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MASTER
LOW-RANK COAL STUDY
NATIONAL NEEDS FOR RESOURCE DEVELOPMENT
RESOURCE CHARACTERIZATION

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LOW-RANK COAL STUDY
National Needs for Resource Development

Volume 2 - Resource Characterization

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Energy Resources Co., Inc.
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PREFACE

This is volume two 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	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
2. Resource Characterization (8%) 2.1 Occurrence 2.2 Properties/Characteristics 2.3 Classification	6. Market Analysis (6%) 6.1 Existing Markets and Penetrations 6.2 Potential Markets
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	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
4. Regulatory Requirements/Constraints (4%) 4.1 Definition 4.2 Roadmap 4.3 Effects on Development	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

<u>Participant</u>	<u>Affiliation</u>
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

Comprehensive data are presented on the quantity, quality, and distribution of low-rank coal (subbituminous and lignite) deposits in the United States. The major lignite-bearing areas are the Fort Union Region and the Gulf Lignite Region, with the predominant strippable reserves being in the states of North Dakota, Montana, and Texas. The largest subbituminous coal deposits are in the Powder River Region of Montana and Wyoming, the San Juan Basin of New Mexico, and in Northern Alaska.

For each of the low-rank coal-bearing regions, descriptions are provided of the geology; strippable reserves; active and planned mines; classification of identified resources by depth, seam thickness, sulfur content, and ash content; overburden characteristics; aquifers; and coal properties and characteristics. Low-rank coals are distinguished from bituminous coals by unique chemical and physical properties that affect their behavior in extraction, utilization, or conversion processes. The most characteristic properties of the organic fraction of low-rank coals are the high inherent moisture and oxygen contents, and the correspondingly low heating value. Mineral matter (ash) contents and compositions of all coals are highly variable; however, low-rank coals tend to have a higher proportion of the alkali components CaO , MgO , and Na_2O . About 90 percent of the reserve base of U.S. low-rank coal has less than one percent sulfur. Water resources in the major low-rank coal-bearing regions tend to have highly seasonal availabilities. Some areas appear to have ample water resources to support major new coal projects; in other areas such as Texas, water supplies may be a constraining factor on development.

2. RESOURCE CHARACTERIZATION

2.1 INTRODUCTION AND SUMMARY

The purpose of this volume is threefold: 1) to define the occurrence of low-rank coals in the United States and summarize resource quantities and geologic characteristics of each coal-bearing region; 2) to present available data on the properties and characteristics that determine the suitability of these coals to various end uses; and 3) to classify the regional low-rank coal resources according to these properties and characteristics. In addition, a summary of the water resources in the major low-rank coal regions is presented because of the strong dependence of western coal development on water supply.

Low-rank coals in this study are defined as lignite and subbituminous coals, using the U.S. ASTM classification system shown in Table 2.1.1 and illustrated in Figure 2.1.1. All low-rank coal deposits in the 50 United States are included within the scope of the study. As Table 2.1.1 indicates, the heating value of the coal on a moist, mineral-matter-free basis is the criterion used to distinguish the low ranks of coal. However, the distinction between high-volatile C bituminous and subbituminous A coals is determined by the agglomerating character of the coal.

2.1.1 Occurrence of U.S. Low-Rank Coals

Low-rank coal deposits in the U.S. occur in vast quantities throughout the Northern Great Plains, the Rocky Mountain states, the Gulf Coast states, and scattered fields in Alaska. Figure 2.1.2 shows the boundaries of all major lignite and subbituminous coal regions of the United States.

Lignite

Extensive lignite deposits are found in two different parts of the country. The Fort Union Region is called the largest coal basin on earth and underlies portions of Montana, North Dakota, and South Dakota. Over 465 billion tons of identified lignite resources (to 3000 feet) are reported for this area. The Gulf Coast Region covers a six-state area from Texas to Georgia. Although greater in square mileage than the Fort Union Region, the Gulf Coast Region contains thinner, relatively impure lignite seams and an estimated regional identified resource of 68 billion tons. A third large lignite region is the Denver Basin, Colorado, which contains about 10 billions of lignite.

Table 2.1.2 shows the estimate tonnages of lignite classified as "identified resources" and "strippable reserve base" in each of these regions. In Table 2.1.3, these identified resources are classified according to depth, thickness, sulfur content, and ash content wherever the data are available. Figure 2.1.3 presents a summary classification of the total strippable reserve base of lignite according to seam thickness, sulfur content, and ash content.

Figure 2.1.1

Comparison on Moist, Mineral-Matter-Free Basis of Heat Values And Proximate Analyses of Coal of Different Ranks

Source: Reference 1

Figure 2.1.2

Low-Rank Coal Regions of the United States

Table 2.1.1

Classification of Coals by Rank

[This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of the high-volatile bituminous and subbituminous ranks. All these coals either contain less than 48 percent dry, mineral-matter-free fixed carbon, or have more than 15,500 British thermal units per pound, calculated on the moist, mineral-matter-free basis. Modified from American Society for Testing and Materials (1974)]

Class	Group	Fixed carbon limits, in percent (Dry, mineral-matter- free basis)		Volatile matter limits, in percent (Dry, mineral-matter- free basis)		Calorific value limits, in Btu per pound (Moist, mineral- matter-free basis) ¹		Agglomerating character
		Equal or greater than	Less than	Equal or greater than	Less than	Equal or greater than	Less than	
I. Anthracitic.....	1. Meta-anthracite.....	98			2			Nonagglomerating. ²
	2. Anthracite.....	92	98	2	8			
	3. Semianthracite.....	86	92	8	14			
II. Bituminous.....	1. Low-volatile bituminous coal.....	78	86	14	22			Commonly, agglom- erating. ⁴
	2. Medium-volatile bituminous coal.....	69	78	22	31			
	3. High-volatile A bituminous coal.....		69	31		\$ 14,000		
	4. High-volatile B bituminous coal.....					\$ 13,000	14,000	
	5. High-volatile C bituminous coal.....					11,500	13,000	
III. Subbituminous.....	1. Subbituminous A coal.....					10,500	11,500	Nonagglomerating.
	2. Subbituminous B coal.....					9,500	10,500	
	3. Subbituminous C coal.....					8,300	9,500	
IV. Lignitic.....	1. Lignite A.....					6,300	8,300	
	2. Lignite B.....						6,300	

¹ Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

² If agglomerating, classify in low-volatile group of the bituminous class.

³ Coals having 69 percent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.

⁴ It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and there are notable exceptions in the high-volatile C bituminous group.

Source: Reference 1

Table 2.1.2

U.S. Lignite Reserves and Resources by Region
(Billion Short Tons)

Region	Strippable Reserve Base ^a	Ref.	Identified Resources ^b	Ref.
Fort Union Region	26.3		465.3	
North Dakota	10.1	2	350.6	1
Montana	15.8	2	112.5	1
South Dakota	0.4	2	2.2	1
Gulf Lignite Region	11.6		68.3	
Texas	7.9	10	52.2	10
Alabama	1.1	2	2.0	1
Arkansas	2.0	11	13.5	11
Louisiana	0.6	12	0.6	12
Mississippi	N/A		N/A	
Denver Region (Colorado)	2.9	2	10.0	8
Others (WA,CA,ID,MS,NV)	--		0.2	1
Total	40.8		543.8	

Notes:

^aCriteria defining "strippable reserve base" vary by state. A few examples:

State	Minimum Seam Thickness (ft.)	Maximum Overburden Thickness (ft.)
Montana	5	125
Wyoming	5	120
Wyoming	3	150
New Mexico	5	250
Texas	4	200

^bIdentified resources included Demonstrated (measured and indicated) and Inferred resources 2-1/2 feet or more thick to an overburden depth of 3000 feet.

Classification of U.S. Lignite Identified Resources,^a By Region
(billion short tons)

A. Classification by Depth

Depth of Coal Seam (feet)

Region	0-1000	1000-2000	2000-3000	Unknown ^b	Total	References
Fort Union	367.7	--	--	97.6	465.3	1,14
Gulf Lignite	43.0	25.3	--	--	68.3	10,11,12,16
Denver	10.0	--	--	--	10.0	8
Others (WA,CA,ID,MS,NV)	--	--	--	0.2	0.2	1
Totals	420.7	25.3	--	97.8	543.8	
% of Total Resource	77.3	4.7	--	18.0	100.0	

B. Classification by Seam Thickness

Seam Thickness (feet)

Region	0-10	10-20	> 20	Unknown ^b	Total	References
Fort Union	6.7	13.0	11.2	434.4	465.3	1,4,14
Gulf Lignite	23.7	2.6	0.2	41.8	68.3	11,14,17
Denver	--	--	--	10.0	10.0	8
Others (WA,CA,ID,MS,NV)	--	--	--	0.2	0.2	1
Totals	30.4	15.6	11.4	486.4	543.8	
% of Total Resource	5.6	2.9	2.1	89.4	100.0	

Classification of U.S. Lignite Identified Resources,^a by Region
(billion short tons)

C. Classification by Sulfur Content

Region	Sulfur Content (weight percent, "as-received" basis)				Total	References
	0-1	1-3	3	Unknown ^b		
Fort Union	465.3	--	--	--	465.3	1,4,14
Gulf Lignite	64.3	2.0	2.0	--	68.3	11,17,18
Denver	10.0	--	--	--	10.0	8,14
Others (WA,CA,ID, MS,NV)	--	--	--	0.2	0.2	1
Totals	539.6	2.0	2.0	0.2	543.8	
% of Total Resource	99.2	0.4	0.4	0.0	100.0	

D. Classification by Ash Content

Region	Ash Content (weight percent, "as-received" basis)				Total	References
	0-5	5-10	> 10	Unknown ^b		
Fort Union	--	465.3	--	--	465.3	1,4,14
Gulf Lignite	--	20.0	48.3	--	68.3	11,17,18
Denver	--	--	--	10.0	10.0	8
Others (WA,CA,ID, MS,NV)	--	--	--	0.2	0.2	1
Totals	--	485.3	48.3	10.2	543.8	
% of Total Resource	--	89.2	8.9	1.9	100.0	

Notes:

^aIdentified resources include Demonstrated (measured and indicated) and Inferred resources 2-1/2 feet or more thick to an overburden depth of 3000 feet.

^b"Unknown" refers to Identified resources not classified into the depth, thickness, sulfur, or ash ranges shown.

Figure 2.1.3

Classification of U.S. Lignite Strippable Reserve Base

Sources: References 14,16,17,18,20,21

Subbituminous Coal

Nine major subbituminous coal regions are identified on Figure 2.1.2. Excluding the three Alaska fields, nearly all of the U.S. subbituminous coal resources lie in basins throughout the Rocky Mountain states, from northern Montana to northern New Mexico. There are over 360 billion tons of identified subbituminous coal resources in the Rocky Mountain regions. The largest of these regions are the Powder River Basin of Montana and Wyoming, and the San Juan Region of New Mexico.

Table 2.1.4 shows the estimated tonnages of subbituminous coal classified as "identified resources" and "strippable reserve base" in each region. Table 2.1.5 classifies these resources, where possible, into depth, thickness, sulfur and ash content categories.^a Figure 2.1.4 presents a summary classification of the total strippable reserve base of subbituminous coal according to seam thickness, sulfur content, and ash content.

To summarize the occurrence of U.S. low-rank coals on a state-by-state basis, Table 2.1.6 shows reserve base and resource estimates for both subbituminous coal and lignite.

The preceding tables indicate that roughly 12 percent of the total U.S. subbituminous coal resource and 7 percent of the lignite is considered surface minable. About 37 percent and 77 percent of the respective ranks lie under less than 1000 feet of overburden. Low-rank coals generally occur in thicker seams than eastern bituminous coals. For example, about one-half of the total low-rank coal resource lies in beds 10 feet or more thick, not including tonnages in the "unknown" categories. Certain coal beds in Wyoming and Montana reach thicknesses exceeding 200 feet.

Almost all the subbituminous coal and lignite resources are low in sulfur content, below one percent by weight on an "as-received" basis. Ash contents are moderate to high: About 86 percent of the subbituminous coal has an ash content greater than 5 percent, and 45 percent of that total contains more than 10 percent ash by weight. Lignite sample data indicate that over 89 percent of the total tonnage contains 5 to 10 percent ash.

2.1.2 Properties of Low-Rank Coals

Some important properties of the organic and inorganic fractions of U.S. coals are summarized in Tables 2.1.7 and 2.1.8, respectively. The data on organic content are based on samples of essentially pure vitrinite,

^aColorado estimates for the North Park and Green River Regions include coals to a depth of 6000 feet; no information is available that delineates tonnages within intermediate depth ranges. Therefore, Colorado's coal resources in these two regions are not classified by depth. It is assumed that the tonnage estimates for seam thickness, sulfur, and ash content are representative of the coals to 6000 feet.

U.S. Subbituminous Coal Reserves and Resources by Region
(Billion Short Tons)

Region	Strippable Reserve Base ^a	Ref.	Identified Resources ^b	Ref.
Powder River Basin	57.5		238.1	
Montana	34.5	4	127.9	3
Wyoming	23.0	5	110.2	5
Northern Alaska	N/A ^e		100.9	6
San Juan Basin Region (New Mexico) ^c	5.5	9	50.64	1
North Park Region (Colorado) ^d	0.12	13	28.7	7
Green River Region	2.9		25.3	
Colorado ^c	1.0	13	19.3	7
Wyoming	1.9	5	6.0	5
Denver Region (Colorado)	N/A ^e		20.0	8
Nenana Field (Alaska)	0.46 ^f	15	6.94	6
Cook Inlet-Susitna Field (Alaska)			2.39	6
Big Horn Basin (Wyoming)	0.02	5	0.56	5
Others:				
Montana			48.9	1
Colorado			11.9	7
Wyoming	1.4	5	6.82	5
Alaska			0.47	6
Washington			4.18	1
Oregon			0.28	1
Calif. & Idaho			0.03	1
Total	67.9		546.1	

U.S. Subbituminous Coal Reserves and Resources by Region
(Billion Short Tons)

Notes:

^aCriteria defining "strippable reserve base" vary by state. A few examples:

State	Minimum Seam Thickness (ft.)	Maximum Overburden Thickness (ft.)
Montana	5	125
Wyoming	5	120
Wyoming	3	150
New Mexico	5	250
Texas	4	200

^bIdentified resources included Demonstrated (measured and indicated) and Inferred resources 2-1/2 feet or more thick to an overburden depth of 3000 feet.

^cResource and strippable reserve estimates include the entire state of New Mexico, not just the San Juan Region.

^dColorado resource estimates for Green River and North Park Regions include coals to 6000 feet. "Strippable" estimates are given as resources, not reserves.

^eNo reliable estimates of the strippable subbituminous reserve base are available.

^fStrippable tonnage represents recoverable reserves, not the reserve base.

Classification of U.S. Subbituminous Identified Resources,^a By Region
(billion short tons)

A. Classification by Depth

Region	Depth of Coal Seam (feet)				Total	References
	0-1000	1000-2000	2000-3000	Unknown ^b		
Powder River	138.2	11.5	1.0	87.4	238.1	4,5,14
Northern Alaska	18.1	4.4	0.4	78.0	100.9	6
San Juan Basin ^{c,e}	21.0	14.8	14.8	--	50.6	1,14
North Park ^d	0.12	--	--	28.6	28.7	7
Green River ^{c,d}	4.9	1.2	0.9	18.3	25.3	5,7,14
Denver ^b	12.3	7.3	0.4	--	20.0	8,14
Nenana Field	4.79	1.45	0.7	--	6.94	6
Cook Inlet-						
Susitna Field	2.39	--	--	--	2.39	6
Big Horn Basin	0.38	0.13	0.05	--	0.56	5,14
Others (MT,CO,WY, AK,WA,OR,CA,ID)	1.40	--	--	71.18	72.58	1,5,6,7
Totals	203.6	40.8	18.2	283.5	546.1	
% of Total Resource	37.3	7.5	3.3	51.9	100.0	

B. Classification by Seam Thickness

Region	Seam Thickness (feet)				Total	References
	2.5-5	5-10	>10	Unknown ^b		
Powder River	13.5	69.7	82.9	72.0	238.1	4,5,14
Northern Alaska	15.5	31.9	53.5	--	100.9	6
San Juan Basin ^{c,e}	3.4	2.8	1.0	43.4	50.6	1,14
North Park ^d	0.04	2.5	26.2	--	28.7	7,13
Green River ^{c,d}	11.2	13.6	0.5	--	25.3	5,7,14
Denver ^b	9.8	10.0	0.2	--	20.0	8,14
Nenana Field	0.10	0.99	5.85	--	6.94	6
Cook Inlet-						
Susitna Field	0.06	0.10	2.23	--	2.39	6
Big Horn Basin ^c	0.41	0.13	0.02	--	0.56	5,14
Others (MT,CO,WY,AK, WA,OR,CA,ID)	--	--	--	72.58	72.58	1,5,6,7
Totals	54.0	131.7	172.4	188.0	546.1	
% of Total Resource	9.9	24.1	31.6	34.4	100.0	

Classification of U.S. Subbituminous Identified Resources,^a By Region
(billion short tons)

C. Classification by Sulfur Content

Sulfur Content
(weight percent, "as-received" basis)

Region	0-1	1-3	3-10	Unknown ^b	Total	References
Powder River	134.7	8.7	--	94.7	238.1	4,5,14
Northern Alaska	100.9	--	--	--	100.9	6
San Juan Basine	50.6	--	--	--	50.6	14
North Park ^d	28.7	--	--	--	28.7	13,14
Green River ^d	25.3	--	--	--	25.3	5,14
Denver	20.0	--	--	--	20.0	2,14
Nenana Field	6.94	--	--	--	6.94	6
Cook Inlet-						
Susitna Field	2.39	--	--	--	2.39	6
Big Horn Basin ^c	0.54	0.02	--	--	0.56	5,14
Others (MT,CO,WY,AK, WA,OR,CA,ID)	--	--	--	72.58	72.58	1,5,6,7
Totals	370.1	8.7	--	167.3	546.1	
% of Total Resource	67.8	1.6	--	30.6	100.0	

D. Classification by Ash Content

Ash Content
(weight percent, "as-received" basis)

Region	0-5	5-10	>10	Unknown ^b	Total	References
Powder River	31.9	106.5	22.2	77.5	238.1	14
Northern Alaska	2.3	--	53.9	44.7	100.9	6
San Juan Basine	--	--	50.6	--	50.6	14
North Park ^{c,d}	5.2	15.7	7.8	--	28.7	13,14
Green River ^{c,d}	8.4	14.5	2.4	--	25.3	5,7,14
Denver	--	20.0	--	--	20.0	8
Nenana Field	--	6.94	--	--	6.94	6
Cook Inlet-						
Susitna Field	--	--	2.39	--	2.39	6
Big Horn Basin	0.15	0.22	0.12	0.07	0.56	14
Others (MT,CO,WY,AK, WA,OR,CA,ID)	--	--	--	72.58	72.58	1,5,6,7
Totals	48.0	163.9	139.4	194.8	546.1	
% of Total Resource	8.8	30.0	25.5	35.7	100.0	

Classification of U.S. Subbituminous Identified Resources,^a By Region
(billion short tons)

Notes:

^aIdentified resources include Demonstrated (measured and indicated) and Inferred resources 2-1/2 feet or more thick to an overburden depth of 3000 feet.

