestone (see Figure 12).

Optimization of FBC technology for low-rank coals involves several key issues: selection of the best overall design configuration for a highly reactive, sulfur-retaining fuel; understanding the properties of an ash-rich fluidized bed with no limestone; preventing agglomeration of solids in the bed due to high-sodium content; and understanding sulfur retention as a function of coal and ash properties and operating conditions. For pressurized FBC, there is a question concerning the effects of alkaline ash (particularly, high-sodium ash) on hot gas cleanup systems.

Coal gasification technology involves many types of processes. Low-rank coals are preferred feedstocks to the first-generation, fixed-bed gasification processes such as Lurgi. This is due primarily to the non-caking behavior of low-rank coals; high reactivity and low-sulfur content are also advantageous. On the negative side, very high-moisture coals are not desirable for fixed-bed gasification. Because the first commerical gasification plants are likely to use low-rank coals, any of the residual problems with the technology (such as waste water treating) are important for low-rank coals.

Figure 12

Percent Sulfur Retention as a Function of Total Alkali-to-Sulfur Ratio in AFBC

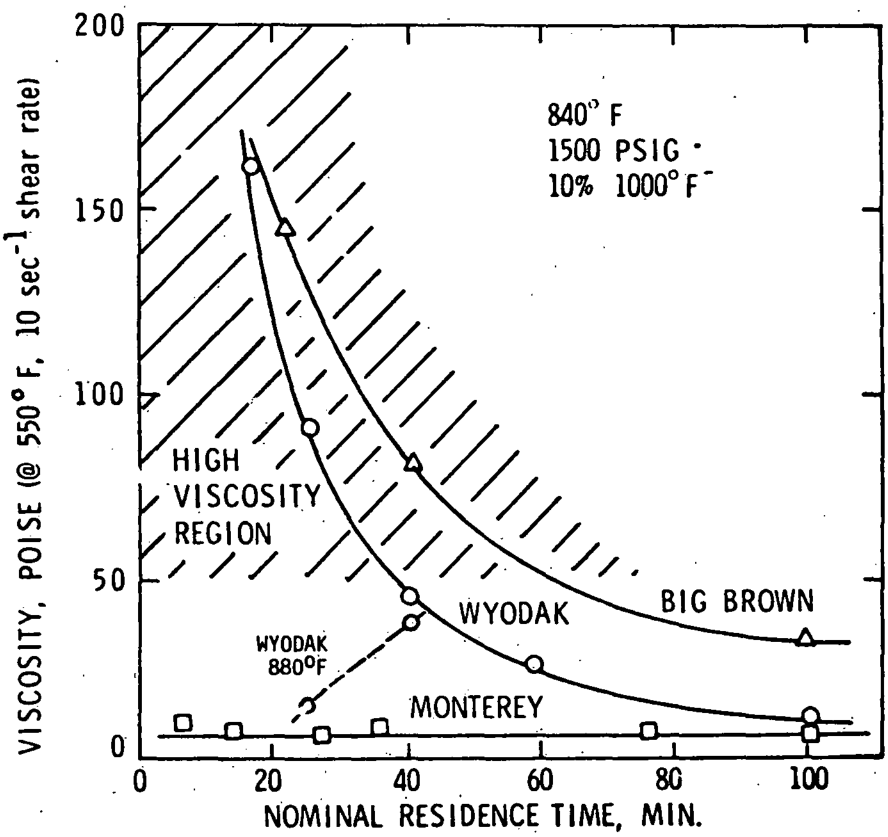


The major driving force behind the development of advanced fluidized bed and entrained flow gasification processes has been the desire to use caking bituminous coals. Thus, data on how to select and apply new technologies for low-rank coal tend to be unavailable. For these emerging technologies, the low-rank coal issues are process-specific and detailed, rather than large central issues. For example: slurry feeding a high-moisture coal to a Texaco gasifier could be a problem; or the alkali recovery unit in the Exxon catalytic gasification process could be adversely affected by the inherent alkali elements in low-rank coals.

The behavior of low-rank coal (especially lignite) has been shown to be different from bituminous coal in all of the developing direct liquefaction processes. High moisture content increases the reactor pressure requirement. High oxygen content leads to high CO_2 production, which also increases pressure requirements. Low-rank coal reacts readily with carbon monoxide, possibly favoring the use of syngas rather than pure hydrogen. The high calcium content in low-rank coal ash causes deposition of calcium carbonate solids in liquefaction reactors. Quality of the liquid products appears to differ for low-rank coals, particularly the high viscosity of the bottoms fraction (see Figure 13).

Figure 13

Effects of Coal Type and Process Conditions on Viscosity of EDS Residual Liquefaction Bottoms



The implication is that low-rank coal liquefaction, once optimized, will involve different process design parameters and operating procedures from those for bituminous coal. There is need for additional RD&D work on low-rank coal liquefaction, including basic research into process mechanisms and product properties, engineering/economic optimization studies, and testing of low-rank coals in the large existing pilot plants.

Coal pyrolysis is a technology that can be used if the objective is to make a combination of products: fuel gas, liquid fuels or specialty chemicals, and char for direct use or briquetting. Data from early studies on low-rank coal pyrolysis indicate problems with both the yields and quality of liquid products. A complete review of existing data and an evaluation of the feasibility of low-rank coal pyrolysis would be worthwhile.

In the areas of preparation, handling, and storage, a number of problems and opportunities exist due to the generally unfavorable handling characteristics of low-rank coal.

The high moisture content causes problems in many areas, and suggests the need for coal drying processes to meet specific needs. These include: 1) drying to improve transport economics, where overall system cost tradeoffs and dried coal stability are the key questions; 2) drying techniques that limit moisture reabsorption to prepare coal for slurrying into pipelines or entrained flow gasifiers; 3) drying techniques that preserve the coal reactivity for liquefaction instead of collapsing active surface area; and 4) drying to very low levels of moisture as required for feed to magnetohydrodynamic reactors.