^b"Unknown" refers to Identified resources not classified into the depth, thickness, sulfur, or ash ranges shown.

^cTonnage estimates for the various ranges have been taken from Reference 14 and proportionally adjusted to match regional resource totals from other sources.

^dColorado resource estimates for Green River and North Park Regions include coals to 6000 feet.

^eResource estimates include all subbituminous coal deposits in New Mexico, not just the San Juan Basin.

Figure 2.1.4

Classification of U.S. Subbituminous Coal Strippable Reserve Base

Sources: References 5,14,29

Table 2.1.6

U.S. Low-Rank Coal Reserves and Resources by State
(Billion Short Tons)

State	Subbituminous Coal				Lignite			
	Strippable Reserve Base ^a	Ref.	Identified Resources ^b	Ref.	Strippable Reserve Base ^a	Ref.	Identified Resources ^b	Ref.
North Dakota	-		-		10.1	2	350.6	1
Montana	34.5	4	176.8	1	15.8	2	112.5	1
Wyoming	26.3	5	123.6	5	-		-	
Alaska	0.46 ^c	6	110.7	6	-		-	
Colorado ^d	1.1	13	79.9	7	2.9	2	10.0	8
New Mexico	5.5 ^e	9	50.6	1	-		-	
Texas	-		-		7.9	10	52.2	10
South Dakota	-		-		0.4	2	2.2	1
Alabama	-		-		1.1	2	2.0	1
Arkansas	-		-		2.0	11	13.5	11
Louisiana	-		-		0.6	12	0.6	12
Washington	-		4.18	1	-		0.12	1
Oregon	-		0.28	1	-		-	
Calif., Idaho	-		0.03	1	-		-	
Others ^f	-		-		-		0.5	1
Total	67.9		546.1		40.8		543.8	

Notes:

^aCriteria defining "strippable reserve base" vary by state. A few examples:

State	Minimum Seam Thickness (ft)	Maximum Overburden Thickness (ft)
Montana	5	125
Wyoming	5	120
Wyoming	3	150
New Mexico	5	250
Texas	4	200

^bIdentified resources include Demonstrated (measured and indicated) and Inferred resources 2-1/2 feet or more thick to an overburden depth of 3000 feet.

^c"Strippable" tonnage represents "recoverable reserves," not the "reserve base."

^dColorado resource estimates for Green River and North Park regions include coals to 6000 feet. "Strippable" estimates are given as "resources," not "reserves."

^eTonnage represents "resources," not "reserves."

^fCalifornia, Idaho, Mississippi, Nevada.

Table 2.1.7

Selected Properties of Vitrinites in U.S. Coals of Different Ranks

	<u>Lignite</u>	<u>Subbituminous</u>	<u>Bituminous</u>	<u>Anthracite</u>
Moisture capacity, Wt.%	40	25	10	<5
Carbon, Wt.% DMMF*	69	74.6	83	94
Hydrogen, Wt.% DMMF	5	5.1	5.5	3
Oxygen, Wt.% DMMF	24	18.5	10	2.5
Vol. Mat., Wt.% DMMF	53	48	38	6
Aromatic C/Total C	0.7	0.78	0.84	1
Density (He,g/cc)	1.43	1.39	1.3	1.5
Btu/lb, DMMF	11,600	12,700	14,700	15,200

*Dry, mineral-matter-free basis.

Source: Reference 19

which is the predominant maceral in U.S. coals.¹⁹ All of the properties listed have an impact on the coal's behavior in extraction, utilization, or conversion processes; the most characteristic properties are the high inherent-moisture and oxygen contents of low-rank coal macerals, and their correspondingly low heating values.

The data on mineral matter content in Table 2.1.8 are reported as ash, which is the residue left after complete incineration of the combustible constituents using the standard ashing procedure. The ash compounds are reported as oxides; however, they may actually occur as a mixture of silicates, oxides, and sulfates. Due to the wide variations in coal ash composition, the data are presented as ranges. A notable trend is the higher proportion of the alkali components, CaO, MgO, and Na₂O in low-rank coals. The acidic components SiO₂ and Al₂O₃ are more prominent in the higher rank coals. Ash analyses of low-rank coals indicate high proportions of SO₃, reflecting the high retention of coal sulfur by the alkaline ash during the ashing process.

Some of the unique mineral matter properties of U.S. low-rank coals can have wide-ranging effects such as: 1) high fouling rates on boiler tubes, primarily linked to high sodium contents; 2) high fly ash resistivity, thus relatively poor ESP performance; 3) unique opportunities for sulfur removal, such as ash-alkali wet scrubbing, dry scrubbing, and ash recirculation in fluid bed combustors; and 4) catalytic effects on certain reactions such as coal hydrogenation (liquefaction).

One additional characteristic of U.S. low-rank coal is its typically low sulfur content, as shown in Table 2.1.9. When these percentages are converted from a dry to an as-mined basis, about 90 percent of the reserve base of U.S. low-rank coal is shown to have less than one percent sulfur.

Table 2.1.8

Limits and Averages of Ash Composition For Various U.S. Coals

	Anthracite				Bituminous				Subbituminous				Lignite			
	Low	High	Average	No. Of Samples	Low	High	Average	No. Of Samples	Low	High	Average	No. Of Samples	Low	High	Average	No. Of Samples
Ash, percent of MF coal	10.2	25.8	17.4		4.0	18.5	8.6		--	--	--		--	--	9.9	
Analysis, percent of Ash								135								444
SiO ₂	47.7	67.7	55.2	29	9.3	69.6	48.2		15.2	52.8	38.2	124	6.3	39.4	19.7	
Al ₂ O ₃	24.7	43.5	34.0	29	5.6	41.7	24.9		9.0	27.6	20.6	124	4.2	26.1	11.1	
Fe ₂ O ₃	2.1	10.2	6.3	29	3.8	84.2	14.9		3.3	31.5	9.8	124	0.9	34.3	9.1	
TiO ₂	1.0	1.8	1.3	9	0.1	2.5	1.10		0.1	2.1	0.8	124	0.0	0.8	0.4	
P ₂ O ₅	0.1	0.1	0.1	6	--	--	--		0.0	2.2	0.4	124	0.0	1.1	0.3	
CaO	0.2	3.7	1.0	29	0.2	36.7	6.6		10.5	52.6	19.5	124	12.4	52.0	24.6	
MgO	0.0	1.2	0.6	29	0.4	6.3	1.7		1.4	9.0	5.4	124	2.8	13.6	6.9	
Na ₂ O	--	--	--		0.0	7.6	1.2		0.1	10.4	2.0	124	0.1	27.8	6.5	
K ₂ O	--	--	--		0.1	6.0	1.5		0.0	1.1	0.3	124	0.0	1.3	0.4	
SO ₃	0.0	2.0	0.7	27	--	--	--		12.9	20.5	15.9	20	8.3	32.0	19.5	
AST, °F	2350	3000	2817	23	1940	2930	2355		1940	2730	2189	124	1970	2730	2290	

Sources: Anthracite: Reference 28
 Bituminous: Reference 27
 Subbituminous: Reference 26
 Lignite: Reference 20

Table 2.1.9

Distribution of U.S. Low-Rank Coal Reserve Base by Sulfur Content

Sulfur Content, % (Dry Basis)	<u>1.0 or Less</u>	<u>1.1-1.8</u>	<u>1.8-3.0</u>	<u>Over 3.0</u>	<u>Total</u>
Subbituminous	89.5	8.1	2.0	0.4	100.0
Lignite	40.7	33.4	23.4	2.5	100.0

Source: Reference 21

2.1.3 Water Resources

Coal extraction and utilization projects in the western low-rank coal regions are critically dependent on the availability of sufficient water resources. Surface water availability throughout much of the West is characterized by high stream flows and groundwater recharge in late spring as the upstream mountainous snowpack melts, followed by greatly reduced flows from late summer through winter. As a result numerous reservoirs have been constructed to retain much of the season runoff for use during the remainder of the year. Most of this impounded water is heavily committed for agricultural purposes. For example, 80 percent of the Upper Missouri Basin waters and 70 percent of the Upper Colorado Basin waters are presently allocated to agricultural uses²² (these percentages include groundwater resources as well). In Texas, agricultural demands have already exceeded the renewable supply of surface water in the High Plains and Winter Garden areas of the Nueces River Basin. Existing water rights already claim much of the available surface water in Texas, which forces new water-intensive projects either to develop new water resources or, more likely to negotiate for the transfer of existing water rights.²³

Groundwater resources in the West are vast. Estimates by the U.S. Department of the Interior indicate that the Upper Missouri River Basin generally contains sufficient groundwater resources to meet future energy-use needs. However, in particular areas such as the Powder River Region and the Yellowstone River Basin, available groundwater supplies are located at considerable distances from coal mining and processing plants.²⁴

Aquifers in the Upper Colorado River Region contain an estimated 38 million acre-feet of water within 200 feet of the surface, and recharge at a rate of about 4 million acre-feet annually. The characteristic low permeability of these aquifers, however, restricts the areas in which adequate well flow rates can be obtained to only about 5 percent of the area containing groundwater reserves.²²

Texas groundwater extraction increases as coastal cities continue to expand. Some aquifers that now supply major areas of Texas with fresh water are associated with saline-water aquifers which either underlie, overlie, or occur downdip of the fresh-water aquifers. When such fresh-water aquifers are heavily pumped, saline water is drawn toward pumping wells resulting in the deterioration of water quality and loss of storage volume for potential recharge with fresh water.²⁵

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2.2 OCCURRENCE - REGIONAL ANALYSIS

The following sections present highly summarized data on the quantity, quality, and distribution of low-rank coals in each of the major low-rank coal-bearing regions in the U.S. Each regional discussion is organized into six topics: 1) brief geologic description of the coal-bearing rocks; 2) data on coal reserves and mines; 3) data on identified coal resources, including a classification of those resources by depth, thickness, sulfur, and ash contents; 4) overburden characteristics; 5) aquifer (groundwater) characteristics; and 6) summaries of coal and ash analyses. More detailed information on any of these topics is available from the references cited at the end of each section.

Another source of detailed information concerning coal resources and the entire coal industry is a computer data base accessible through the Fuels Data Division of the U.S. Department of Energy. Information categories include: Comprehensive data on underground and surface mining operations, production; equipment, waste disposal, and labor statistics; analytical data on resource estimates and analyses obtained from the U.S. Bureau of Mines; coking plant data; and distribution and retailing information. Inquiries may be addressed to:

Charles Heath
Director, Office of Coal and Electric Power Statistics
Energy Information Administration
1000 Independence Ave. SW, Room GB208
Washington, D.C. 20585

Certain standardized criteria are used to delineate U.S. low-rank coal resources; although these criteria are easily obtainable and readily understood, many references incorrectly apply "resource" and "reserve" nomenclature to in-place tonnages. Therefore, the coal resource classification system adopted by the U.S. Bureau of Mines and the U.S. Geological Survey is briefly reiterated here to clarify the nomenclature used throughout this chapter.

Resource estimates for the various coal classes are arbitrarily based upon three criteria: 1) thickness, rank, and quality of the coal bed, 2) depth of the coal bed, and 3) proximity of the coal resource data upon which the estimate was based. These criteria apply only to those coal bodies that are or will be economically extractable by underground, surface, and/or in situ methods. Subbituminous and lignite coals thinner than 30 inches and deeper than 6000 feet are excluded. Also, coal containing more than 33 percent ash is excluded from resource and reserve estimates.¹

Listed below is a glossary of terms used in this report to categorize resource and reserve estimates. Data from some state publications do not follow these guidelines and hence complicate attempts to characterize coal quantities. Fortunately, many of these problems are overcome by careful cross-comparison of resource estimates and properties between state and other documents. Discrepancies that remain are noted and explained in the text for that region.

Wherever possible, coal resource estimates are divided into three categories according to the relative abundance and reliability of data used in preparing the estimates. These categories are termed "measured," "indicated," and "inferred," and are applicable to both the Reserve and Resource components.¹

Measured - Resources are computed from dimensions revealed in outcrops, trenches, mine workings, and drill holes. The points of observation and measurement are so closely spaced and the thickness and extent of coals are so well defined that the tonnage is judged to be accurate within 20 percent of true tonnage. Although the spacing of the points of observation necessary to demonstrate continuity of the coal differs from region to region according to the character of the coal beds, the points of observation are no greater than 1/2 mile apart. Measured coal is projected to extend as a 1/4 mile wide belt from the outcrop or points of observation or measurement.

Indicated - Resources are computed partly from specified measurements and partly from projection of visible data for a reasonable distance on the basis of geologic evidence. The points of observation are 1/2 to 1-1/2 miles apart. Indicated coal is projected to extend as a 1/2 mile wide belt that lies more than 1/4 mile from the outcrop or points of observation or measurement.

Inferred - Quantitative estimates are based largely on broad knowledge of the geologic character of the bed or region and where few measurements of bed thickness are available. The estimates are based primarily on an assumed continuation from Demonstrated coal for which there is geologic evidence. The points of observation are 1-1/2 to 6 miles apart. Inferred coal is projected to extend as a 2-1/4 mile wide belt that lies more than 3/4 mile from the outcrop or points of observation or measurement.

Other terms that appear in this chapter are defined below:

Demonstrated - A collective term for the sum of coal in both Measured and Indicated Resources and Reserves.

Identified Resources - The combined quantity of Demonstrated and Inferred Resources includes sub-bituminous and lignite 2-1/2 feet or more thick to an overburden depth of 3000 feet.

Estimated Resources - Includes beds of subbituminous coal and lignite generally 2-1/2 feet or more thick, to an overburden depth of 6000 feet.

Reserve Base - Includes beds of subbituminous coal 60 inches or more thick that occur at depths to 1000 feet. Includes also thinner and/or deeper beds that presently are being mined or for which there is evidence that they could be mined commercially at this time. Includes beds of lignite 60 inches or more thick which can be surface mined -generally those that occur at depths no greater than 120 feet.

Reserves - That portion of the Reserve Base that can be recovered by mining at the time of classification. Generally, the recovery factor in surface mining is 80-90 percent of the reserve base, whereas a 50 percent recovery factor is used for conventional room-and-pillar underground mining. For the sake of clarity, "reserves" are also termed "recoverable reserves."

Strippable Reserve Base - This term defines that portion of the Reserve Base that could be mined by surface mining methods. The criteria used to define the strippable reserve base are not universal and vary by state. Generally, there are three criteria states (or mining companies) used to delineate this base: 1) a minimum seam thickness, 2) a maximum depth of overburden, and 3) a maximum ratio of overburden thickness to coal seam thickness. The range of values for these criteria are shown below. The actual values used in each region are indicated in the following sections.

Ranges of Strippable Reserve Criteria Used for U.S.
Low-Rank Coal Deposits

Minimum Seam Thickness (ft)	Maximum Overburden Thickness (ft)	Maximum Stripping Ratio
4-16	100-300	4:1-15:1

References - Section 2.2

1. Coal Resource Classification System of the U.S. Bureau of Mines and U.S. Geological Survey, USGS Bulletin 1450-B, 1976.

Fort Union Region

2.2.1 Fort Union Region

The Fort Union Coal Region contains the largest reserves of lignite in the world. It lies within the Northern Great Plains Coal Province and encompasses portions of north-central United States and south-central Canada. The U.S. Geological Survey map, "Coal Fields of the United States, Exclusive of Alaska" (1960), defined the Fort Union Coal Region as including both the subbituminous coals of the northern Powder River Basin and the lignites of the Williston Basin. For the sake of simplicity, this study groups the subbituminous coals of the northern Powder River Basin into the Powder River Coal Region and the lignites of the Williston Basin into the Fort Union Coal Region. The Powder River Region is discussed in Section 2.2.2.

2.2.1.1 Geology

The Williston Basin is a broad structural and sedimentary intracratonic basin that extends over an area of about 150,000 square miles. In the United States it occupies portions of northwestern South Dakota, northeastern Montana, and western North Dakota. In Canada it occupies portions of southern Saskatchewan and southwestern Manitoba (see Figure 2.2.1.1.).

Over 150,000 feet of sedimentary rocks overlie the Williston Basin in its deepest portions in McKenzie County, North Dakota. Every period of geologic time since the Cambrian is represented by these rocks (see Figure 2.2.1.2). Dips of the individual units are normally toward the center of the basin and average between 10-20 feet per mile with considerable variation depending on specific stratigraphic and geographic position.¹⁶ The most notable changes in dip occur around two main structural features of the basin: the northwest-southeast trending Cedar Creek Anticline and the north-south trending Nesson Anticline.

The Mesozoic and Paleozoic rocks of the Williston Basin are largely the product of multiple episodes of advance (transgressions) and retreats (regressions) of vast epicontinental seas that have periodically inundated the North American continent. During the Cenozoic the Williston Basin region received an influx of clastic material derived from erosion of the newly uplifted Rocky Mountains to the west. In the early Paleocene this material was deposited in fluvial, lacustrine, paludal, and deltaic environments along coastal plains bordering the Cannonball Sea. This sea, the last of the epeiric seas to inundate North America, withdrew to the south towards the Gulf of Mexico at the close of the Paleocene.¹⁸ Deposition of continental sediments continued through Eocene, Oligocene, and Miocene time but subsequent erosion has removed all but a few isolated patches of these deposits. Periodic episodes of glaciation characterize the Quaternary and have resulted in a veneer of glacial and glacio-fluvial deposits over much of the Williston Basin.

Figure 2.2.1.1

Location Diagram of the Williston Basin

Source: Reference 17

Figure 2.2.1.2

Stratigraphic Column for the North Dakota Portions
of the Williston Basin

ERA	SYSTEM	SEQUENCE	GROUP	FORMATION	DOMINANT LITHOLOGY	
CENOZOIC	Quaternary	Tejas		Oahe Coleharbor	Silt, Clay, Sand, Gravel Pebble-loam, Sand, Gravel, Silt, Clay	
	Tertiary	Zuni	Fort Union	Golden Valley Sentinel Butte Bullion Creek Slope Cannonball Ludlow	Silt, Clay, Sand Silt, Sand, Clay, Lignite Silt, Sand, Clay, Lignite Silt, Clay, Sand, Lignite Marine Clay, Silt, Sand Silt, Clay, Sand, Lignite	
MESOZOIC	Cretaceous			Hell Creek	Sandstone, Shale, Lignite	
			Montana	Fox Hills Pierre	Marine Sandstone Shale	
			Colorado	Niobrara Carlile Greenhorn Belle Fourche	Shale, Calcareous Shale Shale, Calcareous Shale	
			Dakota	Mowry Newcastle Skull Creek Fall River Lakota	Shale Sandstone Shale Sandstone, Shale Sandstone, Shale	
			Jurassic		Morrison Sundance Piper	Shale, Clay Shale, green and brown, Sandstone Limestone, Anhydrite, Salt, red Shale
Triassic	Absaroka			Spearfish Minnekahta Opeche Minnelusa Amsden Tyler	Siltstone, Salt, Sandstone Limestone Shale, Siltstone, Salt Sandstone Interbedded Dolomite Limestone, Shale, Sandstone Shale, Sandstone	
Permian						
Pennsylvanian						
PALEOZOIC		Mississippian	Kaskaskia	Big Snowy	Heath Otter Kibbey	Shale Sandstone, Limestone Interbedded Limestone, Evaporites
				Madison Bakken Three Forks Birdhear Duperow Souris River Dawson Bay Prairie Winnipegosis	Limestone Siltstone, Shale Shale, Siltstone, Dolomite Limestone Interbedded Dolomite, Limestone Interbedded Dolomite, Limestone Dolomite, Limestone Salt Limestone, Dolomite	
	Devonian					
	Silurian	Tippecanoe		Interlake Stonewall Stony Mountain Red River	Dolomite Dolomite, Limestone Limestone, Dolomite Limestone, Dolomite	
	Ordovician		Winnipeg	Roughlock Ice Box Black Island	Calcareous Shale, Siltstone Shale Sandstone	
	Cambrian	Sauk		Deadwood	Limestone, Shale, Sandstone	
	Precambrian					

Source: Reference 18

Important lignite beds of the Fort Union Region occur within the Ludlow, Slope, Bullion Creek, and Sentinel Butte Formations of the Paleocene Fort Union Group. Lesser beds occur within the underlying Hell Creek Formation of late Cretaceous age and the overlying Golden Valley Formation of late Paleocene - Eocene age.

The Fort Union Group has been defined by the North Dakota Geological Survey and is roughly synonymous with the Fort Union formation as recognized by the United States Geological Survey and the Montana Geological Society. In Montana and South Dakota the Fort Union Formation includes the Tullock, Lebo, and Tongue River Members.

The Ludlow Formation is the lowermost formation of the Fort Union Group. It is compositionally similar to the Hell Creek Formation and is distinguished from it on the basis of its more laterally persistent beds and by faunal and floral differences.¹⁹ The lignites of the Ludlow range in thickness from several inches to twenty-four feet.^{19,20}

The Slope Formation has recently been defined by Clayton and others²¹ and includes strata previously considered upper Ludlow or portions of what was formerly the Tongue River Formation. It consists of alternating beds of nonmarine clay, silt, sand, and lignite which are either unlithified or only partially lithified.¹⁹ The lignite beds constitute approximately 10 percent of the formation and most commonly occur in beds less than 13 feet thick.²¹ In central North Dakota the Slope overlies the marine Cannonball Formation; in western North Dakota it overlies the Ludlow Formation.

The Bullion Creek Formation has also recently been defined.²¹ It includes strata formerly considered to be either the entire Tongue River or portions of the lower, middle, or upper Tongue River. It is characterized by alternating beds of nonmarine clay, silt, sand, and lignite. It is distinguished from the underlying Slope Formation primarily on the basis of color -- the Bullion Creek is generally light yellow; the Slope is generally drab grayish-brown. The lignite beds of the Bullion Creek constitute approximately 10 percent of the formation and occur in beds typically 3 feet thick but locally reaching 13 feet thick.²¹

The Sentinel Butte Formation has been described as a "lignite-bearing, nonmarine, Paleocene unit whose outcrops are somber gray and brown."²² Rock types include sandstone, siltstone, claystone, lignite, and limestone. The lignite beds vary from less than one foot to several tens of feet in thickness.²³ In general, they are less continuous than the lignites of the Bullion Creek.

2.2.1.2 Coal Reserves and Mines

Figure 2.2.1.3 is a map of the Fort Union Region showing the boundaries of the lignite field, the identified surface minable reserve base, and the locations of active surface mines. The region's demonstrated lignite reserve base tonnages (as reported by the U.S. Bureau of Mines for January 1976) are shown in Table 2.2.1.1. Criteria used in estimating strippable reserves vary state by state; the criteria used by the three states containing the Fort Union Region are also shown in Table 2.2.1.1. Table 2.2.1.2 lists the active mines in the region and shows data on the reserve base, overburden thickness, and 1978 production for each of the mines. Table 2.2.1.3 shows similar data on the new mines planned for the Fort Union Region.

Figure 2.2.1.3

Map of the Fort Union Lignite Region
Showing Strippable Reserve Areas and Mines

LEGEND:

Identified lignite resource area

Strippable lignite deposits

1,2,3.... Numbers indicate lignite mine locations (see Table 2.2.1.2)

Table 2.2.1.1

Strippable Lignite Reserve Base and Criteria Utilized in the Fort Union Region

State	Demonstrated Coal Reserve Base (Billion Short Tons)	Ref.	<u>Strippable Reserve Criteria Used by Each State</u>			
			Minimum Seam Thickness (Ft)	Maximum Overburden Depth (Ft)	Maximum Stripping Ratio ^a	Ref.
Montana	15.8	10	5	125	8:1	3
North Dakota ^b	10.1	10	5	100	10:1	12
South Dakota	0.4	10	5	100	12:1	3
Total	26.3					

^aBased on maximum feet of overburden thickness at the highwall per foot of coalbed thickness.

^bAnother widely quoted value for North Dakota's strippable lignite reserve base is 16 billion tons, as reported by the U.S. Bureau of Mines for January 1974 (reference 9); other (unofficial) estimates range as high as 40 billion tons. The 10.1 billion figure is utilized throughout this report because it is the latest officially published US3M figure and is consistent definitionally with the other state estimates.

Table 2.2.1.2

Active Surface Mines in the Fort Union Region

Map No.	Company/Mine Name	County	State	Deposit	Strippable Reserve Base Million Short Tons	Maximum Overburden Thickness (Ft)	1978 Production Million Tons
1.	Baukol-Noonan, Inc.	Burke	N.D.	Noonan	15	50	.540
2.	Consolidation Coal Co. Velva Mine	Ward	N.D.	Velva	5	50	.290
3.	Consolidated Coal Co. Glenharold Mine	Mercer	N.D.	Stanton	21	50	3.686
4.	Baukol-Noonan, Inc.	Oliver	N.D.	Center	253	50	3.400
5.	Knife River Coal Mining Co., Beulah Mine	Mercer	N.D.	Beulah-Zap	NA	NA	1.887
6.	North Americal Coal Corp, Indian Head Mine	Mercer	N.D.	Beulah-Zap	NA	NA	.912
7.	Husky Briquetting Inc. Lehigh Mine	Stark	N.D.	Dickenson	798	100	.135
8.	North American Coal Corp, Falkirk Mine	McLean	N.D.	NA	NA	NA	.142
9.	Knife River Coal Mining Co. Gascoyne (Peerless) Mine	Bowman	N.D.	Bowman- Gascoyne	1372	120	2.872
10.	Knife River Coal Mining Co., Savage Mine	Richland	Montana	Harmon	NA	70	.308
	Total				2464		14.172

Sources: References 6,8,11,12

Table 2.2.1.3

Planned Surface Mines in the Fort Union Region

Mining Company	Mine	County	State	Startup Date	First Year Production, Million Tons
Western Energy	Dominy	Custer	Montana	1986	2.0
Northern Resources	Circle West	McCone	Montana	1982	0.2
Knife River	New Leipzig	Grant	N.D.	1983	1.9
Nokota & Utah Int.	Garrison	McLean	N.D.	1986	6.6
Consolidated	Dakota Star	Mercer	N.D.	1985	4.0
North American	Cotreau	Mercer	N.D.	1981	0.6

Source: Reference 15

2.2.1.3 Identified Coal Resources

Table 2.2.1.4 shows the tonnages estimated for the identified lignite resources of the Fort Union Region, by state. Table 2.2.1.5 presents an approximate classification of these resources by depth, seam thickness, sulfur content, and ash content. In some instances, insufficient data are available and the categorized quantities are indicated as "unknown."

As shown in the table, all of the Region's identified lignite resources which have been classified by depth lie within 1000 feet of the surface. Seam thickness data are not available for the vast majority of Fort Union Region lignite, but known values indicate a wide range of thicknesses varying from inches up to hundreds of feet.⁴ Virtually all of the lignite resource contains low amounts of sulfur--less than one percent on an as-received weight percent basis. Analyses of the ash content in the lignite indicate values of 5 to 10 percent ash by weight on an as received basis in all the coals sampled.

Table 2.2.1.4

Identified Lignite Resources^a of the Fort Union Region, by State

State	10 ⁹ tons	Ref.
North Dakota	350.6	7
Montana	112.5	7
South Dakota	2.2	7
Total	465.3	

Notes:

^aIdentified resources include Demonstrated (Measured and Indicated) and Inferred resources 2-1/2 feet or more thick to an overburden depth of 3000 feet.

Table 2.2.1.5 .

Classification of Fort Union Region Identified Lignite Resources^a

<u>DEPTH OF SEAM</u>			<u>SEAM THICKNESS</u>		
<u>Ft.</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>	<u>Ft.</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>
0-1000	367.7	79.0	0-10	6.7	1.4
1000-2000	--	--	10-20	13.0	2.8
2000-3000	--	--	> 20	11.2	2.4
Unknown ^b	97.6	21.0	Unknown ^b	434.4	93.4
<hr/>			<hr/>		
Total	465.3	100.0	Total	465.3	100.0

<u>SULFUR CONTENT</u>			<u>ASH CONTENT</u>		
<u>Wt. % "as received"</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>	<u>Wt. % "as received"</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>
0-1	465.3	100.0	0-5	0	--
1-3	0	--	5-10	465.3	100.0
> 3	0	--	> 10	0	--
<hr/>			<hr/>		
Total	465.3	100.0	Total	465.3	100.0

Notes:

^aIdentified resources include Demonstrated (Measured and Indicated) and Inferred resources 2-1/2 feet or more thick to an overburden depth of 3000 feet.

^b"Unknown" refers to Identified resources not classified into the depth or thickness ranges shown.

Sources: References 5,7

2.2.1.4 Overburden Characteristics

Three distinct overburden materials are prevalent in the Fort Union Region, and although the detailed overburden information comes from North Dakota sources the characteristics are evident throughout the region. Generally, the southern third of the region is an unglaciated area, so the overburden material consists of fine grained clastics of the Fort Union Group. The area from south or west of the Missouri River to the unglaciated southern area contains a scattering of glacial drift, but the majority of the overburden is fine grained clastics. North of the Missouri River the overburden has a surface mantle of glacial till which obscures the bedrock topography. This area of glaciation complicates lignite reserve estimation because of hidden erosional channels and subsurface weathering caused by the glacial activity.^{1,6}

2.2.1.5 Aquifers

Aquifers in the Fort Union Region are intimately associated with the glacial drift and bedrock overburdens, as well as with major lignite beds. A common problem in many of the regional strip mines is groundwater flowing into the pits. Some pits are self-draining, but often such water must be drained by pumping because many mining operations are proceeding downdip. The water problem is compounded during wet weather when clay-based haulage roads become all but impassable.

Major aquifers in the region can be classified according to the following categories:; glacial drift and outwash, alluvial, and bedrock. Glacial drift and outward aquifers are located throughout the northern glaciated portions of the Region in Montana and North Dakota and are composed of scattered unconsolidated sand and gravel deposits associated with glacial till overlying the bedrock. Alluvial aquifers consist of modern flood plain deposits and unconsolidated sand and gravels that have filled preglacial river valleys in the region. Bedrock aquifers consist principally of consolidated sandstones and limestones with interbedded shales, siltstones and claystones, but some sands and clays are associated with lignite units. Bedrock aquifers containing major lignite beds include the Fort Union and Hell Creek formations.²

2.2.1.6 Coal Analyses and Limits of Variation

An extensive program of sampling and characterization of the Fort Union Region lignite has been conducted by the Grand Forks Energy Technology Center. Proximate and ultimate analyses, plus detailed analyses of ASTM-prepared ash properties, have been reported for over 400 lignite samples from nine mining areas in North Dakota and one in Montana.⁸ The results of this effort are condensed here and provide the bulk of the information presented in this section.

The ten sampling locations used in the GFETC study represent the major lignite mining areas in western North Dakota and eastern Montana. Samples were obtained by auger drilling the beds after overburden had been stripped; a total of 444 samples were taken at 212 sampling locations within the mines. Table 2.2.1.6 presents average values obtained for the proximate and ultimate analyses of these lignite samples, and table 2.2.1.7 presents average values obtained for the analyses of ash from these samples.

The Fort Union Region lignite analysis indicates a moisture content averaging 37 percent by weight. Compared to moisture averages for bituminous (2.9-14.4%) and subbituminous (16.9-25.1%) coals,¹³ lignite has the highest moisture content of all ranks. Ash content averages 6.2 percent, which compares favorably with other coals on a weight percent basis; however, since more lignite is needed to provide an equivalent amount of energy contained in higher ranked coals, the moisture, volatile matter, fixed carbon, and ash percentages all appear higher for lignite than for higher rank coals when calculated on a per Btu basis.

Fort Union lignite ash analyses are generally high in alkaline metal oxides. Calcium and sodium are the most prominent of the alkaline constituents in the lignite ash. For most locations the calcium concentration was found to vary about a characteristic value of approximately 24 percent expressed as the oxide; at one mine (Velva) the concentration was approximately 40 percent. Sodium oxide was found in average quantities generally between 5 and 9 percent of the ash for the different mines; the overall average sodium oxide content for the Fort Union Region was found to be about 6.5 percent of the ash.

The average compositions listed in the following tables do not portray the wide variability in the composition of Fort Union Region lignite and its ash. As a complement to these tables, Tables 2.2.1.8 and 2.2.1.9 present a statistical summary of the limits of variation in the analyses of lignite and ash from Mercer County (N.D.) and the entire sampled region. Quantities shown on the tables include: 1) the range, which gives the high and low values observed for the sample group; 2) the "2s" limit which represents twice the estimated standard deviation, or the approximate interval on either side of the average within which 95 percent of individual values would be expected to lie (this form for expressing variations is more useful than the range in that it tends to discount the effect of a few high or low non-representative analyses); and 3) the confidence range on the average, which gives the range on either side of the average within which there is 95 percent confidence that the true average lies.

The wide variability found among adjacent samples in the same mine, and the even wider variability among samples from different mines, are believed to have resulted from mineral penetration of the lignite seams during their formative geologic periods. As the carbonaceous vegetable matter collected in the swamps and shallow lakes, it was gradually covered by layers of sand, clay, or other sediments. During the coalification period the peat-like material was penetrated by variable amounts of mineral constituents originating both with the parent vegetable matter and from the underlying and overlying cover. The ion-exchange activity of these low-rank coals further contributed to the accumulation by exchange of metallic ions between the coal substance and groundwater.⁸

Table 2.2.1.6

Average Proximate and Ultimate Analyses
of Fort Union Region Lignite from Selected Mines
(as-received basis)

Sample Group	Number of sample locations	Proximate Analysis, Weight Percent				Ultimate Analysis, Weight Percent					Chlo- rine, ^a per- cent	Heating Value, Btu/lb	True specific gravity ^a
		Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitro- gen	Oxygen	Sulfur			
Fort Union Region	212	37.2	26.3	30.3	6.2	6.9	40.7	0.6	45.0	0.62	0.01	6,820	1.56
Mercer County	126	36.7	26.6	30.5	6.2	6.9	41.1	.6	44.5	.68	.01	6,890	1.56
Mines:													
South Beulah	25	36.2	26.8	30.4	6.6	6.8	41.5	.7	43.5	.90	.00	6,920	1.57
North Beulah	39	36.6	26.4	30.8	6.2	6.8	40.9	.6	44.9	.63	.01	6,820	1.59
Indianhead	22	35.6	26.4	31.1	6.9	6.8	41.9	.6	43.0	.77	.01	7,020	1.57
Glenharold	33	38.3	26.8	29.6	5.3	7.0	40.2	.6	46.4	.50	.00	6,770	1.54
Dakota Star ^b	7	37.3	26.1	30.8	5.8	6.9	41.0	.5	45.1	.71	.00	6,850	--
Velva	27	39.8	25.9	30.1	4.2	7.1	39.6	.7	48.2	.23	.01	6,590	1.54
Baukol-Noonan	26	35.2	26.3	32.5	6.0	6.8	43.3	.7	42.9	.34	.01	7,280	1.54
Kincaid ^b	6	36.3	25.6	29.2	8.9	6.8	39.7	.6	43.2	.76	.01	6,720	--
Gascoyne	6	43.8	24.3	24.9	7.0	7.4	35.4	.5	48.9	.79	.01	5,990	--
Savage	21	38.7	25.0	29.6	6.7	6.9	39.5	.6	45.8	.52	.01	6,520	1.57

Notes:

^aAverages for chlorine and true specific gravity are for selected samples and represent a smaller number of sample locations than listed.

^bMine now closed.

Source: Reference 8

Table 2.2.1.7

Average Ash Analyses of Fort Union
Region Lignite from Selected Mines

Sample Group	Number of sample locations	Chemical analysis, weight-percent of ash										Ash, weight- Percent of Coal		Ash Fusibility ST, °F
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	P ₂ O ₅	CaO	MgO	Na ₂ O	K ₂ O	SO ₃	As-received	Dry Basis	
Fort Union Region	212	19.7	11.1	9.1	0.4	0.3	24.6	6.9	6.5	0.4	19.5	6.2	9.9	2,290
Mercer County	126	17.9	9.9	10.2	.3	.4	23.6	6.7	7.4	.4	21.8	6.2	9.8	2,280
Mines:														
South Beulah	25	17.2	11.2	10.4	.4	.5	23.4	6.9	4.8	.3	23.3	6.6	10.3	2,290
North Beulah	39	17.3	10.9	8.9	.3	.5	24.2	8.9	5.5	.3	21.2	6.2	9.7	2,330
Indianhead	22	18.2	10.0	10.6	.3	.5	21.2	6.0	8.8	.3	22.8	6.9	10.7	2,170
Glenharold	33	18.4	9.0	10.1	.3	.1	25.6	6.1	8.3	.5	20.1	5.3	8.7	2,100
Dakota Star ^a	7	16.5	8.4	12.1	.4	.5	24.6	6.7	6.4	.3	22.8	5.8	9.2	2,320
Velva	27	17.1	10.7	7.2	.4	.2	38.9	8.5	4.4	.3	11.0	4.2	7.0	2,490
Baukol-Noonan	26	24.4	13.6	7.0	.3	.1	22.6	5.6	11.0	.4	13.1	6.0	9.2	2,200
Kincaid ^a	6	31.8	18.3	6.2	.6	.1	16.7	3.6	4.2	.4	15.2	8.9	14.0	2,070
Gascoyne	6	29.1	9.1	5.6	.5	.1	22.6	8.3	1.7	.3	20.6	7.0	12.4	2,200
Savage	21	23.1	16.6	5.6	.4	.8	25.3	9.9	.3	.2	16.4	6.7	10.9	2,430

Notes:

^aMine now closed.