Incentives also exist to develop low-rank coal cleaning processes for sodium, sulfur, or ash removal. Conventional gravity separation techniques can be usefully adapted to some low-rank coals which have appreciable extraneous ash contents. In general, the potential for sulfur removal from low-rank coals by washing is low. Ion exchange has been shown to be feasible for sodium reduction, and may find applications in the Fort Union Region to alleviate boiler fouling problems.

Low-rank coal extraction and transportation technologies are generally well-developed. Most of the technical issues involve optimization of systems and cost reduction. Reclamation of surface-mined land in arid regions continues to provide research challenges. Dewatering of coal slurries and treatment, reuse, or disposal of water are areas of concern for proposed coal slurry pipelines.

1.6 RD&D PROGRAM RECOMMENDATIONS

Based on a detailed review of the key technical issues, market needs, and various constraints to development, a national RD&D program for low-rank coal is recommended. The approach taken was to identify major research topics, state their objectives, identify supporting data and/or ongoing related research, and indicate how the results of the research would be integrated with other work to advance low-rank coal development. Within each research topic the approach to the work has been stated only in general terms. Definition of the step-by-step details of the work has been left to the organizations that will perform the RD&D.

To indicate the general level of importance or urgency associated with each recommended project, "Priority I" and "Priority II" designations have been assigned. Taken as a whole, the Priority I program represents RD&D that is considered essential to the advancement of low-rank coal development. It is in essence a zero-base program recommendation. The Priority II program represents RD&D that is considered very important, and could greatly enhance the longer-term development of low-rank coal. Other worthwhile ideas and projects were considered, but were relegated to a lower priority level and excluded from the recommended program.

The overall emphasis of the program is on exploratory, technology, and engineering development efforts which make systematic use of the knowledge and understanding gained from basic and applied research. This emphasis is illustrated on Figure 14, which classifies the recommended RD&D in each technology area into various phases, defined briefly as follows:

1. Basic Research - efforts to increase knowledge and quantitative understanding of natural phenomena. An example is the recommendation for improved petrographic characterization of low-rank coals.

2. Applied Research - systematic study to devise processes or systems of possible (but uncertain) practical utility. An example is the recommended development of standard analytical methods to characterize coal-derived liquids.

3. Exploratory Development - efforts to explore possible innovation in a particular technology area, and to assess whether further development is warranted. An example would be the study of coal mineral catalysis in recycle liquefaction processes.

4. Technology Development - development of processes or subsystems at laboratory scale, as well as preliminary studies encompassing systems analysis, trade-offs, cost-benefits, and environmental analyses. An example is the recommended small-scale testing to select additives for ash fouling control in boilers.

5. Engineering Development - detailed design, construction, and test for performance, producibility, and reliability of system prototypes and pilot plants. An example is the recommended acquisition and testing of novel devices for fine particulate collection.

6. Demonstration - verification of economic and environmental viability for commercial application, through design, construction, test and evaluation of large-scale systems. An example would be the recommended demonstration of a direct ignition system for pulverized low-rank coal fired boilers.

Figure 14

Classification of Recommended RD&D Program Into Phases of RD&D

TECHNOLOGY AREA \ PHASE OF RD&D	BASIC RESEARCH	APPLIED RESEARCH	EXPLORATORY DEVELOPMENT	TECHNOLOGY DEVELOPMENT	ENGINEERING DEVELOPMENT	DEMONSTRATION	COMMERCIALIZATION PRODUCT AND OPERATION
EXTRACTION AND TRANSPORTATION		II	I II	I II	I	I	
PREPARATION, HANDLING & STORAGE		II	I II	I II	I II	II	
CONVENTIONAL COMBUSTION		I	I II	I II	I II	I II	I
COMBUSTION ENVIRONMENTAL CONTROL TECHNOLOGY			I II	I II	I II	I II	I
FLUIDIZED BED COMBUSTION			I	I II	I II	I	
GASIFICATION				I II	I	I	I
LIQUEFACTION & PYROLYSIS			I II	I II	I II		
BASIC COAL SCIENCE	I II	I II	I II				

Legend: I - Priority I
II - Priority II

7. Commercialization, Production, and Operation - self explanatory. An example would be the recommended systematic evaluation of the first utility spray dryer FGD units.

Brief summaries of the recommended RD&D in each major technology area are presented below.

Extraction

As shown on Table 12, the Priority I recommendations for low-rank coal extraction involve reclamation techniques for surface mined land, new and improved surface mining techniques, and underground coal gasification.

Reclamation studies should involve a combination of field work and monitoring, laboratory or controlled growth experiments, and modeling.

Improvement of surface mining techniques requires the application of open pit or other methods to difficult mining situations such as multiple seams, thick or pitching seams, and deeper seams. European techniques such as bucketwheel excavators combined with conveyor belt systems are difficult to apply to the overburden and climate conditions in the Northern Great Plains, for example. Design and operation of earth-moving machinery, as well as overall mine planning, could be enhanced by the development of computerized design, monitoring, and control systems.

Table 12

Recommended RD&D For Low-Rank Coal Extraction

Priority I	Priority II
1. Surface Mined Land Reclamation	4. Dewatering of Mine Area and Groundwater Control
2. Surface Mining a. Techniques for multiple thin seams, thick seams and deeper overburden b. Optimization of equipment specifications c. Cost reduction through operations research and systems engineering	5. Underground Mining a. Mining thick seams b. Mining under unconsolidated overburden c. Dewatering and groundwater control
3. Underground Coal Gasification a. Aquifer disruption and groundwater contamination b. Subsidence and gas leakage c. Linking techniques d. Coal seam characterization and process monitoring	

Underground coal gasification has future potential as a method for extracting coal energy from deeper seams that would be uneconomical to mine. It also promises to provide a relatively inexpensive source of coal-derived syngas. Several major areas of research need to pursued, as noted on the table, before this technology can be considered sufficiently reliable or environmentally sound. DOE has an ongoing program addressing these research needs, and several industry projects are underway as well.