Source: Reference 8

Table 2.2.1.8

Limits of Variation in Proximate and Ultimate Analyses of Fort Union Region Lignite
(as-received basis)

Sample Group	Number of sample locations	Proximate Analysis, Weight Percent				Ultimate Analysis, Weight Percent					Heating Value Btu/lb
		Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	
Fort Union Region-Average	212	37.2	26.3	30.3	6.2	6.9	40.7	0.6	45.0	0.62	6820
Range: High		43.59	28.30	34.82	12.09	88.1	45.37	1.05	50.63	1.94	7580
Low		32.47	23.40	24.10	3.16	6.35	34.62	0.39	39.40	0.11	5880
2s limit ^a		2.16	1.46	1.91	1.70	0.66	1.67	0.17	2.28	0.43	312
Confidence range on average ^b		0.15	0.10	0.13	0.12	0.04	0.11	0.01	0.16	0.03	21
Mercer County - Average	126	36.7	26.6	30.5	6.2	6.9	41.1	0.6	44.5	0.68	6890
Range: High		38.50	28.30	32.70	9.94	7.28	43.13	1.01	50.57	1.94	7230
Low		33.39	24.82	26.69	4.03	6.35	36.47	0.39	39.40	0.28	6060
2s Limit ^a		1.89	1.24	1.66	1.47	0.74	1.61	0.16	1.90	0.44	299
Confidence range on average ^b		0.17	0.11	0.15	0.13	0.07	0.14	0.01	0.17	0.04	26

Notes:

^a"2s limit" equals twice the standard deviation and represents the interval on either side of the average within which 95 percent of the individual values are expected to lie.

^b"Confidence range on average" represents the range around the average within which there is 95 percent confidence that the true average lies.

Source: Reference 8

Table 2.2.1.9

Limits of Variation in Ash Analyses of Fort Union Region Lignite

Sample Group	Number of sample locations	Composition, Weight Percent of Ash										Ash Softening, Temperature OF
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	P ₂ O ₅	CaO	MgO	Na ₂ O	K ₂ O	SO ₃	
Fort Union Region-Average	212	19.7	11.1	9.1	0.4	0.3	24.6	6.9	6.5	0.4	19.5	2290
Range: High		39.4	26.1	34.3	0.8	1.1	52.0	13.6	27.8	1.3	32.0	2730
Low		6.3	4.2	0.9	0.01	0.0	12.4	2.8	0.1	0.01	8.3	1970
2s limit ^a		8.39	3.06	7.25	0.23	0.34	6.57	2.13	5.14	0.23	7.27	206
Confidence range on average ^b		0.57	0.21	0.49	0.02	0.02	0.45	0.15	0.35	0.02	0.49	14
Mercer County - Average	126	17.9	9.9	10.2	0.3	0.4	23.6	6.7	7.4	0.4	21.8	2280
Range: High		33.1	14.8	34.3	0.8	1.1	32.3	11.9	12.6	0.9	32.0	2550
Low		8.2	5.4	2.9	0.1	0.0	13.8	2.8	0.2	0.1	11.6	1970
2s Limit ^a		6.64	2.43	8.14	0.23	0.32	6.01	2.05	4.60	0.22	7.56	196
Confidence range on average ^b		0.59	0.21	0.72	0.02	0.03	0.53	0.18	0.41	0.02	0.67	17

Notes:

^a"2s limit" equals twice the standard deviation and represents the interval on either side of the average within which 95 percent of the individual values are expected to lie.

^b"Confidence range on average" represents the range around the average within which there is 95 percent confidence that the true average lies.

Source: Reference 8

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Powder River Region

2.2.2 Powder River Region

The Powder River Region is a broad syncline oriented along a north-south axis from southeastern Montana into Northern Wyoming. Much of the coal lies in the continuation of Fort Union formation members discussed in the previous section; however, geological differences have increased the coal rank in the Powder River Region to subbituminous quality. References made in this section to Fort Union formation coals refer only to subbituminous deposits found in this geologic stratum within the Powder River Region.

2.2.2.1 Geology

The Paleocene Fort Union formation contains three coal-bearing members which are, from top to bottom, the Tongue River, Lebo, and Tulloch. In the Montana portion of the Powder River Region, 11 coal beds are found in the Tulloch Member and two in the Lebo. South of the Yellowstone River, most of the land is underlain by the Tongue River Formation, which is 1500-1700 feet thick. In places, the Tongue River formation contains as many as 20 coal beds, some of which are as much as 40 feet thick. The Wyoming portion of the Powder River Region contains the thickest coal seams in the U.S., with some seams averaging 70 feet in thickness.¹

Large parts of the original near-surface coal reserves of the Tongue River member have been destroyed by burning at their outcrop and beneath shallow cover. This phenomenon is attributed to spontaneous combustion, and has caused fusion and baking of the strata overlying the coal bed, which produces a reddish, permeable zone known as clinker. The thickness of the clinker is roughly proportional to the original thickness and quality of the coal, and is one factor utilized in the exploration of coal deposits. A coal bed 5 to 10 feet thick will produce a clinker zone 10 to 30 feet thick, whereas a coal bed 50 feet thick may produce a clinker zone 100 to 200 feet thick.²

Underlying the Tongue River Member is the 300 to 600 foot thick Lebo Member of the Fort Union Formation. Except for the basal coal bed, called the "Big Dirty," the Lebo is devoid of coal beds. The "Big Dirty" coal bed has been used as fuel by local ranchers, but in most places it contains so much carbonaceous shale that it produces too much ash to be of commercial value.

The Tulloch Member of the Fort Union Formation consists of sequential beds of sandstone, sandy and carbonaceous shale, and numerous thin impure coal beds. The Tulloch is directly below the "Big Dirty" coal bed of the Lebo Member, and varies in thickness from 275 to 500 feet. Although this area contains ten lenticular coal beds, none of them is of adequate quantity or quality to be economically recoverable.

The Wasatch Formation of the Eocene Age overlies the Fort Union Formation in a few places. It is about 500 feet thick in the Powder River Region along the Montana-Wyoming border, where it consists of multicolored claystone, sandstone, and shale. The top of the Roland coal bed marks the base of the Wasatch Formation, which contains commercial grade coal in the Wyoming portion of the Powder River Region.²

2.2.2.2 Coal Reserves and Mines

Figure 2.2.2.1 is a map of the Powder River Region outlining the subbituminous coal field, strippable coal deposits, and the locations of active coal mines. Table 2.2.2.1 shows estimates of the region's demonstrated coal reserve base tonnages, as well as the criteria used to define strippable subbituminous coal reserves in Montana and Wyoming. Table 2.2.2.2 lists the active coal mines in the region, and shows data on the reserve base, overburden thickness, and 1978 production for each of the mines. Table 2.2.2.3 shows similar data on the new mines planned for the Powder River Region.

2.2.2.3 Identified Coal Resources

Table 2.2.2.4 shows the tonnages estimated for the identified subbituminous coal resources of the Powder River Region, by state. Table 2.2.2.5 presents an approximate classification of these resources by depth, seam thickness, sulfur content, and ash content. Approximately 35 percent of the resources are not classified into these categories due to insufficient data, and are listed as "unknown."

Well over half of the identified Powder River Region resources lie within 1000 feet of the surface, (and nearly half of these "shallow" resources are considered part of the strippable reserve base). Approximately 35 percent of the identified coal is found in seams 10 feet thick or larger; however, this number does not indicate that the maximum thickness of at least nine seams ranges from 20 to 220 feet.⁶ The Powder River subbituminous coals are low in sulfur (most less than one percent) and have an ash content averaging between 5 and 10 percent by weight on an "as received" basis.

2.2.2.4 Overburden Characteristics

The strippable subbituminous coal deposits of the Powder River Region are generally found under less than 200 feet of overburden. Outcrops of coal seams occur for miles parallel to the eastern edges of Wyoming's Wyodak bed, where almost every seam greater than 5 feet thick has burned inward and formed an erosion-resistant cap of thick reddish clinker. This eastern edge forms a continuous north-south line of buttes that grades westerly into prominent clinker-capped ridges. West of the ridges the topography changes to comparatively flat farmland and rangeland. Burnings have occurred elsewhere throughout the Region, wherever the coal outcrops or lies under shallow cover. In areas where the coal has not burned, the overburden consists mainly of alluvial sandstone, silt, shale, and gravel.

Figure 2.2.2.1

Map of the Powder River Region
Showing Strippable Reserve Deposits and Mines

Table 2.2.2.1

Strippable Subbituminous Coal Reserve Base and Criteria Utilized in the
Powder River Region

State	Demonstrated Coal Reserve Base (billion short tons)	Ref. ^c	<u>Strippable Reserve Criteria Utilized by Each State</u>			
			Minimum Seam Thickness (ft)	Maximum Overburden Depth	Stripping Ratio ^b	Ref.
Montana	34.5	4	5	125	8:1	5
Wyoming	<u>23.0</u>	6	5	120 ^a	10:1	3
Total	57.5					

Notes:

^aExcept where strata-breaking characteristics appear ideal and coal thickness is more than 20 feet in single or multiple beds.

^bBased on maximum feet of overburden thickness at the highwall per foot of coalbed thickness.

^cThese subbituminous coal reserve base tonnages differ slightly from those reported by the U.S. Bureau of Mines for January 1976, which were 33.8 b.t. for Montana, and 23.7 b.t. for Wyoming.¹³

Table 2.2.2.2

Active Surface Mines in the Powder River Region

Map Number	Company/Mine Name	County	State	Deposit	Estimated Strippable Reserve Base 10 ⁶ Tons	1978 Production 10 ⁶ Tons
1.	Decker Coal Co./Decker West	Big Horn	Montana	Anderson-Dietz 1 & 2		6.000
2.	Decker Coal Co./Decker East	Big Horn	Montana	Anderson Dietz 1 & 2	2239.99	2.045
3.	Westmoreland Resources/Absaloka	Big Horn	Montana	Rosebud-McKay	1500.00	4.900
4.	Coal Creek Mining Co./Coal Creek	Powder River	Montana	Knobloch	2696.20	.0085
5.	Peabody Coal Co./Big Sky	Rosebud	Montana	Rosebud		2.100
6.	Western Energy Co./Rosebud	Rosebud	Montana	Rosebud	1439.26	10.500
7.	Amax Coal Co./Belle Ayr	Campbell	Wyoming	Wyodak	c	13.303
8.	Big Horn Coal Co./Big Horn No. 1	Sheridan	Wyoming	Wyodak	c	2.394
9.	Carter Mining Co./Rawhide	Campbell	Wyoming	Wyodak	c	1.096
10.	Glenrock Coal Co./Dave Johnston	Converse	Wyoming	School-Badger	108.80	3.237
11.	Cordero Mining Co./Cordero	Campbell	Wyoming	Wyodak	c	2.128
12.	ARCO/Black Thunder	Campbell	Wyoming	Wyodak	c	.0428
13.	Wyodak Resources/Wyodak	Campbell	Wyoming	Wyodak	c	.857
14.	Kerr-McGee/Jacobs Ranch	Campbell	Wyoming	Wyodak	c	15.0 ^a
15.	Carter Mining Co./Caballo	Campbell	Wyoming	Wyodak	c	5.0 ^a
16.	Amax Coal Co./Eagle Butte	Campbell	Wyoming	Wyodak	c	b
17.	Black Mountain/Black Mountain	Sheridan	Wyoming	Dietz		
Total					26,939.25	68.611

Notes:

^aActual production for this new mine is unavailable. Number listed represents the design capacity.

^bReserve base, design capacity, and/or actual production tonnages not available.

^cTotal remaining strippable reserve base for the Wyodak Deposit is 18,955 million tons.

Sources: References 4,6,7,8

Table 2.2.2.3

Planned Surface Mines in the Powder River Region

Mining Company	Mine	County	State	Startup Date	First Year Production (million tons)
Consolidated	CX Ranch Project	Big Horn	Montana	1985	1.5
Nerco	Spring Creek	Big Horn	Montana	1980	2.0
Peter Kiewit	Squirrel Creek	Big Horn	Montana	1983	2.0
Shell Oil	Pearl	Big Horn	Montana	1984	2.0
Shell Oil	Youngs Creek	Crow Res.	Montana	1985	2.0
Montco	Nance	Rosebud	Montana	1984	1.0
ARCO	Coal Creek	Campbell	Wyoming	1982	0.5
Kerr-McGee	East Gillette	Campbell	Wyoming	1983	2.0
Mobil	Pojo Caballos	Campbell	Wyoming	1983	3.0
Kaneb Svcs.	Unnamed	Campbell	Wyoming	1986	2.0
Peabody	N. Antelope	Campbell	Wyoming	1983	2.5
Peabody	Rochelle	Campbell	Wyoming	1983	2.0
Pittsburg & Midway	Wildcat Creek	Campbell	Wyoming	1985	5.0
Shell	Buckskin	Campbell	Wyoming	1981	0.4
WYMO Fuels	Unnamed	Campbell	Wyoming	1982	2.0
PP&L (Nerco)	Antelope	Converse	Wyoming	1983	4.0
Texas Eastern	Lake deSmet	Johnson	Wyoming	1985	2.0
JMT Co.	Dutchman	Sheridan	Wyoming	1980	0.2
Peter Kiewit	Whitney	Sheridan	Wyoming	1980	1.0
Publ. Serv. of Okla.	Ask Creek	Sheridan	Wyoming	1980	0.1

Source: Reference 14

Table 2.2.2.4

Identified Subbituminous Coal Resources^a of the Powder River Region, by State

State	10 ⁹ Tons	References
Montana	127.9	15
Wyoming	110.2	6
Total	238.1	

Notes:

^aIdentified resources include Demonstrated (measured and indicated) and Inferred resources 2-1/2 feet or more thick to an overburden depth of 3000 feet.

Table 2.2.2.5

Classification of Powder River Region Identified Subbituminous Resources^a

<u>DEPTH OF SEAM</u>			<u>SEAM THICKNESS</u>		
Ft.	10 ⁹ Tons	Percent of Total	Ft.	10 ⁹ Tons	Percent of Total
0-1000	138.2	58.0	2.5-5	13.5	5.7
1000-2000	11.5	4.9	5-10	69.7	29.3
2000-3000	1.0	0.4	>10	82.9	34.8
Unknown ^b	87.4	36.7	Unknown ^b	72.0	30.2
Total	238.1	100.0	Total	238.1	100.0

<u>SULFUR CONTENT</u>			<u>ASH CONTENT</u>		
Wt. % "as received"	10 ⁹ Tons	Percent of Total	Wt. % "as received"	10 ⁹ Tons	Percent of Total
0-1	134.7	56.6	0-5	31.9	13.4
1-3	8.7	3.6	5-10	106.5	44.7
3-10	--	--	>10	22.2	9.3
Unknown ^b	94.7	39.8	Unknown ^b	77.5	32.6
Total	238.1	100.0	Total	238.1	100.0

Notes:

^aIdentified resources include Demonstrated (Measured and Indicated) and Inferred resources 2-1/2 feet or more thick to an overburden depth of 3000 feet.

^b"Unknown" refers to Identified resources not classified into the depth, thickness, sulfur, and ash ranges shown.

Sources: References 4,6,9

2.2.2.5 Aquifers

Many of the coal seams in the Powder River Region are aquifers. Consolidated aquifers in the lease area of the Big Sky mine in Rosebud county, Montana, have been found to be largely sandstone and coal beds in the Tongue River and Tulloch Members of the Fort Union Formation. Tongue River aquifers underlie the McKay coal beds by 350 feet and the Tulloch and Hell Creek aquifers are 500 to 1500 feet below the Sawyer and McKay coal beds. The Tulloch and Hell Creek formations consist of sandstones and interbedded shales with coal beds also present in the Tulloch.

The Wasatch aquifer is reported to yield up to 500 gpm from well depths of 50 to more than 1000 feet in parts of the Wyoming portion of the Powder River Basin. In the western portion of the Basin in Wyoming, the Lance aquifer is reported to yield from 50 to 480 gpm (mostly 100-400 gpm) from depths of 110 to 235 feet. Hell Creek-Fox Hill aquifers yield 3 to 500 gpm (generally less than 100 gpm) from well depths between 200 and 2300 feet.¹⁰ Water yields from the Parkman sandstone member of the Mesaverde Group have been reported in Montana and Wyoming.

Older major aquifers consist of sandstones and limestones and are extensive throughout the Region. The Madison Limestone and underlying carbonate aquifers in the Powder River Basin have been studied at the reconnaissance level by the USGS for the Northern Great Plains Resource Program. Large yields, 3700 gpm and 9475 gpm, have been reported from wells in these aquifers in Montana and Wyoming, respectively.^{1,10,11}

2.2.2.6 Coal Analyses and Limits of Variation

GFETC has conducted a sampling and characterization program of Powder River Region subbituminous coals, similar to (but less extensive than) the earlier study on Fort Union Region lignites.^{16,17} Tables 2.2.2.6 and 2.2.2.7 present average coal and ash analyses, respectively, for samples taken from five subbituminous coal mines in the region.

Comparing these average analyses with the Fort Union lignite analyses in the preceding section, the most significant difference noted is the typical moisture content of about 25 percent for the subbituminous coal samples (as compared to about 37 percent for the lignite). Fixed carbon and volatile matter contents in the subbituminous coal are correspondingly higher than in the lignites. Ash contents are roughly the same, averaging in the 5 to 8 percent range for the subbituminous coals. Examination of the average ash composition of the subbituminous coals shows the usual wide variation; however, four of the five subbituminous coal mines contain significantly lower sodium oxide concentrations in the ash than the Fort Union lignite mines.

To illustrate the wide variability encountered in the coal and ash analyses from the Powder River Region, Tables 2.2.2.8 and 2.2.2.9 present a statistical summary of the limits of variation of 104 subbituminous

Table 2.2.2.6

Average Proximate and Ultimate Analyses of Powder River Region Subbituminous Coal From Selected Mines
(as-received basis)^a

Sample Group	Number of sample locations	Proximate Analysis, Weight Percent				Ultimate Analysis, Weight Percent ^a					Heating Value
		Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Btu/lb
Belle Ayr Mine, Wyoming	8	24.9	32.3	37.8	5.0	6.3	51.2	0.7	36.3	0.4	8660
Big Horn Mine, Wyoming	12	24.2	32.0	38.9	4.8	6.4	53.1	0.9	34.2	0.4	9080
Big Sky Mine, Montana	8	23.7	29.7	39.0	7.6	5.2	76.4	1.1	16.2	1.1	9045
Rosebud Mine, Montana	38	25.6	27.9	37.8	7.7	5.0	76.1	1.2	16.7	1.0	8510
Decker Mine, Montana	13	24.4	30.8	41.3	3.5	5.3	75.6	1.1	17.4	0.5	9445

Sources: Wyoming - Reference 16
Montana - Reference 17

Note: ^aAll data are on an as-received basis, except for the ultimate analyses of the Montana mine samples. These are on a dry, mineral-matter-free basis.

Table 2.2.2.7

Average Ash Analyses of Powder River Region Subbituminous Coal From Selected Mines

Sample Group	Number of sample locations	Chemical Analysis, Weight Percent of Ash									Ash Softening Temp. °F
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	P ₂ O ₅	CaO	MgO	Na ₂ O	K ₂ O	
Belle Ayr Mine, Wyoming	8	29.0	16.6	5.6	1.1	0.8	24.9	4.5	1.5	0.2	2295
Big Horn Mine, Wyoming	12	27.4	12.7	13.9	0.6	0.5	16.6	5.5	2.1	0.5	2200
Big Sky Mine, Montana	8	48.3	22.5	7.2	0.7	0.3	14.3	5.6	0.5	0.5	2180
Rosebud Mine, Montana	38	42.2	23.1	6.4	0.8	0.4	21.7	5.1	0.3	0.1	2210
Decker Mine, Montana	13	31.2	22.2	8.6	1.0	0.8	21.6	4.5	9.5	0.5	2095

Sources: Wyoming - Reference 16
Montana - Reference 17

Table 2.2.2.8
Limits of Variation in Proximate and Ultimate Analyses of Montana Subbituminous Coal
(as-received basis)^c

Sample Group	Number of sample locations	Proximate Analysis, Weight Percent				Ultimate Analysis, Weight Percent ^c					Heating Value Btu/lb
		Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	
Montana Subbituminous-Coal - Average	104	25.4	28.6	38.3	7.8	5.0	75.7	1.2	17.0	1.1	8620
Range: High		30.5	31.7	42.6	16.0	5.4	73.2	1.5	19.5	3.5	9610
Low		20.2	24.5	31.6	3.0	4.4	72.3	1.0	14.6	0.1	7360
2s limit ^a		4.2	2.8	4.0	4.8	0.4	2.0	0.2	2.0	1.2	990
Confidence range on average ^b		0.4	0.3	0.4	0.5	0.0	0.2	0.0	0.2	0.1	95

Notes:

^a"2s limit" equals twice the standard deviation and represents the interval on either side of the average within which 95 percent of the individual values are expected to lie.

^b"Confidence range on average" represents the range around the average within which there is a 95 percent confidence that the true average lies.

^cUltimate analyses are on a dry, mineral-matter-free basis.

Source: Reference 17

Table 2.2.2.9

Limits of Variation in Ash Analyses of Montana Subbituminous Coal

Sample Group	Number of sample locations	Chemical Analysis, Weight Percent of Ash									Ash Softening, Temperature °F
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	P ₂ O ₅	CaO	MgO	Na ₂ O	K ₂ O	
Montana Subbituminous Coal - Average	104	40.2	21.8	9.7	0.8	0.4	19.4	5.4	2.0	0.3	2180
Range: High		52.8	27.6	31.4	2.1	1.4	52.6	9.0	10.4	1.1	2730
Low		23.6	9.9	3.3	0.1	0.0	10.5	1.4	0.1	0.0	1940
2s limit ^a		13.4	6.6	12.2	0.6	0.6	12.6	2.6	6.6	0.4	220
Confidence range on average ^b		1.3	0.6	1.2	0.1	0.1	1.2	0.2	0.6	0.0	21

Notes:

^a"2s limit" equals twice the standard deviation and represents the interval on either side of the average within which 95 percent of the individual values are expected to lie.

^b"Confidence range on average" represents the range around the average within which there is 95 percent confidence that the true average lies.

Source: Reference 17

coal samples from Montana (These include the 59 samples from the three Montana mines on the previous tables, plus 45 core samples taken by Burlington Northern Railroad.). It should be noted that the average sulfur content (1.1%) for this particular selection of Powder River Region coals appears to be higher than would be the case for a wider geographic sampling of the region's coal (i.e., see Tables 2.2.2.6 and 2.2.2.10).

In order to provide a more comprehensive data base on the characteristics of the Powder River Region's coal resources, the results of extensive core analysis programs by the Montana Bureau of Mines and Geology^{2,12} and the Geological Survey of Wyoming⁶ have been summarized in Tables 2.2.2.10 and 2.2.2.11. Proximate analyses, sulfur contents, and heating values are presented for 29 coal seams (791 samples in all). The difference between this type of core sampling program (to support geologic surveys of coal resources) and the more rigorous mine sampling and coal/ash analysis programs conducted by GFETC should be kept in mind when comparing the data. No tipple or outcrop samples were included in the data shown in Tables 2.2.2.10 and 2.2.2.11, to assure that these analyses are representative of coal-in-place resources.

Table 2.2.2.10

Average Analyses of Powder River Region Coal Beds
("as received" basis)

Coal Bed	Number of Samples	Proximate Analysis, Weight Percent				Sulfur, Weight Percent	Heating Value, Btu/lb
		Moisture	Volatile Matter	Fixed Carbon	Ash		
Powder River Region - Average	791	27.7	30.5	35.0	6.8	.59	8177
Anderson (MT,WY)	98	26.4	29.8	36.7	6.2	1.3	8345
Badger (WY)	5	27.4	33.3	31.4	7.9	.45	7951
Brewster-Arnold (MT)	7	22.1	30.9	41.9	5.1	.42	9056
Broadus (MT)	9	30.1	29.2	33.8	6.9	.26	7377
Canyon (MT,WY)	41	27.5	29.4	36.6	6.4	.45	8306
Cook (MT)	16	33.2	28.0	31.8	7.0	.83	7264
Dietz (MT,WY)	35	26.1	25.7	37.3	6.1	1.3	8552
Dominy (MT)	29	36.8	25.6	30.4	6.7	.41	6691
Dunning (MT)	4	30.7	29.2	35.3	4.9	.26	7814
Elk (MT)	9	32.7	28.0	34.4	4.9	.32	7563
Felix (WY)	42	28.0	31.7	32.5	7.8	.89	8053
Flowers-Goodale (MT)	5	29.9	27.3	35.3	7.5	.59	7807
Glenrock-Big Muddy Zone (WY)	10	23.4	35.9	34.0	6.8	.66	8742
Healy (WY)	5	28.5	30.0	33.9	7.6	.60	7884
Knoblock (MT)	78	28.4	29.2	36.9	5.4	.31	8348
Mesaverde (WY)	2	21.9	37.5	31.5	9.0	.71	8479
Monarch (WY)	203	21.5	34.5	39.6	4.4	.40	9600
Pawnee (MT)	7	33.9	25.9	30.4	9.8	.88	6964
PK, Ulm 2, Ulm 1 (WY)	5	30.2	31.2	34.3	4.3	1.5	8000
Roland (MT)	15	30.4	30.1	33.8	5.7	.30	7928
Rosebud (MT)	27	23.5 ^a	28.7	39.1	8.7	1.0	8900 ^a
Sawyer (MT)	12	31.3	29.1	33.3	6.3	.51	7598
School (WY)	3	22.2	35.9	30.5	11.4	.60	8183
Smith (MT,WY)	3	24.2	27.5	34.0	15.7	.79	7825
Sussex "Lower Coal Bed" (WY)	1	23.5	35.6	35.7	5.2	.49	9160
T. (MT)	13	36.1	27.0	30.8	6.2	.57	7120
Terret (MT)	4	30.3	26.9	37.0	5.8	.32	7870
Wall (MT)	43	24.5	30.5	40.4	4.6	.30	9077
Wyodak-Anderson (WY)	59	29.8	30.7	33.5	6.0	.50	8244

Notes:

^aAverage from 28 samples.

Sources: References 2,6,12

Table 2.2.2.11

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Limits of Variation in Coal Bed Analyses, Powder River Region
(as-received basis)

Coal Bed	Number of Samples	Proximate Analysis, Weight Percent				Sulfur, Weight Percent	Heating Value, Btu/lb
		Moisture	Vol. Matter	Fixed Carbon	Ash		
Anderson ^a (MT,WY) - Average	98	26.4	29.8	36.7	6.2	1.3	8345
Range: High		34.100	35.710	44.925	27.315	2.132	9850
Low		19.270	21.066	28.686	2.927	0.065	6594
Badger ^a (WY) - Average	42	27.4	33.3	31.4	7.9	0.45	7951
Range: High		29.3	34.5	32.6	9.8	0.5	8290
Low		22.7	31.7	28.5	6.6	0.4	7606
Brewster-Arnold (MT) - Average	7	22.1	30.9	41.9	5.1	0.42	9056
Range: High		24.980	33.550	44.191	4.902	0.725	9417
Low		18.290	29.494	39.722	3.128	0.236	7987
2s limit ^b		5.1	2.9	3.3	3.5	0.42	1035
Confidence range on average ^c		2.3	1.4	1.5	1.6	0.19	479
Broadus (MT) - Average	9	30.1	29.2	33.8	6.9	0.26	7377
Range: High		34.6	35.8	37.5	9.07	0.46	8490
Low		19.5	26.4	31.3	6.1	0.19	7120
2s limit		9.1	5.8	4.0	2.1	0.17	1099
Confidence range on average		3.5	2.2	1.5	0.82	0.07	422

Table 2.2.2.11 (continued)

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Limits of Variation in Coal Bed Analyses, Powder River Region
(as-received basis)

Coal Bed	Number of Samples	Proximate Analysis, Weight Percent				Sulfur, Weight Percent	Heating Value, Btu/lb
		Moisture	Vol. Matter	Fixed Carbon	Ash		
Canyon ^a (MT,WY) - Average	41	27.5	29.4	36.6	6.4	0.45	8306
Range: High		33.450	33.300	42.936	31.184	3.242	9691
Low		16.390	21.019	22.197	2.485	0.092	6958
Cook (MT) - Average	16	33.2	28.0	31.8	7.0	0.83	7264
Range: High		35.550	34.371	36.857	20.697	2.054	8198
Low		28.960	29.889	22.121	3.130	0.151	5881
2s limit		4.0	5.2	7.8	9.8	1.3	1136
Confidence range on average		1.1	1.4	2.1	2.6	0.36	302
Dietz ^a (MT,WY) - Average	35	26.1	25.7	37.3	6.1	1.3	8552
Range: High		32.4	34.800	45.434	34.809	2.375	9710
Low		17.3	21.218	26.663	2.557	0.201	6019
Dominy (MT) - Average	29	36.8	25.6	30.4	6.7	0.41	6691
Range: High		42.13	28.021	32.881	10.484	0.890	7271
Low		34.12	22.130	27.179	10.314	0.184	6297
2s limit		5.2	2.7	2.7	3.9	0.42	505
Confidence range on average		0.99	0.52	0.51	0.75	0.08	96

Limits of Variation in Coal Bed Analyses, Powder River Region
(as-received basis)

Coal Bed	Number of Samples	Proximate Analysis, Weight Percent				Sulfur, Weight Percent	Heating Value, Btu/lb
		Moisture	Vol. Matter	Fixed Carbon	Ash		
Dunning (MT) - Average	4	30.7	29.2	35.3	4.9	0.26	7814
Range: High		33.810	30.188	36.350	5.809	0.395	8005
Low		28.590	28.190	33.398	4.356	0.210	7445
2s limit		4.4	1.6	2.7	1.3	0.17	521
Confidence range on average		3.5	1.3	2.2	1.0	0.14	415
Elk (MT) - Average	9	32.7	28.0	34.4	4.9	0.32	7563
Range: High		35.980	28.822	36.282	7.478	0.535	7852
Low		30.610	26.447	31.304	3.701	0.208	7125
2s limit		3.5	1.5	3.3	2.6	0.21	531
Confidence range on average		1.3	0.59	1.3	1.0	0.08	204
Felix ^a (WY) - Average	42	28.0	31.7	32.5	7.8	0.89	8053
Range: High		33.5	36.4	39.4	14.9	3.26	9535
Low		17.8	29.1	28.4	4.5	0.32	7180
Flowers-Goodale (MT) - Average	5	29.9	27.3	35.3	7.5	0.59	7807
Range: High		31.5	28.591	36.85	9.0	0.961	8271
Low		27.770	26.2	34.1	5.56	0.380	7540
2s limit		3.1	2.0	2.3	2.5	0.55	704
Confidence range on average		2.0	1.3	1.5	1.6	0.34	437

Table 2.2.2.11 (continued)

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Limits of Variation in Coal Bed Analyses, Powder River Region
(as-received basis)

Coal Bed	Number of Samples	Proximate Analysis, Weight Percent				Sulfur, Weight Percent	Heating Value, Btu/lb
		Moisture	Vol. Matter	Fixed Carbon	Ash		
Glenrock-Big Muddy Zone ^a (WY) - Average	10	23.4	35.9	34.0	6.8	0.66	8742
Range: High		27.2	49.3	41.3	10.6	0.97	9270
Low		19.9	29.7	20.3	4.8	0.40	7695
Healy ^a (WY) - Average	15	28.5	30.0 ^d	33.9 ^d	7.6	0.6	7884
Range: High		30.7	31.9	34.8	22.1	3.00	8270
Low		22.6	28.6	32.8	5.1	0.26	6480
Knobloch (MT) - Average	78	28.4	29.2	36.9	5.4	0.31	8348
Range: High		36.480	37.536	43.386	13.816	5.320	9314
Low		21.720	25.519	28.188	3.237	0.095	7220
2s limit		5.0	4.2	5.6	3.8	1.2	918
Confidence range on average		0.56	0.47	0.62	0.42	0.14	102
Mesaverde ^a (WY) - Average	2	21.9	37.5	31.5	9.0	0.71	8479
Range: High		24.1	41.4	36.8	12.6	0.72	8712
Low		19.8	33.6	26.2	5.5	0.70	8246

Table 2.2.2.11 (continued)

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Limits of Variation in Coal Bed Analyses, Powder River Region
(as-received basis)

Coal Bed	Number of Samples	Proximate Analysis, Weight Percent				Sulfur, Weight Percent	Heating Value, Btu/lb
		Moisture	Vol. Matter	Fixed Carbon	Ash		
Monarch ^a (WY) - Average	203	21.5	34.5	39.6	4.4	0.4	9600
Range: High		26.0	38.4	44.0	8.2	0.7	10410
Low		14.5	30.3	34.9	3.1	0.3	9000
Pawnee (MT) - Average	7	33.9	25.9	30.4	9.8	0.88	6964
Range: High		36.370	27.555	34.343	25.315	2.731	7902
Low		28.980	23.128	22.577	3.877	0.149	5556
2s limit		5.5	2.9	7.7	14.9	1.9	1469
Confidence range on average		2.6	1.3	3.6	6.9	0.87	680
PK, Ulm 2, Ulm 1 (WY) ^a - Average	5	30.2	31.2	34.3	4.3	1.5	8000
Range: High		30.7	33.2	38.4	8.8	3.2	8320
Low		27.4	28.9	31.0	2.3	0.3	7640
Roland (MT) - Average	15	30.4	30.1	33.8	5.7	0.30	7928
Range: High		36.710	37.275	41.953	14.174	0.674	9114
Low		25.75	24.607	27.130	2.959	0.163	6608
2s limit		7.7	6.8	8.4	5.9	0.30	1423
Confidence range on average		2.1	1.9	7.6	1.6	0.08	394

Table 2.2.2.11 (continued)

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Limits of Variation in Coal Bed Analyses, Powder River Region
(as-received basis)

Coal Bed	Number of Samples	Proximate Analysis, Weight Percent				Sulfur, Weight Percent	Heating Value, Btu/lb
		Moisture	Vol. Matter	Fixed Carbon	Ash		
Rosebud (MT) - Average	27	23.5 ^e	28.7	39.1	8.7	1.0	8900 ^e
Range: High		26.5	30.4	40.3	16.42	7.20	9330
Low		20.24	20.24	34.74	6.4	0.6	7810
2s limit		3.2 ^e	2.1	2.4	3.9	2.5	552 ^e
Confidence range on average		0.63 ^e	0.42	0.47	0.78	0.49	107 ^e
Sawyer (MT) - Average	12	31.3	29.1	33.3	6.3	0.51	7598
Range: High		35.2	33.051	37.700	9.99	1.8	8070
Low		26.6	27.440	29.396	4.0	0.24	6930
2s limit		3.9	3.0	4.6	3.6	0.88	698
Confidence range on average		1.2	0.97	1.4	1.1	0.28	222
School ^a (WY) - Average	3	22.2	35.9	30.5	11.4	0.6	8183
Range: High		26.4	38.1	33.6	15.7	0.7	8870
Low		19.5	34.4	28.3	8.8	0.5	7830
Smith ^a (MT,WY) - Average	3	24.220	27.495	34.019	15.662	0.791	7825
Range: High		31.800	28.700	36.014	30.193	0.957	7991
Low		12.960	25.604	31.243	4.700	0.630	7607

Table 2.2.2.11 (continued)

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Limits of Variation in Coal Bed Analyses, Powder River Region
(as-received basis)

Coal Bed	Number of Samples	Proximate Analysis, Weight Percent				Sulfur, Weight Percent	Heating Value, Btu/lb
		Moisture	Vol. Matter	Fixed Carbon	Ash		
Sussex "Lower Coal Bed" (W.)							
		Note: Only one sample is reported - see Table 2.2.2.10 for the analysis.					
T (MT) - Average	13	36.1	27.0	30.8	6.2	0.57	7120
Range: High		38.360	29.516	35.187	13.151	1.181	7592
Low		31.840	19.821	27.474	4.242	0.314	6867
2s limit		3.9	4.6	3.9	5.6	0.48	421
Confidence range on average		1.2	1.4	1.2	1.7	0.15	127
Terret (MT) - Average	4	30.3	26.9	37.0	5.8	0.32	7870
Range: High		31.6	27.4	38.322	6.2	0.691	8170
Low		28.99	26.6	35.4	5.1	0.2	7630
2s limit		2.2	0.68	2.4	1.0	0.49	447
Confidence range on average		1.7	0.54	1.9	0.83	0.39	356
Wall (MT) - Average	43	24.5	30.5	40.4	4.6	0.30	9077
Range: High		28.700	36.671	47.055	12.584	1.115	10079
Low		16.840	27.500	32.693	2.533	0.119	7637
2s limit		4.3	4.7	4.8	3.5	0.42	833
Confidence range on average		0.65	0.70	0.72	0.52	0.06	124

Table 2.2.2.11 (continued)

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Limits of Variation in Coal Bed Analyses, Powder River Region
(as-received basis)

Coal Bed	Number of Samples	Proximate Analysis, Weight Percent				Sulfur, Weight Percent	Heating Value, Btu/lb
		Moisture	Vol. Matter	Fixed Carbon	Ash		
Wyodak-Anderson ^a (WY) - Average	59	29.8	30.7	33.5	6.0	0.5	8244
Range: High		36.9	35.5	41.4	12.2	1.2	9600
Low		22.1	26.5	29.6	3.9	0.2	7420

Notes:

^aCalculations of the "2s limit" and "Confidence range on average" cannot be determined due to lack of proper data on Wyoming analyses.