The Priority II recommendations in Extraction include: 1) development of better mine dewatering methods and groundwater control systems, especially for deeper coal seams; and 2) development of appropriate underground mining technology for thick western coal seams, which often have unconsolidated overburden and act as major aquifers.

Transportation

The recommended RD&D for low-rank coal transportation is limited to one transport mode -- coal slurry pipelines (see Table 13). Rail, barge, truck, and conveyor systems will continue to evolve and improve, but do not generate any major research needs (with the exception of coal dust, reactivity and freezing problems, which are addressed under Coal Preparation).

Table 13

Recommended RD&D For Low-Rank Coal Transportation

Priority I	Priority II
1. Slurry Dewatering a. Separation of coal fines b. Treatment of separated water c. Utilization of treated slurry water	3. Slurry Pipeline Reliability a. Restarting slurry flow b. Freeze protection c. Ruptured slurry pipelines d. Distances over which coal suspension can be maintained.
2. Slurry Pipeline Water Requirements	

In the Priority I area, slurry dewatering at the receiving end of a coal pipeline is a problem that could benefit from scientific investigation. Laboratory tests indicate that during transport some low-rank coals (especially lignite) become very finely divided, making separation by standard gravity techniques ineffective. Investigation of the surface properties of coal fines and of chemical means to enhance separation processes would be worthwhile. Site-specific studies of the treatment and utilization alternatives for the separated water should also be made.

A major issue with respect to slurry pipelines in arid regions of the west is the utilization of large amounts of water to transport the coal. Studies to minimize water requirements should include investigations of slurry media other than water -- oil, methanol, or CO_2, for example.

In the Priority II area for low-rank coal transporation, the recommendations include systems studies, simulations, and some laboratory research to address questions about slurry pipeline reliability.

Preparation, Handling, and Storage

The Priority I recommendations for low-rank coal preparation research include two projects on coal drying, two on coal cleaning or beneficiation, and an investigation of fines generation during crushing and handling (see Table 14).

Drying of low-rank coals for use in conversion processes requires that different techniques be used to meet different process requirements. Techniques that limit reabsorption would be useful for processes using slurry feed systems: drying to very low moisture levels is required by the MHD process; drying the coal without collapsing its pore structure is required for liquefaction. Techniques exist or have been proposed for all of these purposes; they need to be verified.

Chemical cleaning processes for low-rank coals would include: 1) ion exchange for sodium removal; 2) removal of potentially hazardous elements; and 3) sulfur and ash removal. Processes have been partially developed for several of these purposes, but need further testing and economic tradeoff studies to verify their usefulness.

Table 14

Recommended RD&D for Low-Rank Coal Preparation, Handling, and Storage

Priority I	Priority II
1. Coal Drying For Conversion Processess	6. Briquetting or Pelletizing
2. Chemical Cleaning Processes for Low-Rank Coals	7. Preparation and Beneficiation Techniques Applied to Slurry Pipeline Systems
3. Physical Cleaning Processes for Low-Rank Coals	8. Waste Disposal from Coal Beneficiation
4. Coal Drying to Improve Transport Economics	9. Control of Dust, Oxidation and Spontaneous Combustion
5. Optimized Crushing & Handling Equipment to Minimize Fines Generation	10. Freeze Control
	11. Comminution Techniques

Physical coal cleaning processes would be applicable to low-rank coals containing significant amounts of extraneous mineral matter. Multi-solvent approaches have been suggested, and should be investigated. Techniques applicable to separation of fine particles, as well as magnetic separation techniques, should be tested for applicability to low-rank coals. To determine the overall potential or need for this technology, an assessment of the trend towards extraction of lower-grade low-rank coal (as better deposits are mined out) should be done.

Drying of low-rank coal to improve long-distance transport economics has two major problems: high costs, and difficulty in handling and storage of dried coal. A state-of-the-art review of various thermal, gas and liquid phase drying techniques is needed. Effects of dried coal on boiler design need to be determined. Cleanup and utilization of the separated water should be investigated.

The generation of coal fines during low-rank coal handling and crushing needs to be studied to: 1) determine the specific procedures that generate fines, and 2) develop modifications to reduce production of, and/or utilize fines.

A large number of Priority II projects are recommended in Preparation, Handling, and Storage, reflecting the need for improvement in the physical and handling properties of low-rank coals. Briquetting technology has been developed and applied to many types of coal, and could be applied once again in this country if markets for the product existed.

The study of slurry preparation techniques should incorporate the results of coal drying studies to limit moisture reabsorption, as well as other means to improve the properties of low-rank coal slurries. The concept of incorporating thermal, chemical, and mechanical beneficiation techniques into a slurry pipeline system should be investigated.

Concentrated wastes from coal beneficiation processes should be characterized to determine RCRA requirements applying to their disposal.

Techniques to control dust, oxidation, and spontaneous combustion problems have been developed, but these problems still occur. Additional work on new cost-effective solutions would be worthwhile.

Control of freezing problems in coal transport and handling systems is a persistent problem that could be amenable to solution by novel techniques.

Finally, improvement of low-rank coal comminution (crushing and grinding) technology is a continuing need.

Conventional Combustion

Table 15 lists the recommended RD&D for improvement of conventional low-rank coal combustion technology. The Priority I projects address the problems of ash fouling and slagging, and the opportunity to decrease our oil consumption by developing a direct coal ignition system.