^b"2s limit" equals twice the standard deviation and represents the interval on either side of the average within which 95 percent of the individual values are expected to lie.

^c"Confidence range on average" represents the range around the average within which there is 95 percent confidence that the true average lies.

^dRepresents average for five samples.

^eCalculated from 28 samples.

Sources: References 2,5,12

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San Juan Basin

2.2.3 The San Juan Basin Region

The San Juan Basin Region is a major physiographic subdivision of the Colorado Plateau in northwestern New Mexico and southwestern Colorado. The region is about 200 miles long (north to south) and 130 miles wide, covering 26,000 square miles.¹

The basin is an asymmetrical circular structure, deepest to the northeast. Steeply dipping coal beds occur on the eastern and northern margins, whereas the beds on the southern and western margins dip gently.

The seven different formations included in the region are: 1) Crevasse Canyon, part of the Mesaverde Group; 2) Dakota Formation; 3) Fruitland Formation; 4) Menefee, part of the Mesaverde Group; 5) Cleary Coal member of the Menefee, part of the Mesaverde Group; 6) Upper member of the Menefee, part of the Mesaverde Group; and 7) Mesaverde Formation.

The San Juan Basin Region contains coals ranging from subbituminous B to high-volatile A bituminous.² Certain fields within the San Juan Basin which contain solely bituminous coal will not be characterized here; however, those fields which contain both subbituminous and bituminous coal will be discussed. The coals within the the San Juan Basin are borderline in rank between subbituminous and bituminous and are not always easily distinguishable. References often disagree on the rank of various coal beds, but for the purpose of this report, if a field was said to contain subbituminous coal it is treated as such here. In general, the Colorado portion of the San Juan Basin Region is thought to contain only bituminous coals and is not discussed in this report.

2.2.3.1 Geology

The San Juan Basin is generally comprised of sandstone ribs and shale flats, with sand sheets and local sand dunes near the dry washes. As the sedimentary beds dip gently, and have been subjected to long periods of erosion in an arid to semi-arid climate, the table land, rock terrace, dry arroyo, cuesta, canyon, and erosion escarpment are the distinctive physiographic land forms.¹

The basin is an asymmetric structural depression which contains Cambrian, Devonian, Pennsylvanian, Permian, Triassic, Jurassic, Upper Cretaceous, Tertiary and Quaternary rocks. The maximum known thickness of sedimentary rocks in the basin was discovered when a well was drilled to a total depth of 14,423 feet and penetrated Precambrian rock at 14,030 feet. The Upper Cretaceous rocks of the basin are 6,000 or more feet thick and consist of intertonguing marine and nonmarine units that represent three basin-wide transgressive-regressive cycles of deposition.³

The accumulation of coal started with the organic matter that was accumulated, preserved, and subsequently coalified, primarily in the paludal (swamp) freshwater environment in the lowlands shoreward from the sea margin.⁴

The assymetric structure of the basin, with Cretaceous and early Tertiary strata dipping steeply into the basin on the north and east sides, limits the amount of strippable coal in those areas. Coals cropping out on the basin edges lie at altitudes greater than 7,000 feet above sea level in many areas; in the structurally lowest part of the basin, which is in the northeastern part about 30 miles west of the Monero Field, the lowest Cretaceous coal beds are as much as 9,000 feet below the surface.⁵

2.2.3.2 Coal Reserves and Mines

Figure 2.2.3.1 is a map of the fields and areas of strippable coal in the San Juan Basin Region. A total of 24 fields or areas are contained in the seven formations mentioned earlier. There are 19 fields or areas in New Mexico and five in Colorado of which 15 contain subbituminous coal. The strippable coal reserves are grouped in two broad categories--those consisting of beds three feet thick or thicker beneath 100-150 feet of overburden, and those in beds five or more feet thick beneath 150 to 250 feet of overburden.¹

Table 2.2.3.1 shows the subbituminous strippable reserve base in the San Juan Basin. These reserves, which may include some bituminous coal, total 5.5 billion short tons.

Estimates for the subbituminous coal resources in the San Juan Basin are classed as inferred due to insufficient data. Inferred resources are based on drill-hole or outcrop measurements more than a mile apart, and involve considerable extrapolation of data and projection of geologic evidence. The inferred category encompasses a wide range of reliability, from that in areas in which drilling density is almost one hole per square mile but thickness variations are too great to permit accurate thickness contouring, to that in areas in which the reserve estimate is a speculation based on only a few measurements per township.¹

Reserves are to be considered "original," in that no account has been taken of tonnage mined, but such a small percentage of the total in any one field or area has been mined that the reserves can be thought of as "original" or "remaining" with no loss in accuracy. To avoid the problem of deciding on a reasonable recoverability factor, the full tonnage is reported without deduction for mining losses.¹

The tonnage estimates for strippable coal in the San Juan Basin are taken primarily from a New Mexico report by Shomaker and others (Reference 1). For this New Mexico report, an effort was made to restrict reserve estimates to coals minable at a 10:1 stripping ratio or better. As data were assembled, however, it became evident that such a restriction was not reasonable because thickness could not be determined accurately enough between data points. Accordingly, no stripping ratio limitation was placed on calculations made for the report. Data obtained as complete tonnage figures from coal lessees, however, are limited by various stripping ratios, these tonnages are indicated as such in Table 2.2.3.1.

Figure 2.2.3.1

Fields and Areas of Strippable Low-Sulfur Coal in San Juan Basin

LEGEND:

MINES:

Fields Containing Strippable Coal:

Bituminous

Subbituminous

Bituminous and Subbituminous

----- Designates San Juan Basin Coal Region

Sources: References 1,2,4

1. McKinley Mine
2. San Juan Mine
3. Navajo Mine

Table 2.2.3.1

Original Strippable Subbituminous Reserve Base^a of the San Juan Basin
(Millions of Short Tons)

Coal Field or Area	County (NM)	Overburden Less Than 150 Feet	Overburden 150 Feet to 250 Feet
Gallup ^b	McKinley	270.0 ^c	88.0 ^c
Newcomb	San Juan	78.5	6.3
Chaco Canyon	San Juan	31.0	--
Chacra Mesa	McKinley	--	--
San Mateo	McKinley	21.2	--
Standing Rock	McKinley	63.5	75.0
Zuni	McKinley	6.2	--
Crownpoint	McKinley	15.0	--
East Mt. Taylor ^b	Sandoval	--	--
La Ventana ^b	Sandoval	15.0	--
Tierra Amarilla	Rio Arriba	--	--
Monero ^b	Rio Arriba	--	--
Navajo	San Juan	1024.7 ^c	1352.8 ^c
Bisti	San Juan, McKinley	958.0	912.0
Star Lake	McKinley	365.0	270.0
Subtotal		2848.1	2704.1
TOTAL		5552.2	

Notes:

^aThe reserve base consists of inferred resources in the depth categories shown. Inferred resources are based on drill holes more than one mile apart and include considerable speculation of bed continuity.

^bThese fields include bituminous coals.

^cSome portion of these is limited by stripping ratio.

Source: Reference 1

Three of the fields in New Mexico (Navajo, Bisti, and Star Lake) are thought to contain the most extensive strippable reserve base in the basin. The fields are adjacent to one another and have estimated reserves of approximately 2.5 billion tons under less than 130 feet of overburden. Other estimates have placed surface reserves in excess of 4.8 billion tons under less than 250 feet of overburden.⁴

Low-rank coal mining activities are limited to three active mines in subbituminous areas within the San Juan Basin, as listed in Table 2.2.3.2. Table 2.2.3.3 lists the planned subbituminous mines and their expected first year productions.

2.2.3.3 Identified Coal Resources

Estimation of the subbituminous coal resources in the San Juan Basin is difficult due to the manner in which most references categorize the resources. Table 2.2.3.4 lists the subbituminous coal resources estimated for the state of New Mexico, not distinguishing between the San Juan Basin and other subbituminous coals in the state. Table 2.2.3.5 lists the coal resources in the San Juan Basin classified by formation, not distinguishing the bituminous and subbituminous coals within that formation.

Of the total 50.6 billion tons of subbituminous coal estimated for New Mexico, 45.8 billion tons lie in the San Juan and McKinley Counties of the San Juan Basin. This is over 90 percent of the subbituminous coals in New Mexico, not including the other fields of the San Juan Basin not within those two counties.^{9,5} (This percentage varies depending on rank classifications of other basins, e.g., Raton Mesa, in the area.)⁸

The majority of these resources lie in the "inferred by zone" thickness classification which are thicker than 2.5 feet. "Inferred by zone" was established to include resources that could not be determined by conventional methods. Because the coal beds are limited in extent, but the coal bearing zones are very persistent and cover large areas, the classification method did not permit the usual breakdown of resources according to thickness of bed. Therefore, the "inferred by zone" will cover this category which includes much thick coal.⁵

As the table indicates, the majority of the subbituminous coal in this area is low in sulfur and high in ash.

2.2.3.4 Overburden Characteristics

The overburden in the San Juan Basin Region ranges from 0 to more than 4,000 feet thick. The overburden consists mainly of sandstones and shale beds.

The existing pattern of overburden is primarily due to the structure of the basin combined with the present day topographic surface. The thickest overburden occurs when areas of higher altitude overlie the lower part of the structure basin.

Table 2.2.3.2

Active Mines in Subbituminous Fields of the San Juan Basin

Mine	Location	Name of Company	1978 Tonnage Mined (million short tons)
1. McKinley Mine	Gallup, N.M.	Pittsburg & Midway Coal Mining Company	2.99
2. San Juan Mine	North of Fruitland, N.M.	Western Coal Company	2.61
3. Navajo Mine	Fruitland, N.M.	Utah International Inc.	8.0

Source: Reference 2

Table 2.2.3.3

Planned Mines in the Subbituminous Fields of the San Juan Basin

Mining Company	Mine	County, State	Startup Date	First Year Production (million tons)
Consol-El Paso	Burnham	San Juan, N.M.	1980	0.3
Tucson Gas & Electric	Gallo Wash	San Juan, N.M.	1984	0.7
Chaco Energy	Hospah	McKinley, N.M.	1983	1.0
Chaco Energy	Star Lake	McKinley, N.M.	1985	0.5
Freeman United Coal	Star Lake East	McKinley, N.M.	1984	0.5
Eastern Assoc.	Bisti East	McKinley, N.M.	1983	2.5
Arch Minerals	Unit No. 1	San Juan, N.M.	1985	0.4
Arch Minerals	Unit No. 2	San Juan, N.M.	1986	0.4
Consol-El Paso	Unnamed	San Juan, N.M.	1984	1.2
Cimarron	La Plata	San Juan, N.M.	1980	0.5
Western Coal	Bisti	San Juan, N.M.	1980	0.1

Source: Reference 10

Table 2.2.3.4

Classification of Identified Subbituminous Coal Resources of New Mexico^{a, b}

<u>DEPTH OF SEAM</u>			<u>SEAM THICKNESS</u>		
<u>Ft.</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>	<u>Ft.</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>
0-1000	20.95	42	> 2.5 (inferred by zone) ^{a, c}	42.81	85
1000-2000	14.82	29	2.5-5	3.43	7
2000-3000	14.83	29	5-10	2.82	5
			> 10	0.97	2
			Unknown ^d	0.58	1
<hr/>			<hr/>		
Total	50.6	100.0	Total	50.6	100.0

Sources: References 5,9

<u>SULFUR CONTENT</u>			<u>ASH CONTENT</u>		
<u>Wt. % "as received"</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>	<u>Wt. % "as received"</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>
< 1	50.6	100	0-5	--	--
1-3	--	--	5-10	--	--
> 3	--	--	> 10	50.6	100
<hr/>			<hr/>		
Total	50.6	100.0	Total	50.6	100.0

Sources: References 7,9

Notes:

^aThese tonnage estimates are for the entire state of New Mexico, not distinguishing between the San Juan Basin and other subbituminous coal-bearing areas in the state.

^bIdentified resources include Demonstrated (Measured and Indicated) and Inferred resources 2-1/2 feet or more thick to an overburden depth of 3000 feet.

^c"Inferred by Zone" category includes estimates based on sample data too sparse for conventional classification. See reference 5.

^dTonnages not delineated into thickness ranges but included in the total state estimate.

Table 2.2.3.5

Classification of Total Coal Resources of the San Juan Basin (Includes Bituminous)^aFruitland Formation

<u>Depth, Feet</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>
0-500	14.64	7
500-1000	13.87	7
1000-2000	27.94	14
2000-3000	58.81	29
3000-4000	82.82	41
4000+	3.06	2
<hr/>		
Total	201.14	100.0

Source: Reference 6

Menefee Formation

Northern San Juan Basin

<u>Feet</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>
1500-2000	.019	6
2000-2500	.083	24
2500-3000	.100	29
3000-3500	.079	23
3500-4000	.070	18
<hr/>		
Total	.341	100.0

Southern San Juan Basin

<u>Feet</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>
0-500	.283	42
500-1000	.063	10
3000-3500	.024	4
3500-4000	.291	44
<hr/>		
Total	.661	100.0

Source: Reference 6

Notes:

^aData for the Mesaverde Formation are not available.

Gently dipping beds and rolling topography along the south and west flanks of the basin result in a band 4-6 miles wide that is underlain by the Fruitland coal bed at depths of less than 500 feet. Another band of approximately equal width lies to the northeast where the coal is less than 1000 feet below the surface. Along the north and east sides of the basin, the Fruitland beds dip steeply basinward in monoclinal hogbacks and are generally more than 1000 feet below the surface within 1-2 miles of their outcrops. Coal is generally absent from the Fruitland outcrop along the east side of the basin and lies at depths exceeding 2000 feet where identified from well logs near the east rim of the basin. The thickest coal zones of the Fruitland crop out only along the northwest flank of the basin where they dip abruptly to depths in excess of 2000 feet.³

In the Gallup, Crownpoint, East Mt. Taylor, Zuni, and fields included in the Fruitland Formation, the irregularity of the beds presents some mining problems, but the sandstone and shale overburden is not particularly difficult to strip mine.

2.2.3.5 Aquifers

Sedimentary rocks (mainly sandstone, limestone, and unconsolidated sand and gravel) are the most productive aquifers or water bearing beds in New Mexico. Evaporite rock (mainly anhydrite and gypsum) are relatively impermeable, but may be productive where they are leached or fractured. Volcanic rocks in New Mexico are not good aquifers, but locally they may yield large quantities of water. Intrusive igneous and metamorphic rocks are generally poor aquifers. Widespread thick aquifers will yield more water than equally permeable, thin discontinuous aquifers.¹

In the San Juan Basin the aquifers consist primarily of sandstone with a stretch of sand and gravel aquifers along the San Juan River and another stretch of limestone aquifers in the Gallup and Zuni area. The depth to ground water in the basin ranges from less than 200 feet in the area of the limestone aquifer (Gallup and Zuni) to 200-500 feet in the basin of the San Juan Basin to more than 500 feet elsewhere.⁵

2.2.3.6 Coal Analyses and Limits of Variations

The coals in the San Juan Basin Region range from subbituminous B to high-volatile A bituminous. The Mesaverde Group of coals, of which the Menefee and Mesaverde Formations are a part, are mainly nonagglomerating subbituminous A or B coals in the lower part of the unit and high-volatile C to B bituminous in the upper beds. The large reserves of the Fruitland Formation coals in the San Juan Basin range from subbituminous A non-agglomerating beds to high volatile C bituminous nonagglomerating coals; in general, the northern Fruitland coals are somewhat higher in rank than those to the southeast.²

The Fruitland Formation coal has been described as hard, brittle, and black; like other low-rank coals it decomposes or slacks on exposure to weather. It contains, in places, many woody charcoal fragments and small lumps of fossil resin. Iron sulfide in the form of small grains and veinlets of pyrite and marcasite (FeS_2) have been observed in many well cuttings and cores.⁶

The representative analyses in Table 2.2.3.6 illustrate the ranking difficulties encountered with San Juan Basin coals. The relatively low moisture contents (10-20%) are more characteristic of bituminous coals than low-rank coals, and in fact these analyses may include some bituminous coal samples. Additional information is needed to more accurately describe the coal resources of this region.

As shown in Table 2.2.3.7, the ash from San Juan Basin coals is generally higher in the acidic components (SiO_2 , Al_2O_3 , Fe_2O_3) than the alkali components (CaO , MgO , Na_2O). This is more typical of high-rank coals than low-rank coals.