Table 15

Recommended RD&D For Low-Rank Coal Conventional Combustion

Priority I	Priority II
1. Ash Fouling and Slagging Mechanisms	4. Improved Boiler Cleaning Procedures
2. Control of Fouling and Slagging With Additives	5. Temperature Limitation Vs. Boiler Corrosion
3. Direct Ignition of Pulverized Coal Without Oil	6. Improved Stoker Furnace for Small Applications

The study of ash fouling and slagging mechanisms builds on the knowledge gained from years of research at the Grand Forks Energy Technology Center. Recommended research elements include developing analytical techniques to predict the fouling and slagging potential of coal samples, and the effects of boiler design or operating procedure modifications.

One potential method to ease removal of ash fouling deposits would be the injection of additives to the boiler. This requires a sequence of: 1) basic studies to determine mechanisms of additive reactions with ash; 2) small-scale testing to screen and select promising additives; and 3) demonstration of the best additives in operating boilers.

A direct ignition method to replace the current oil ignition systems in pulverized-coal-fired boilers would be designed to take advantage of the high reactivity of low-rank coal.

The Priority II recommendations for Conventional Combustion include the development of improved boiler cleaning procedures, an investigation of extending tube metal temperature limits, and development of an improved stoker furnace for small institutional uses.

Improvement of boiler cleaning procedures (on line) requires developing criteria for predicting the ease of deposit removal as well as methods for more accurately determining sootblower requirements. Improved methods for deposit removal during boiler outages would be useful.

Research to determine the temperature limitations of alloys in relation to external corrosion in the convection pass of low-rank coal-fired boilers might lead to the ability to operate at higher steam temperatures, thus increasing the steam cycle efficiency. Probes could be utilized to measure corrosion rates in operating boilers. Experiments should be conducted with additives that might extend the upper temperature limitation of alloys.

Studies to develop an environmentally, economically, and technically acceptable stoker furnace for institutional use of low-rank coals should be initated. These studies would include an evaluation of currently available stokers to identify needed improvements; development of improved furnace designs, as well as improved low-rank coal fuels; and demonstration of the operability of prototype systems.

Combustion Environmental Control Technology (ECT)

As shown on Table 16, the Priority I recommendations for low-rank coal combustion ECT involve the key areas of stack gas cleaning for SO_2, NO_x, and particulate emissions control, and solid waste disposal. A systems analysis project is recommended to evaluate integrated environmental control systems for low-rank coals. The tendency has been to add control systems to power plants in series without much regard for their interactions. By considering the interactions among alternative control systems, it might be possible to devise more efficient, reliable, and cost-effective methods to achieve the multiple cleanup objectives.

Table 16

Recommended RD&D For Low-Rank Coal Combustion Environmental Control Technology

Priority I	Priority II
1. Integrated Environmental Control Systems	9. Solid Waste Utilization
2. Improved Spray Dryer and Dry Sorbent Systems	10. Retrofit SO_2 Reduction Techniques Such as Lime/Limestone Injection
3. Improved Particulate Control Methods	
4. Fine Particulate Control Technology	
5. Solid Waste Disposal Procedures	
6. Improved Reliability of Ash Alkali Wet Scrubbing	
7. Trace Elements and Organic Compounds in Flue Gas	
8. Improved Procedures for NO_x Control	

Spray dryer and dry sorbent systems are believed to be capable of meeting SO_2 removal standards for many low-rank coals, and to be preferable to wet scrubbers in terms of cost and reliability. A research project should be conducted to: 1) evaluate the performance of the first commercial units; and 2) develop improved systems -- both hardware and sorbents -- through a combination of laboratory, pilot, and field tests.

Research into improved particulate control methods for low-rank coal involves a number of critical elements: 1) continued investigation of means to improve ESP performance, such as advanced charging techniques, fly ash conditioning, and improved fly ash removal methods; 2) testing and improvement of of fabric filter technology, including improved bag cleaning methods, fabrics and fabric finishes, and reduced baghouse size and pressure drop; and 3) developing and proving new concepts.

The study of fine particulate control technology is given separate emphasis because regulations are still evolving and sampling, analytical, and control methods for very fine particles are not well developed.

Solid waste disposal procedures are being scrutinized in general, due to the new RCRA regulations and concern about hazardous wastes. The solids from low-rank coal-fired power plants -- bottom ash, fly ash, and wet or dry scrubber sludges -- tend to have unique characteristics and require focused research.

The ash alkali wet SO_2 scrubbing process has significant cost advantages over conventional lime/limestone scrubbing for low-rank coals with high alkali-to-sulfur ratios. However, continuing work to improve the reliability and efficiency of the process is needed.

An area of growing concern, but lacking data, is the emission of trace elements and organic compounds in the flue gas of coal-fired power plants. The first step is to develop sampling and analytical procedures that can measure these emissions from low-rank coal-fired plants.

Another area of growing concern for fossil fuel combustion plants is NO_x emissions. Increasingly stringent standards for this difficult-to-control combustion product are anticipated. Possible emission control techniques include both combustion system modifications and add-on flue gas treating devices. In both cases, the unique burning properties and emissions associated with low-rank coals could impact the NO_x control system design.

The Priority II recommendations for combustion ECT include: 1) investigation of possible ways to utilize, rather than dispose of, solid wastes from low-rank coal combustion; and 2) development of effective retrofit SO_2 reduction techniques that could be applied to existing power plants.

Fluidized Bed Combustion

The Priority I recommendations for RD&D on fluidized bed combustion of low-rank coals deal primarily with the special problems associated with alkaline ash (see Table 17).

Table 17

Recommended RD&D For Low-Rank Coal Fluidized Bed Combustion (FBC)

Priority I	Priority II
1. Agglomeration of Solids in Fluidized Bed	7. Coal and Sorbent Feeding and Distribution
2. Sulfur Retention by Inherent Alkali in Low-Rank Coals	8. Staged Combustion for NO_x Control
3. Design Configuration of FBC Optimized for Low-Rank Coal	9. Temperature, Gas, and Solids Distribution in Low-Rank Coal FBC
4. Properties of Limestone-Deficient, Ash-Rich Fluidized Bed	
5. Hot-Gas Cleanup and Turbine Reliability for Pressurized FBC	
6. Materials Problems and Selection for Low-Rank Coal FBC	

Tests on some low-rank coals with high sodium content have shown a tendency for the bed solids to agglomerate into large chunks. Further studies are needed to determine the conditions and mechanisms that cause or prevent agglomeration, including the selection of bed materials and sorbents.

Additional information is needed on sulfur retention in low-rank coal FBC, as a function of coal and ash properties, pressure, other operating conditions, bed materials, and sorbents.

Studies to determine the best design configurations for different coals and for different applications (i.e., large utility versus small industrial boilers) are needed. These include evaluation of different overall systems (i.e., fluidized bed versus circulating bed) as well as identification of optimal design parameters for low-rank coals (e.g., bed depth, velocity, and heat transfer surface).

The ability of many low-rank coals to absorb SO_2 on the alkaline ash creates a need for studies on the properties of an ash-rich bed with little or no added sorbent. Data needed include the long-term operability of an ash-rich bed, physical and chemical properties, heat transfer coefficients and thermal diffusivity.

A critical R&D area for pressurized FBC is hot gas cleanup, which is required to protect turbine blades from corrosive/erosive attack. It is expected that low-rank coals, with highly alkaline ash, present unique hot gas cleanup problems.

Because of the unique chemistry of low-rank coal FBC, studies to identify if problems exist with materials of construction in these systems are needed. This would include in-bed and above-bed heat transfer surfaces, as well as air distributors and cyclones.

In the Priority II area for FBC, the recommended RD&D includes: 1) optimizing coal and sorbent feeding and distribution systems; 2) evaluating staged combustion systems for NO_x control; and 3) basic studies of temperature, gas, and solids distributions in fluidized beds. In all of these areas, the high reactivity and alkalinity characteristic of low-rank coals are expected to have significant effects.

Gasification

As shown in Table 18, the Priority I recommendations for RD&D on low-rank coal gasification cover a number of topics. The first project is an engineering/economic analysis of both existing and developing gasification processes to select and optimize process(es) for low-rank coals.

Table 18

Recommended RD&D For Low-Rank Coal Gasification

Priority I	Priority II
1. Process Adaptation for Low-Rank Coals	7. Effects of Pressure, Temperature, and Atmosphere on Evolution and Destruction of Volatile Matter
2. Wastewater Treatment for Process Effluent	8. Distribution Coefficients of Soluble Organics in Wastewater
3. Slag Behavior	9. Slurry Feeding of Low-Rank Coal to High-Pressure Gasifiers
4. Catalytic Effects in Low-Rank Coal Gasification	
5. Slag, Ash, and Residue Leaching Characteristics and Immobilization	
6. Minimizing Health Effects of Coal Liquids	

Wastewater treatment studies are needed to determine whether differences in coal properties or gasification processes affect the quality of the wastewater and the required treatment. This would include development of laboratory methods for screening novel treatment techniques, as well as demonstration of new methods at pilot scale.

Slag behavior is important in a number of high-temperature gasification processes. Critical areas include the effects of slag on refractory materials, as well as flow properties (viscosity) as a function of temperature. The alkali-rich mineral matter in low-rank coals causes different slag behavior compared to the iron- and silica-rich slags from eastern coals.

Studies of catalytic effects in low-rank coal gasification could lead to improved processes. This would include both the catalytic activity of inherent mineral matter in the coal, plus possible interactions between the inherent mineral matter and added catalysts.

Proper disposal of solid wastes from gasification plants requires that data be obtained on the leaching characteristics of slags, ashes, and wastewater treating residues. As required, techniques to immobilize leachable components should be developed.

Some coal liquids produced as gasification by-products are known to have carcinogenic or toxic effects. Characterization of these liquids from low-rank coal gasification should be pursued, as well as methods to insure that humans are not exposed.

In the Priority II area for gasification, some basic studies are recommended that could result in significant improvements in the technology. These include: 1) studies of the effects of pressure, temperature, and atmosphere on evolution and destruction of volatile matter from low-rank coals; 2) determination of distribution coefficients of soluble organics in gasifier wastewater streams; and 3) methods to increase the solids content of high-moisture coals in slurry feeding systems to high-pressure gasifiers.

Liquefaction

A large number of RD&D efforts are recommended in the area of low-rank coal liquefaction, reflecting both the many unresolved issues for liquefaction technology in general, and the unique problems associated with the properties of low-rank coal organic and mineral matter (see Table 19). In the Priority I group, the first project is an engineering/economic analysis of the best process configuration and operating conditions for low-rank coals. This would utilize results from many of the other recommended projects.

Table 19

Recommended RD&D For Low-Rank Coal Liquefaction

Priority I	Priority II
1. Process Adaptation for Low-Rank Coal	9. Bottoms Viscosity Studies
2. Recycle Solvent Studies	10. Effects of Staged or Continuous Removal of Gas
3. Syngas and Hydrogen Effectiveness Studies	11. Fate of Nitrogen
4. Calcium Carbonate Formation in Reactors	12. Effects of Staged Temperature Exposure
5. Coal Moisture Content and Drying	13. Disposable Catalyst Approaches
6. Coal Mineral Catalysis in Recycle	14. Corrosion of Stainless Steel by Coal Liquids
7. Bottoms Recycle	15. Erosion in Liquefaction Systems
8. Minimize Health Effects of Coal Liquids	16. Mathematical Reactor Model to Account for Mixing and Turbulence Effects

Recycle solvent studies are needed to determine the effects of solvent composition on the rate of hydrogenation of the coal, and on the yields and quality of products.