Table 2.2.3.6

Page 1 of 2

Representative Analyses of Coal Samples from Fields Containing Subbituminous Coal in the San Juan Basin
(as-received basis)

Coal Field or Area	Number of Samples	Proximate Analysis, Weight Percent				Ultimate Analysis, Weight Percent						Heating Value Btu/lb.	Ash Softening Temp °F
		Moisture	Volatile Matter	Fixed Carbon	Ash	H	C	N	O	S	Ash		
La Ventana Mesaverde Formation - Average	6	16.1	33.85	43.0	7.0	6.1	58.5	1.1	25.6	1.1	7.0	10,340	2,253
Range: High		20.0	35.8	45.1	9.9	6.4	61.5	1.2	29.5	2.8	9.9	10,940	2,340
Low		12.1	32.0	40.8	4.9	5.5	52.8	1.1	21.2	0.6	4.9	8,910	2,110
Standing Rock Upper Menefee - Average	6	16.2	33.5	39.0	11.4	5.9	56.5	0.9	24.7	0.7	11.4	9,895	2,658
Range: High		17.3	36.9	43.3	18.4	6.4	61.5	1.0	26.2	1.0	18.4	10,810	2,900
Low		15.3	31.1	34.5	4.8	5.4	50.5	0.8	23.5	0.5	4.9	8,870	2,460
Chaco Canyon Upper Menefee - Average	4	13.4	29.3	35.3	21.9	4.3	39.9	0.9	18.2	1.5	35.8	8,023	2,780
Range: High		17.5	34.8	42.8	61.3	5.7	57.1	1.3	24.8	2.2	61.3	10,220	2,910
Low		7.2	16.8	14.7	7.5	2.8	22.6	0.5	11.5	0.9	10.2	3,980	2,650
Newcomb Mesaverde Formation - Average	6	17.3	32.3	39.2	11.3	5.8	54.7	1.1	26.1	0.9	11.3	9,515	2,678
Range: High		19.1	35.5	42.7	22.7	6.3	59.1	1.3	30.8	1.4	22.7	10,410	2,780
Low		15.3	27.7	31.1	6.6	5.5	43.9	0.9	23.3	0.5	6.6	7,660	2,570

Table 2.2.3.6 (continued)

Page 2 of 2

Representative Analyses of Coal Samples from Fields Containing Subbituminous Coal in the San Juan Basin
(as-received basis)

Coal Field or Area	Number of Samples	Proximate Analysis, Weight Percent				Ultimate Analysis, Weight Percent						Heating Value Btu/lb.	Ash Softening Temp °F
		Moisture	Volatile Matter	Fixed Carbon	Ash	H	C	N	O	S	Ash		
Gallup Mesaverde Formation - Average	16	12.1	37.6	42.8	6.9	6.0	63.6	1.1	21.9	0.7	7.5	11,272	--
Range: High		15.4	40.7	46.3	10.5	6.3	66.1	1.2	24.7	1.4	7.9	11,890	--
Low		10.0	34.6	40.5	4.3	5.3	60.6	1.0	18.6	0.4	6.8	10,680	--
Monero Mesaverde Formation - Average	5	4.0	37.3	51.0	7.7	5.4	71.7	1.5	10.7	1.4	--	12,895	2,463
Range: High		7.2	39.0	55.1	10.4	5.5	75.4	1.6	11.3	3.5	--	13,730	2,820
Low		1.7	36.1	48.4	5.3	5.2	69.2	1.4	10.2	0.7	--	12,160	2,230
Star Lake Fruitland Formation - Average	16	11.7	33.2	33.9	21.2	5.4	53.2	1.0	21.9	0.53	--	9,154	2,725
Range: High		13.6	40.0	43.0	32.7	5.9	64.2	1.3	22.9	.67	--	10,141	2,750
Low		9.2	27.4	26.7	5.8	4.8	43.0	0.8	20.4	0.4	--	7,393	2,700
Bisti Fruitland Formation - Average	23	11.8	27.1	39.1	20.2	4.7	49.5	0.71	24.8	0.57	--	9,075	2,458
Range: High		19.4	33.9	47.8	35.1	6.8	58.6	1.5	32.4	.86	--	11,035	2,800
Low		4.5	20.7	31.9	10.1	2.9	42.3	0.5	20.9	0.3	--	7,410	2,225
REGION AVERAGE		12.8	33.0	40.4	13.4	5.4	56.0	1.0	21.7	0.9	14.6	10,020	2,252

Sources: References 1,2

Table 2.2.3.7

Analyses of Ash From Core Samples Collected in the San Juan Basin

Coal Area	Number of Samples	Chemical Analysis, Weight Percent of Ash									
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	MnO	Na ₂ O	K ₂ O	SO ₄
Newcomb	2	60.6	22.3	8.2	1.4	2.8	1.1	.03	2.1	0.6	2.1
Bisti	5	57.7	29.2	3.6	1.5	2.6	0.4	0.04	3.2	0.5	2.9
Chaco Canyon	1	83.4	9.2	3.5	0.6	0.5	0.6	.02	0.9	1.4	0.7
Star Lake	2	56.7	28.8	2.7	1.4	3.4	0.5	.03	2.7	0.5	3.5
Standing Rock	6	54.7	22.1	6.2	1.3	4.9	.95	.09	3.0	.5	6.6
REGION AVERAGE		62.6	22.3	4.8	1.2	2.8	0.7	.04	2.4	0.7	3.2

Source: Reference 1

References - Section 2.2.3

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Northern Alaska

2.2.4 Northern Alaska Region

Alaska contains vast quantities of coal and other minerals, but because geologic knowledge of Alaska is still far from complete, coal resource estimates are based on insufficient data and are probably conservative. The main source of information for this and the other Alaskan regions is the USGS Bulletin 1242-B (Barnes, 1967).¹

2.2.4.1 Geology

The principal coal-bearing districts of northern Alaska lie north of the Brooks Range and west of Iktalik and lower Colville Rivers. The southern part of this area consists of a broad upland dissected into rolling hills, north of which the nearly flat Arctic Coastal Plain extends to the Arctic Ocean. Coal-bearing Cretaceous rocks are known or inferred to underlie about 58,000 square miles of this area. These rocks, consisting mainly of alternating layers of sandstone and shale, have been folded into eastward-trending anticlines and synclines. Because of differences in resistance of the rocks to erosion, the folds are expressed topographically by the general east-west alignment of the ridges and valleys. Near the mountains the folding and faulting has been more intense and in places the strata stand nearly vertical, but in the northern foothills, which include the southernmost coal-bearing rocks, deformation has been only moderate, and further north under the Coastal Plain the beds are nearly horizontal. Beds of subbituminous coal, ranging from 3 to 14-1/2 feet in thickness, crop out at several points along the Kuk and Kugrua Rivers near the Arctic coast south and west of Wainwright. These beds are all nearly horizontal, and some of them reportedly have been traced for several miles along the east shore of the Kuk estuary,² so they may closely underlie many square miles of the surrounding Coastal Plain.

Farther inland a test well near the Kaolak River, a principal head water tributary of the Kuk, disclosed a thick coal-bearing section, including 36 coal beds ranging from 3 to 26 feet in thickness, within 3,000 feet of the surface. Geophysical evidence indicates that the well is near the axis of a broad anticline with gently dipping limbs. Although no fresh samples from this well have been analyzed, the coal is probably of subbituminous rank because in northern Alaska coal-bearing rocks that are more intensely folded generally contain bituminous coal. Subbituminous coal crops out at several localities between points 25 and 100 miles from the mouth of the Meade River, which runs northward through the middle part of the Region. The beds are thin, mostly less than 5 feet thick. A test well a few miles west of the river near the southern edge of the Coastal Plain cuts a coal-bearing section that includes 21 coal beds 4-30 feet thick, within 2000 feet of the surface. This coal also lies in a broad anticline and is considered to be of subbituminous rank. Other subbituminous coals are exposed at several places along the Ikpikuk River on the Coastal Plain, but all the known beds are too thin to be of value. On the Kigalik River, a headwater tributary of the Ikpikuk in the foothills belt, several beds of subbituminous coal 2-1/2 - 5 feet thick are exposed, and two beds of comparable thickness were found in a test well just east of the upper Ikpikuk River.

In the Colville River district, including the basin of the Colville River and its many large tributaries, coal is widely distributed both in the foothills and on the Coastal Plain. Subbituminous coal occurs in the eastern part of the district, principally in the Prince Creek Formation of Late Cretaceous age, in beds that are mostly less than 5 feet thick but include a few that are 10 feet thick. The subbituminous coals south of the Colville River generally occur in broad synclinal basins with low dips; those west of the north-flowing segment of the Colville River are nearly horizontal.

2.2.4.2 Coal Reserves

The Northern Alaska Region has not been sufficiently mapped to delineate reliable estimates of coal reserves or of the strippable reserve base. No mining activity currently exists in the region, although small amounts of subbituminous coal have been produced from the Meade River District in the past.

2.2.4.3 Identified Coal Resources

Figure 2.2.4.1 is a map of the Northern Alaska Region showing the boundaries of the subbituminous coal field and areas containing known surface minable deposits. Six subbituminous coal fields within the Northern Region and their estimated resources are listed in Table 2.2.4.1. Because of insufficient data, resource estimates include only "indicated" and "inferred" tonnages; sample spacings were too sparse throughout the Region to delineate any "measured" resource estimates.¹ The total resource is further classified in Table 2.2.4.2 according to depth, seam thickness, sulfur content, and ash content.

The depth of overburden data for the Region varies considerably due to some moderate folding of seams and the overall lack of reliable test data. Almost 85 percent of the subbituminous coal lies in seams 5 feet thick or greater, and all of the coal resource has a very low sulfur content. Ash content is variable, but the majority of samples average greater than 10 percent by weight, on an "as received" basis.

2.2.4.4 Overburden Characteristics

No information is available that specifies overburden composition within the Northern Alaska Region.

2.2.4.5 Aquifers

Again, no information is available on the existence and/or characteristics of Northern Alaska groundwater. However, it is anticipated that any groundwater below the permafrost is frozen solid year-round.

Figure 2.2.4.1

Northern Alaska Subbituminous Region Showing Areas of Surface Movable Coal

Source: Reference 1

Table 2.2.4.1

Estimated Original Resources of Subbituminous Coal
in the Northern Alaska Region
 (0-3000 feet)

Coal District	Resources, 10 ⁶ tons		
	Indicated	Inferred	Total
Utukok River	70	1,287.3	1,357.3
Kaolak Test Well I	100.8	43,280.0	43,380.8
Kuk River (Wainwright)	62.6	1,395.1	1,457.7
Kugrua River (Peard Bay)	44.2	796.0	840.2
Meade River	194.5	6,161.8	6,356.3
Meade R. Test Well I	597.0	32,803.0	33,400.0
Ikpikpuk River	80.4	1,597.5	1,659.9
Titalus Test Well II	17.0	947.0	964.0
Colville River	431.5	10,855.1	11,286.6
Umial Test Well II	11.4	191.1	202.5
Totals	1,609.4	99,295.9	100,905.3

Source: Reference 1

Table 2.2.4.2

Classification of Northern Alaska Region Identified Subbituminous Coal Resources^a

<u>DEPTH OF SEAM</u>			<u>SEAM THICKNESS</u>		
<u>Ft.</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>	<u>Ft.</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>
0-1000	18.1	17.9	2.5-5	15.51	15.4
1000-2000	4.4	4.4	5-10	31.85	31.6
2000-3000	.44	.4	> 10	53.54	53.0
Unknown ^b	77.96	77.3			
<hr/>			<hr/>		
Total	100.9	100.0	Total	100.9	100.0

<u>SULFUR CONTENT</u>			<u>ASH CONTENT</u>		
<u>Wt. % "as received"</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>	<u>Wt. % "as received"</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>
0-1	100.9	100.0	0-5	--	--
1-3	--	--	5-10	--	--
3-10	--	--	> 10	--	--
			Unknown ^b	100.9	100.0
<hr/>			<hr/>		
Total	100.9	100.0	Total	100.0	100.0

Notes:

^aIdentified resources for the Northern Alaska region include Indicated and Inferred resources 2-1/2 feet or more thick to an overburden depth of 3000 feet.

^b"Unknown" refers to Identified resources not classified into the depth or ash ranges shown.

Source: Reference 1

2.2.4.6 Coal Analyses and Limits of Variation

Available data on subbituminous coal compositions are listed in Table 2.2.4.3, which includes analyses of moisture, volatile matter, fixed carbon, ash, sulfur, and heating values.

The overall average moisture content is roughly 14 percent, a low percentage for most subbituminous coals.

Table 2.2.4.3

Northern Alaska Region Subbituminous Coal Analyses
(as-received basis)

Location	Sample Source	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	Heating Value Btu/lb.
Kuk and Kugrua Rivers	Outcrop	17.8-26.7	29.1-31.9	40.5-42.5	2.3-9.8	.2- .3	8780-9510
Meade and Ikpikpuk Rivers	Mine	14.4	33.5	47.3	4.8	.6	10,330
	Outcrop	8.3-9.9	32.4-35.5	37.7-49.9	6.4-20.0	.2- .8	7700-10,720
Colville River	Outcrop	5.2-16.4	28.3-31.6	41.9-49.2	11.8-23.4	.3- .7	8450-9390

Source: Reference 1

References - Section 2.2.4

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Gulf Coast Lignite Region

2.2.5 Gulf Lignite Region

The Gulf Lignite Region covers a five state area, which includes southern Alabama, Mississippi, eastern and southeastern Arkansas, northern Louisiana, and southeastern Texas. Tennessee is included on the map but no lignite activity is evident in this state. Lignite mining in the region has been active for decades; however, intensified interest in this energy resource has spawned new geologic investigations and mining operations. Reports on resource and reserve estimates are still far from complete.

2.2.5.1 Geology

Conditions leading to the deposition and formation of lignite-producing materials existed in the Gulf Coast area during the Tertiary Period. These conditions developed during the Eocene Epoch, approximately 38 to 54 million years ago. Strata of the Tertiary System crop out in a narrow belt through the states of the lower Mississippi Valley region. This belt, which extends as far north as the southern tip of Illinois, roughly outlines the structural basin associated with the Mississippi River. Thousands of feet of Tertiary sediments have been deposited and downwarped along the southward plunging axis of the basin. These sediments subsequently were covered by a blanket of Quaternary gravels, sands, silts, and loam.

The basin underwent slow subsidence during the Cretaceous and Tertiary Periods. Subsidence permitted the ancestral Gulf of Mexico to advance northward approximately five hundred miles from the present Mississippi coast line. The advance of the Gulf of Mexico created an inland extension of the sea known as the Mississippi Embayment.

The geological history of the Embayment is marked by five major advances and regressions of the sea, which occurred from early Cretaceous to late Eocene time. The advances and retreats of the sea are noted in the geologic column of the Gulf Coastal region by alternating sequences of sedimentary beds of marine and continental origin.

The commercial lignite deposits of the Gulf Coastal area are found in a narrow band of Tertiary strata that almost continuously outlines the margin of the Mississippi Embayment. The lignite-bearing strata have been exposed on the surface by erosion of the overlying Quaternary sediments and by structural dip associated with the embayed area. Lignites of commercial quantity and quality are present in the Wilcox, Claiborne, and Jackson Groups of the Gulf Coastal province. However, the principal lignite deposits are found in sediments of the Wilcox Group.¹ In Texas, lignite deposits of secondary importance to the Wilcox Group are found in the Jackson Group as well as the upper Eocene Yegua Formation.

Lignite deposits are found as components of either ancient fluvial (river-deposited), deltaic (deposits at the river mouth), or lagoonal (deposits on lagoon bottoms) rocks. Commercial deposits of fluvial lignite occur only in the Wilcox Group. Small deposits of deltaic lignite occur in the Yegua and Manning formations, but are most evident in the Wilcox group. Lagoonal lignite occurs with equal abundance in the Wilcox group, Indio formation, Yegua formation, and Jackson group.

Alabama Wilcox formational units contain some beds of known marine origin. In Mississippi the Wilcox group is composed almost entirely of non-marine beds devoid of diagnostic fossils. Transitional deposits are present in Kemper and Lauderdale counties, Mississippi, where non-marine strata of the Wilcox group interfinger and interbed with the marine facies of the Alabama Wilcox formations.

Mississippi Wilcox lignite deposits are unpredictably irregular in shape, limited in areal extent, and erratic in seam thickness. They are characterized by small, stacked deposits and appear irregular in shape, varying from narrow meandering fluvial deposits to roughly elliptical deposits of deltaic origin. Seam thicknesses vary from a few inches at the outer edges up to 10 to 12 feet at the center of the downwarped basins.

Claiborne Group lignites are very similar in nature to those of the Wilcox Group and are found principally in sediments of the Cockfield (Yegua) formation. Test holes in Arkansas encountered beds of lignite three feet thick or more at depths less than 150 feet. Compared to the Wilcox lignites, Claiborne lignites are not as well developed. They are frequently high in ash and subsequently low in heating value.

Lignites have been reported in the upper Eocene Jackson Group in Texas and Mississippi, but are mostly in thin seams and only locally developed. In parts of the Texas lignite region the Yegua and Jackson beds are indistinguishable and are referred to as a single group.

2.2.5.2 Coal Reserves and Mines

Figure 2.2.5.1 is a map of the five-state Gulf Lignite Region, identifying the main lignite-bearing groups and the locations of existing mining areas within the Region. The region's demonstrated strippable lignite reserve base is shown in Table 2.2.5.1, totaling approximately 11.6 billion tons.

The existing lignite mines in the Gulf Lignite Region are all in Texas and are listed in Table 2.2.5.2. Very rapid development of the Gulf lignite will occur during the 1980's, as indicated by the long list of planned mines in Table 2.2.5.3. Most of this growth will occur in Texas but lignite mines are planned in the states of Louisiana and Arkansas as well.

Figure 2.2.5.1

Map of the Gulf Lignite Region, Showing Lignite-Bearing Groups and Mines

Source: Reference 3

Table 2.2.5.1

Strippable Lignite Reserve Base and Criteria
Used in the Gulf Lignite Region

State	Strippable Reserve Base (billion short tons)	Ref.	Strippable Reserve Criteria Used by Each State			
			Minimum Seam Thickness (ft)	Maximum Overburden (ft)	Maximum Stripping Ratio	Ref.
Texas	7.9	4	4	200	15:1	8
Louisiana	0.6	5	--	--	15:1	5
Arkansas	2.0	7	--	150	--	7
Mississippi	--	-	--	150	10:1	1
Alabama	1.1	9	--	250	--	6
Total	11.6					

Table 2.2.5.2

Active Surface Mines in the Gulf Lignite Region

Map No.	Company/Mine Name	County	State	Deposit	1978 Production (10 ⁶ Tons)
1	San Miguel/San Miguel Mine	Atascosa	Texas	Yegua-Jackson	4.400 (est.)
2	Alcoa/Sandow Mine	Milam	Texas	Wilcox	2.008
3	Texas Utility/Monticello	Titus	Texas	Wilcox	6.966
4	ICI/Darco	Harrison	Texas	Wilcox	.271
5	Texas Utility/Martin Lake	Panola	Texas	Wilcox	5.972
6	Texas Utility/Big Brown	Freestone	Texas	Wilcox	5.298

Source: Reference 3

Table 2.2.5.3

Planned Surface Mines in the Gulf Lignite Region

Company	Mine Name	County	State	Startup Date	Initial Capacity (MTPY)
Texas Utilities	Twin Oak	Robertson	TX	1984	3.5
Texas Utilities	Oak Grove	Limestone & Robertson	TX		
Phillips Coal	Oxbow	DeSoto, Red River, Parish	LA	1984	0.6
Texas Utilities	Forest Grove	Henderson	TX	1984	3.5
Texas Utilities	Mill Creek	Rusk	TX		
Sunetco	Swanee Creek	Angelina	TX	1983	1.0
Lower Colorado R. Author.	Camp Swift	Bastro	TX	1988	3.0
Lower Colorado R. Author.	Unnamed	Fayette	TX	1986	3.5
Northwestern Res.	Jewett	Freestone & Leon	TX	1985	4.0
Tex. Muni. Power Agency	Gibbon Creek	Grimes	TX	1981	1.5
Swepeco	Henry W. Pirkey	Harrison	TX	1983	0.7
Shell Oil	Milam	Milam	TX	1983	0.5
AMCA	Sunrise	DeSoto	LA	1981	0.3
Cleco-Swepeco	Bolet Hill	DeSoto	LA	1985	0.7
Shell Oil	Hampton	Calhoun	AK	1987	4.0
Titan Mining	Scranton	Logan	AK	1980	0.2
Carter	N/A	Rusk	TX	--	--
Dow Chemical	N/A	Freestone	TX	--	--
Gulf States	N/A	Houston & Leon	TX	--	--
Peabody Coal	N/A	McCulloch	TX	--	--
Phillips	N/A	Robertson, Hopkins, Van, Zandt & Wood	TX	--	--
Dahlstrom Industries	N/A	Maverick	TX	--	--
Tenneco?	N/A	N/A	TX	--	--
Atlantic Richfield Co.	N/A	N/A	TX	--	--
Temple Industries	N/A	Angelina	TX	--	--
CPS-San Antonio	N/A	N/A	TX	--	--
General Crude Oil Co.	N/A	Cass, Bowie, Rusk, Marion, Panola, & Cherokee	TX	--	--
Central Southwestern Serv.	N/A	Harrison, Marion, Grimes & Walker	TX	--	--
Farco Mining Co. (state land)	N/A	Webb	TX	--	--
Texas Lignite Products Corp.	N/A	Harrison	TX	--	--

Sources: References 2,13

2.2.5.3 Identified Coal Resources

Table 2.2.5.4 lists the Identified Lignite resources of the Gulf Region by state. Alabama and Arkansas resource estimates are based on inferred estimates only.^{6,7} Table 2.2.5.5 presents summary data on the Gulf Lignite Region identified lignite resources, classified by depth, seam thickness, sulfur content, and ash content. Seam thickness data on all the resource is not known and over half is listed as "unknown."