Building on earlier work using syngas ($CO + H_2$) for low-rank coal liquefaction, more detailed studies comparing the pros and cons of syngas versus hydrogen should be conducted.

Additional efforts are needed to determine the conditions under which calcium carbonate reactor solids are formed (i.e., effects of pressure) in liquefaction reactors.

More data are needed to understand the effects of coal moisture content (as fed to the reactor), and the effects of various methods of coal drying, on liquefaction yields and products.

An evaluation of catalytic effects of coal mineral matter in recycle liquefaction needs to be made with regard to the unique low-rank coal mineral forms.

Recycle of heavy bottoms material has been shown in limited testing to significantly improve yields of distillate products from lignite. Additional work on this concept should be done.

Health effects of coal liquids must be minimized in coal liquefaction processes, as in other conversion systems.

The Priority II RD&D recommendations for liquefaction include: 1) liquefaction bottoms viscosity studies (effects of coal and recycle solvent, process conditions, nitrogen, oxygen, and hydrogen content); 2) reactor configuration studies, such as staged removal of gas, staged temperatures, and effects of mixing and turbulence; 3) nitrogen fate determinations in both hydrogen and syngas liquefaction; 4) evaluations of disposable catalyst approaches for low-rank coals; and 5) corrosion and erosion in liquefaction systems.

Pyrolysis

In the Priority I area for coal pyrolysis, an evaluation of the feasibility of low-rank coal pyrolysis is recommended (see Table 20). This would include a review of data from earlier studies, selection of process configurations for analysis, and engineering/economic tradeoff studies of potential processes.

Studies to minimize health effects of coal liquids are required for coal pyrolysis processes as well.

Table 20

Recommended RD&D for Low-Rank Coal Pyrolysis

Priority I	Priority II
1. Feasibility of Pyrolysis for Selected Low-Rank Coals	3. Improved Analytical Methods for LRC Pyrolysis Studies
2. Minimizing Health Effects of Coal Liquids	4. Improved Pyrolysis Product Properties and Yields

In the Priority II area, the recommendations include: 1) development of improved analytical methods for pyrolysis studies, such as tests for char reactivity and pyrolytic oil characterization; and 2) investigation of methods to improve the chemical and physical properties of low-rank coal pyrolysis products as well as product yields, including maximization of BTX chemical feedstocks by flash hydropyrolysis.

Basic Research

As indicated on Table 21, there are many basic research studies that could enhance low-rank coal and peat technology significantly in the long run. In general, there is a basic need in all coal regions for detailed resource and coal seam characterization efforts. These would delineate the properties of specific reserves and resources in terms of geology, organic and mineral matter composition, variability, washability, and so on. There is also a need for establishing a suite of standard low-rank coal samples for reference and comparison purposes among coal research laboratories.

Petrographic characterization of low-rank coals must start with development of techniques and classification systems that apply to these coals. Then, systematic efforts can begin to relate petrographic data on low-rank coals to reactivity and yields in conversion systems.

Basic studies on the reactions between alkali elements and sulfur that occur in low-rank coals could have applicability in a number of areas, such as conventional combustion, fluidized bed combustion, wet and dry flue gas scrubbing.

Table 21

Recommended Basic Research for Low-Rank Coals and Peat

Priority I	Priority II
1. Resource and Coal Seam Characterization	11. Surface Characteristics of Low-Rank Coal and Peat Fines
2. Standard Low-Rank Coal Samples	12. Reactivity of Low-Rank Coals at 1200-1800°F in FBC
3. Petrographic Characterization	13. Impacts of Drying Methods on Rheological Properties of Low-Rank Coal-Water Mixtures
4. Reactions Between Alkali Materials and Sulfur	14. Kinetics and Reaction Mechanisms of Low-Rank Coals and their chars with H_2O, H_2, CO and CO_2
5. Surface Tension of Coal Slags	15. Fate of Oxygen and Nitrogen Components in Coal and Peat Conversion Systems
6. Composition and Characteristics of Ashes and Slag from Low-Rank Coals and Peat	16. Reactivity of Peat in Various Atmospheres
7. Analytical Characterization of Liquefaction Solvents	
8. Coal Liquefaction Catalysis	
9. Oxidative Depolymerization of Low-Rank Coal	
10. Toxicity of Coal Liquids	

Similarly, exploratory studies on surface tension of low-rank coal slags could lead to chemical or physical improvements in wet-bottom combustion or gasification systems.

In a similar vein, experimental and theoretical studies on the composition and characteristics of ashes and slags from low-rank coals and peat will improve our understanding of why they behave as they do and how their properties can be altered or used to advantage.

Standard analytical methods, which are consistent among laboratories, for characterizing solvents derived from low-rank coals would be very helpful to all of the researchers in coal liquefaction. A reproducible measure of solvent quality (hydrogen donor ability) would allow for better comparison among alternative processes.

A state-of-the-art review of low-rank coal liquefaction catalysis is needed to understand possible catalytic mechanisms and to formulate a catalyst development program.

Oxidative depolymerization processes should be explored as a concept for converting low-rank coals to liquid fuels or chemicals.

Toxicity studies on coal liquids are needed to provide basic data to help in devising means for minimizing adverse health effects.

In the Priority II area, a number of additional basic research projects are recommended for low-rank coals and peat. These include: 1) studying the surface characteristics of low-rank coal and peat fines with regard to the applicability of froth flotation beneficiation processes; 2) evaluating the reactivity of low-rank coals at 1200 - 1800°F in fluidized bed combustion; 3) studying the effects of various drying methods on the rheological properties of low-rank coal-water mixtures for slurry pipeline and high-pressure feeding application; 4) conducting comprehensive basic studies of the kinetics and mechanisms of reactions of low-rank coals and their chars with H_2O, H_2, CO and CO_2, including catalyst effects; 5) determining the fate of oxygen and nitrogen components in coal conversion systems (and their roles in product quality); and 6) studying the reactivity of peat in various gaseous and liquid atmospheres to support process development efforts.

1.7 PEAT

Peat is generally considered a "young" coal; it is partially decomposed plant matter that represents an early stage in the coalification process. Most peat deposits are less than 5000 years old, whereas coal deposits are generally 50-100 million years old.

Occurrence and Properties

Peat accumulates in water-saturated environments that inhibit active biological decomposition of the plant material and promote the retention of carbon and oxygen. As-received peat samples can contain up to 95 percent water. Even after drainage and solidification, peat can still retain over 70 percent of its weight as water. Air drying will reduce the water content to between 30 and 50 percent.

A typical composition of air-dried peat is shown on Table 22. At a 50 percent moisture level, the energy content of a pound of fuel peat is 4000-5000 Btu. The chemical composition of peat and its energy content can vary -- both between separate deposits and within the same deposit. Compared to lignite, peat contains about 60 percent more volatile matter and has about half as much fixed carbon (on a dry, mineral-matter-free basis).

Table 22

Typical Composition of Air-Dried Peat

Component	Percent By Weight
Ash	3.86
Carbon	26.39
Hydrogen	2.77
Oxygen	15.63
Nitrogen	1.23
Sulfur	.12
Moisture	50.00

Peat is typically lower in sulfur and higher in nitrogen than most coals. Sulfur concentration generally varies from negligible to less than one percent in dried peat. On the other hand, the ash content of peat can vary greatly as a result of the manner in which water is supplied to the peat bog. If water comes purely from precipitation, the ash will be very low. If the bog is fed by surface waters that periodically flood and carry heavy sediment loads, the ash will be high. Ash contents vary from 2 percent to 70 percent in reported assays of dry peat from a variety of sources.

The composition of peat ash, like the total percentage of ash, will depend on the history of the peat bog. Very little information is currently available on peat ash analyses.

United States peat resources are located primarily within three geographical regions: the Atlantic coast, the Great Lakes, and Alaska. Other regions also contain peat, as indicated on the resource map (Figure 15). Excluding permafrost areas, Alaska contains over half of the nation's peat (see Table 23). Within the contiguous U.S., the deposits in Minnesota, Michigan, Florida, and Wisconsin are the largest. Peat represents a very large potential energy resource for the U.S. (refer back to Figure 3 for a comparison with other fossil fuels).

In terms of total world resources of peat, the U.S.' 52.6 million acres are second only to the 228 million acres of peat in the Soviet Union. Finland, Canada, East and West Germany, Sweden, Poland, Ireland, Great Britain, Indonesia, and Norway all have significant peat resources. The Soviet Union accounts for 95 percent of the total world's annual peat harvest (primarily for burning in power plants). The U.S. accounts for 0.2 percent of the world's annual harvest -- all for agricultural purposes at this time.

Markets and Economics

Unlike the Soviet Union, Ireland, and Finland, the U.S. has not yet begun developing its peat resources for energy production. Experimental programs have been conducted for several decades, and commercial projects are now being considered.

The conventional technologies applicable to energy production from peat are quite similar to those for lignite once the peat has been extracted from the bog and dried to a level of 30-50 percent moisture. From this perspective, technical, market, and economic considerations would be very similar to those for lignite if "peat fuel" could be produced at a comparable cost (roughly $0.50-1.00 per million Btu in 1980).

The most critical differences between peat and lignite development occur in the extraction, dewatering, and peatland reclamation phases. If the environmental concerns about harvesting and reclamation can be resolved, and technology for cost-competitive production of peat fuel proves out, then peat would have very favorable market prospects compared to Fort Union Region lignite. Like lignite, peat would have to be utilized locally to produce steam, electricity, or synthetic gases or liquids. Unlike Fort Union Region lignite, large peat resources are located very close to major eastern and midwestern energy markets where high-cost oil and gas are currently used heavily. Low sulfur content might help to give peat a significant competitive advantage over eastern and midwestern bituminous coal in these areas.

Regulatory and Environmental Issues

Peatland development will impact the local aquatic and terrestrial plant and wildlife ecosystems. Of particular concern is the fragile ecology of peat bogs, which may in some locations be considered protected wetlands.

Figure 15

Geographic Regions Containing Significant Amounts of Peat Resources

Table 23

United States Peat Resources

State	Acres (Millions)	Quantity[a] (Billion Tons)
Alaska	27.0[b]	61.7
Minnesota	7.2	16.5
Michigan	4.5	10.3
Florida	3.0	6.9
Wisconsin	2.8	6.4
Louisiana	1.8	4.1
North Carolina	1.2	2.7
Maine	0.78	1.8
All Other States	4.3	9.9
Total	52.6	120.3

[a]Assumes peat dried to 35 weight percent moisture; deposits are 7 feet thick, and have a bulk density of 15 lbs per cubic foot.

[b]Excludes peat in permafrost areas.

The acidic qualities of peat bog waters may be toxic to downstream aquatic ecosystems unless sufficient dilution occurs. Such contamination could occur during initial bog drainage procedures prior to harvesting. Similar toxification could occur if peat dewatering pressates were released untreated into receiving waters. Preliminary studies have found concentrations of heavy metals such as mercury in peat.

Peatland harvesting will affect water flows through the bog. Vegetation removal, drainage, and peat extraction will affect discharge rates.

Large-scale peat development presents an opportunity to transform areas of unused land into productive agricultural areas or high-diversity wildlife refuges, with the option of retaining some of the original character of the peat bog areas.

Environmental and regulatory concerns associated with the use of peat in boilers or conversion plants are generally similar to those for coal. New source performance standards specific to peat processes do not exist, but can be expected to follow similar patterns to those for coal. Areas of possibly unique concern are the water- and solid waste-related impacts associated with the wet peat conversion processes.

Key Technology Issues

Harvesting

European harvesting methods for peat fuel include the sod peat and milled peat methods. Both approaches first require the construction of ditches to drain the bog. After draining, the bog surface can support machinery for tree removal, levelling, and finally, extraction of peat.

An alternative to these drained-bog methods -- hydraulic harvesting -- is currently being investigated by U.S. and Canadian agencies. In the proposed approach, peat would be harvested directly from the cleared bog as a peat-water slurry. This approach circumvents the problems associated with draining large acreages of wetlands.

Dewatering

Use of peat as a fuel requires that its moisture content be reduced to about 50 percent for combustion, and 35 percent for gasification processes. The drained-bog harvesting methods (sod and milled peat) can achieve these values, given suitable dry weather. Mechanical dewatering can reduce the moisture content to about 60-70 wt.%, using a filter press concept similar to ones used to dewater washed coal and pulp.

Wet carbonization is an alternative to mechanical or solar dewatering, and has been used commercially by the Soviets. In this process, high pressure steam heats a water-peat slurry to a point where the colloidal bonds break. The resulting peat sludge can then be mechanically pressed to remove much more water than if the incoming peat slurry was filtered by the presses alone.

Wet Conversion Processes

Wet carbonization, described above, is one of a family of biomass energy conversion processes that could use hydraulically harvested peat directly in slurry form. Other processes of this type are wet oxidation and biomethanation (anaerobic digestion). Both of these processes are commercially used with other fuel sources -- for example, in treating sewage waters or sludges. Some experimentation and small-scale process development work has been done on peat.

Solvent extraction is another possible means of dewatering peat, while producing a bitumen product of high energy content. In this process, a peat-water slurry is heated under pressure and mixed with an organic solvent. Water is extracted from the peat by the organic phase; hydrogen and CO_2 are released.

Combustion

Peat has been used successfully in various types of furnaces in Europe. The choice of sod peat, milled peat, peat briquettes, or pellets depends upon the furnace design. The established trends in Europe favor sod peat for small stoker-fired boilers (5-20 Mw), and milled peat for pulverized boilers (20-40 Mw). Conversion of boilers now firing coal to use with peat (or peat/coal blends) may encounter problems with ash fouling, lower ash softening temperatures, and incomplete combustion. CO_2 and NO_x emissions from peat will generally be higher than from lignite combustion. Cyclone furnaces appear to be well suited for peat combustion. Fluidized bed combustion is another potential firing method.

Gasification

Tests conducted at the Institute of Gas Technology (IGT) show that peat has a higher reactivity for gasification than lignite, and more carbon is converted directly to hydrocarbon gases in a short-residence time hydrogasifier than is converted by gasifying coal. Therefore, less severe operating conditions are adequate for converting peat to synthetic natural gas (SNG). Also, peat hydrogasification gives a high yield of hydrocarbon gas at relatively low hydrogen partial pressures.

RD&D Recommendations

The Department of Energy is providing funding for peat RD&D activities in the following areas: resource characterization; harvesting; dewatering; gasification; environmental; and socioeconomic evaluations. Of these areas, the primary support has been directed towards developing a large-scale peat gasification technology. The Minnesota Department of Natural Resources has also been a major supporter of peat RD&D, including environmental, socioeconomic, technological and reclamation studies.

Recommended RD&D projects for peat are shown in Table 24. In the priority I area, environmental impact studies of large-scale peat harvesting and utilization operations are needed. Harvesting techniques need development for application to U.S. peatlands. Dewatering techniques should be studied.

Conversion processes to derive energy from peat that deserve high-priority attention are the wet peat conversion processes, combustion processes, and gasification.

Peat resources in the U.S. need to be characterized in detail to provide data for harvesting and environmental impact studies.

Effluents from peat processing, across the board, need to be characterized, and control systems need to be adapted to any special problems.

Health and safety aspects of peat harvesting and utilization need to be studied to determine if any special problems exist.

Priority II recommendations for peat RD&D include: 1) development of crushing and grinding techniques; 2) briquetting and pelletizing of peat fuel; 3) handling and storage of dried peat, to prevent dust or spontaneous heating problems; 4) solid waste disposal from peat utilization; and 5) development of liquefaction processes for peat, including direct hydrogenation and oxidative depolymerization.

Table 24

Recommended RD&D for Peat

Priority I	Priority II
1. Environmental Impacts of Large-Scale Peat Utilization	10. Peat Comminution Techniques
2. Harvesting Techniques: Hydraulic, Milled, Sod.	11. Briquetting and Pelletizing of Peat Fuel
3. Peat Dewatering Techniques	12. Handling and Storage of Dried Peat
4. Wet Peat Conversion Processes: - Wet Oxidation, Wet Carbonization, Anaerobic Digestion, Aqueous Phase Liquefaction.	13. Solid Waste Disposal from Peat Utilization
5. Peat Combustion Techniques: - Stoker, Pulverized Peat, Fluidized Bed Combustion.	14. Liquefaction of Peat by Direct Hydrogenation and by Oxidative Depolymerization
6. Gasification of Peat: - High-Btu Gas, Medium-Btu Gas, Low-Btu Gas.	
7. Peat Resource Characterization	
8. Characterization and Control of Effluents from Peat Processing: - Heavy Metals, SO_2, NO_x, Particulate, Organics.	
9. Health and Safety Aspects of Peat Harvesting and Utilization	