As seen from Table 2.2.5.5 the Gulf lignites are typically low in sulfur and high in ash content - over 70 percent of the total resources have an ash content higher than 10 percent by weight, as received. Only 17 percent of all the lignite is considered strippable, which means other mining or utilization methods will be necessary if the remaining 56 billion ton resource is to be recovered.

2.2.5.4 Overburden Characteristics

Unlike the vast lignite-bearing lands of the Fort Union Region, Gulf lignite deposits began as alluvial, deltaic, and fluvial sediments. The associated overburdens reflect similar geologic depositions and consist of unconsolidated sands, silt, clays, and gravel. The Gulf lignite province is a coastal plain supporting forest, farmland, and prairie on gently rolling to relatively flat lowland. Surface mining within the Region, although in existence for many years, is advancing from its infancy into a prominent industry. To help meet the problems of increased overburden disturbance, parallel studies are being conducted on land reclamation methods at mining sites.

Much of the lignite-bearing land is covered by soil that is not markedly different from the underlying sediments and rocks; hence, topsoils are not much more fertile than overburden. This simplifies reclamation because the topsoil need not be segregated during initial overburden removal. The dominant problem encountered in Gulf Region lignite surface mining is the disruption of aquifers overlying or within the lignite seams.

2.2.5.5 Aquifers

The depositional history of the Gulf Lignite Region has caused an intimate, almost unavoidable association between lignite deposits and groundwater systems. The environments for both were established during the period of deltaic and coastal plain sedimentation.

The Wilcox Group, Carrizo Sand, Queen City Sand, and the Sparta Sand are the most important water-bearing units in the Gulf Coastal Plain of Texas. Among these, the major sources of water are the Wilcox Group and the Carrizo Sand. Movement of water in these units varies from negligible

Table 2.2.5.4

Identified Lignite Resources^a of the Gulf Lignite Region, by State

State	10 ⁹ Tons	Ref.
Texas	52.2	4
Alabama	2.0	6
Arkansas	13.5	7
Louisiana	0.6	5
Mississippi	--	
Total	68.3	

Notes:

^aIdentified resources include Demonstrated (Measured and Indicated) and Inferred resources 2-1/2 feet or more thick to an overburden depth of 3000 feet.

Table 2.2.5.5

Classification of Gulf Lignite Region Identified Lignite Resources^a

<u>DEPTH OF SEAM</u>			<u>SEAM THICKNESS</u>		
Ft.	10 ⁹ Tons	Percent of Total	Ft.	10 ⁹ Tons	Percent of Total
0-1000	43.0	63.0	0-10	23.7	34.7
1000-2000	25.3	37.0	10-20	2.6	3.8
2000-3000	--	--	> 20	0.2	0.3
			Unknown ^b	41.8	61.2
Total	68.3	100.0	Total	68.3	100.0

<u>SULFUR CONTENT</u>			<u>ASH CONTENT</u>		
Wt. % "as received"	10 ⁹ Tons	Percent of Total	Wt. % "as received"	10 ⁹ Tons	Percent of Total
0-1	64.3	94.0	0-5	--	--
1-3	2.0	3.0	5-10	20.0	29.3
> 3	2.0	3.0	> 10	48.3	70.7
Total	68.3	100.0	Total	68.3	100.0

Notes:

^aIdentified resources include Demonstrated (Measured and Indicated) and Inferred resources 2-1/2 feet or more thick to an overburden depth of 3000 feet.

^b"Unknown" refers to Identified resources not classified into the thickness ranges shown.

Sources: References 5,6,7,8

to more than several hundred feet annually. The rates of movement in most of the sand formations are between 10 and 100 feet per year. For the purposes of calculating water availability, an average coefficient of transmissibility for the Wilcox Group and Carrizo Sand around Milam County, Texas, has been assumed to be 50,000 gal/day/ft. The combined thickness of these two water-bearing units range from 15,000 to 4,340 feet.¹¹

Less detailed information on groundwater systems is available on other states in the region, but the integral association between lignite deposits and aquifers exists throughout the five state area. Any surface mining operation removes and mixes the overburden, destroying the aquifer system that existed prior to mining.

2.2.5.6 Coal Analyses and Limits of Variation

Lignite sample analyses from each of the five states in the Gulf Lignite Region are listed in Table 2.2.5.6. The ranges between samples from the same state are extremely wide for many properties; therefore, statistical calculations for the "2s limit" (twice the standard deviation) and the "confidence range for the average" have been calculated from available data (reference 1, 5, 7, 8) for this report. As an example of sample variability, the moisture content in Alabama lignite ranges from an extremely low 4.1 percent up to 64.3 percent, "averaging" 45.8 percent. According to the confidence range, the actual average of this sample population has a 95 percent possibility of lying between 42.3 and 49.3 weight percent.

It is evident from Table 2.2.5.6 that several state lignite analyses include "bad" samples. For example, note the low end of the moisture ranges from Texas and Alabama, and the Alabama low heating value. No effort was made in preparing this table to screen state data by arbitrarily establishing cut-off values; all "as-received" sample analyses were included. The evaluation of the standard deviation and confidence range help compensate for "bad" samples by numerically illustrating the total sample distributions around the average.

Gulf Region lignite samples are, on the average, lower in moisture content, higher in volatile matter and ash, and lower in heating value than Fort Union Region lignite. In general, the lignite deposits in the eastern portion of the Gulf Region are younger with higher moisture contents and lower energy contents than those deposits with similar environments of deposition in Texas and Louisiana. Luppens¹² notes that the relative quality of the lignites depends on the depositional environment and that their overall quality decreases from the western to the eastern portions of the Gulf Coast.

Table 2.2.5.6

Limits of Variation in Proximate and Ultimate Analyses of Gulf Coast Region Lignite
(as-received basis)

Sample Group	Proximate Analysis, Weight Percent				Ultimate Analysis, Weight Percent					Heating Value Btu/lb	Ref.
	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur		
Gulf Lignite Region-Average Number of Samples: 495	31.3	31.2	25.2	13.7	6.7	32.7	0.6	43.0	1.0	5803	
Alabama-Average Number of Samples: 68	45.8	25.1	21.7	12.8	7.4	25.5	0.45	52.6	2.0	4640	6
	68	39	39	48	20	21	21	21	40	56	
Range: High	64.3	45.7	38.7	42.2	8.5	44.1	0.64	62.8	3.74	7560	
Low	4.1	11.4	7.3	2.9	3.3	10.4	0.2	13.8	0.31	1780	
2s limit ^a	29.6	17.4	14.2	20.5	2.5	14.8	0.21	21.9	1.7	2177	
Confidence range on average ^b	3.5	2.7	2.2	2.9	0.58	3.4	0.05	5.0	0.26	285	
Arkansas - Average Number of Samples: 78	38.6	25.6	18.6	17.1	6.8	31.6	0.54	43.0	0.58	5487	7
	78	78	78	78	77	77	77	77	78	78	
Range: High	47.9	33.5	28.5	48.2	8.1	42.1	1.1	52.2	3.07	7218	
Low	19.4	13.6	7.3	5.2	2.7	13.0	0.3	11.2	0.2	2224	
2s limit ^a	10.0	8.5	6.3	18.7	1.8	11.5	0.27	12.2	0.79	2232	
Confidence range on average ^b	1.1	0.94	0.92	2.1	.20	1.3	0.03	1.4	0.09	248	

Table 2.2.5.6 (continued)

Limits of Variation in Proximate and Ultimate Analyses of Gulf Coast Region Lignite
(as-received basis)

Sample Group	Proximate Analysis, Weight Percent				Ultimate Analysis, Weight Percent					Heating Value Btu/lb	Ref.
	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur		
Texas-Wilcox Formation											
Average	25.5	35.1	28.7	10.6	--	--	--	--	1.1	7792	8
Number of Samples:	244	229	233	230	--	--	--	--	207	159	
Range: High	46.3	76.4	79.1	58.6	--	--	--	--	5.77	11221	
Low	1.2	18.0	3.4	1.4	--	--	--	--	0.08	3299	
2s Limit ^a	18.1	14.9	16.0	13.7	--	--	--	--	1.6	1761	
Confidence range on average ^b	1.1	0.97	1.0	0.89	--	--	--	--	0.1	137	
Texas-Yegua-Jackson Formation											
Average	17.9	36.2	23.4	22.0	--	--	--	--	1.3	6992	8
Number of Samples:	34	35	35	35	--	--	--	--	32	27	
Range: High	41.5	47.5	36.8	48.4	--	--	--	--	2.67	8836	
Low	4.5	21.1	7.1	6.4	--	--	--	--	0.40	5010	
2s Limit ^a	22.1	12.6	11.5	27.8	--	--	--	--	1.4	2046	
Confidence range on average ^b	3.7	2.1	1.9	3.6	--	--	--	--	0.25	405	

Table 2.2.5.6 (continued)

Limits of Variation in Proximate and Ultimate Analyses of Gulf Coast Region Lignite
(as-received basis)

Sample Group	Proximate Analysis, Weight Percent				Ultimate Analysis, Weight Percent					Heating Value Btu/lb	Ref.
	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur		
Louisiana											
Average	31.8	25.7	26.0	16.5	6.3	37.7	0.84	37.9	0.67	6281	5
Number of Samples:	43	43	43	43	43	43	43	43	43	43	
Range: High	48.3	38.9	43.6	55.6	7.7	58.5	1.3	49.4	1.97	10120	
Low	6.8	16.1	9.6	3.8	3.7	16.1	0.31	20.6	0.30	2730	
2s Limit ^a	20.9	11.5	16.8	25.9	2.0	21.6	0.48	16.6	0.71	3910	
Confidence range on average ^b	3.1	1.7	2.5	3.9	.30	3.2	0.07	2.5	0.11	584	
Mississippi											
Average	42.2	23.8	19.3	16.4	6.1	34.3	0.6	44.2	1.0	5429	1
Number of Samples:	28	22	22	23	17	17	15	15	24	24	
Range: High	51.7	33.1	25.6	47.1	8.1	59.1	0.8	56.5	4.2	10310	
Low	11.8	17.4	8.9	2.4	1.9	26.4	0.4	21.7	0.3	2750	
2s Limit ^a	25.2	7.0	9.2	27.0	4.1	19.6	0.2	25.7	2.0	3372	
Confidence range on average ^b	4.9	1.6	2.0	5.8	1.1	5.1	0.1	7.1	0.42	712	

Notes:

^a2s limit "equals twice the standard deviation and represents the interval on either side of the average within which 95 percent of the individual values are expected to lie.

^b"Confidence range on average" represents the range around the average within which there is a 95 percent confidence that the true average lies.

Sources: References 1,5,6,7,8

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Denver Region

2.2.6 Denver Region

The Denver Region covers a 7,500 square mile basin east of the Front Range extending from the vicinity of Colorado Springs north to near the Wyoming border.¹ Within the Denver Region are two separate coal-bearing subbasins, the Denver Basin and, to the north, the Cheyenne Basin, separated by a structural high termed the Greeley arch. The coal-bearing sequences have been removed by erosion from the Greeley arch.²

About 36 percent of the area within Colorado that is underlain by coal at a depth less than 3,000 feet is within these two sub-basins. Subbituminous coal and lignite occur in the Upper Cretaceous Laramie Formation and lignite occurs in the Upper Cretaceous-Paleocene Denver Formation.²

2.2.6.1 Geology

The Denver basin coal region is defined geologically by the exposure of the basal coal-bearing part of the Laramie Formation of Late Cretaceous age. Structurally, the region is a major synclinal depression, the axis of which trends from north to south; the deepest portion is located directly below Denver. The strata are near-vertical on the west flank where the basin sediments abut the Front Range; they are moderately inclined on the north, east, and south sides, where the Laramie crops out in the plains.⁵

Coal of both Late Cretaceous and Early Tertiary (Paleocene) ages occurs in the Denver basin, the Cretaceous coal being in the Laramie Formation and Tertiary coal being in the Dawson Arkose or its lateral equivalent, the Denver Formation.⁵

In the Laramie Formation of the Denver Region, Upper Cretaceous consists of approximately 300-700 feet of sandstone with interbedded shale and coal. The sequence was deposited in a marginal-marine environment. Mined coal beds range from 1 to over 14 feet thick.⁴ In general, the Laramie coal beds are thicker and somewhat more continuous in the Denver Basin than in the Cheyenne Basin.²

The Denver Formation and Upper Cretaceous-Paleocene consist of approximately 600-1580 feet of claystone, siltstone, and fine grained sandstone.⁴ These lignite beds appear to have been deposited in two Early Paleocene swamp areas. Each of these swamp areas contain unique sequences of lignite beds, shales, claystones, and sandstones.² The lignite beds are absent in the Cheyenne Basin inasmuch as the Denver Formation is not present in this northern sub-basin of the Denver Region.

2.2.6.2 Coal Reserves and Mines

Figure 2.2.6.1 is a map of the Denver Region showing the boundaries of the coal field and the identified surface minable reserve base.

The original demonstrated reserve base has been estimated to contain 4 billion short tons. Cumulative production of coal in this region, until January 1979, has been approximately 130.4 million short tons from 387 mines since the late 1800's. The total reserve base depletion has been 260.2 million short tons leaving a remaining reserve base for the Denver Region of 3.74 billion short tons.⁴

To this date no further analyses have been completed to categorize this remaining reserve base by rank.⁹ However, from an earlier publication, 2.96 billion tons of lignite are identified as the demonstrated surface minable reserve base in the Denver Region.⁸ No number can be distinguished for the subbituminous coals.

Of the 130.4 million tons of coal and lignite mined in the Denver Region, almost all (99%) has been mined in the Laramie Formation of the Denver Basin. Of this coal and lignite mined, most was produced from underground mines with less than one percent being surface mined.²

There is only one active mine in the Denver Region, the Lincoln mine, located in the Boulder-Weld field.² There are, however, two proposed surface mines in the Buick Matheson Area.¹¹

2.2.6.3 Identified Coal Resources

Resource estimates for the Denver Region range from 5.2 billion tons to over 42 billion tons of coal lignite, depending on the reported area of land in which the coal-bearing formations are located.² A recent study has recognized the estimate of over 42 billion tons and considers it high.² For the purpose of this report, the more conservative estimates are used, those of 20 billion tons from the range of 20-25 billions tons for the Laramie Formation, and 10 billion tons from the range of 10-15 billion tons for the Denver Formation.

The total remaining in place resource estimates for the Laramie Formation are considered to be in coal beds greater than 2.5 feet thick at depths less than 3,000 feet.² The Denver Formation lignite estimate is considered to be contained in beds at least 4 feet thick and less than 1,000 feet deep. There is probably less than 1 billion tons of lignite at depths greater than 1,000 feet.²

The estimated strippable resources for the Denver Region are over 13 billion tons, as shown by county in Table 2.2.6.1. These resources

Coal and Lignite Resources of The Denver Region

LEGEND:

MINE:

Lignite

Subbituminous

Strippable Resource Areas

Lincoln

Sources: References 5,10

Table 2.2.6.1

Strippable Coal and Lignite Resources in the Denver Region

County	Quantity (million short tons)
Weld	3,363
Boulder	223
Morgan	24
Adams	2,553
Arapahoe	1,960
Elbert	3,717
El Paso	1,210
Total	13,050

Source: Reference 5

have a minimum coal bed thickness of 2 feet and a maximum overburden thickness of 150 feet. An attempt has been made to classify the 30 billion tons of identified low-rank coal resources in the Denver Region into depth, thickness, sulfur, and ash categories as shown in Table 2.2.6.2. All of the coal and lignite is considered to have less than 1 percent sulfur, except for those coals on the western margin of the Denver Basin which contain sulfur content greater than 1 percent. These are not quantified. Thickness of the beds is generally less than 10 feet.

2.2.6.4 Overburden

Both the Denver and Cheyenne Basins are doubly plunging synclines. The Laramie coal zone has been deformed along with the other rocks in the area into this same structural configuration. The coal zone crops out along the basin margin and the deepest coal occurs in the deepest part of the basins. Amount of overburden above the coal zone is, of course, dependent on the local topography. For instance, the structural center of the Denver Basin is southeast of Cherry Creek Reservoir. In this area the top of the coal zone is at an elevation of about 3,800 feet above sea level and about 1,700 feet below land surface. In another area, the top of the coal zone is at an elevation of 4,100 feet but there is 2,900 feet of overburden. Topography significantly influences the amount of overburden and minability in such areas. Similar overburden relationships hold true where strippable coal exists.²

About 25 percent of the formation is within 200 feet of the surface, usually around the basin margins. Throughout the rest of the area the coal zone occurs at depths greater than 200 feet of which about 25 percent of the total Laramie Formation coal is in the range of 500-1500 feet.²

The upper part of the Laramie Formation consists of claystone, shale, thin sandstone, and lignite lenses. In between the beds of coal are massive sandstone, thin shale and claystone beds.²

The overburden of the Denver Formation lignites consists of thick arkosic sandstones and conglomerates. Most of the lignite beds also contain numerous non-coal partings. Parting thickness can range from 0.1 inch to over 2 feet. These partings contain kaolin, a pale yellowish-brown mineral.²

2.2.6.5 Aquifers

One of the major limiting factors to coal development in the Denver Region is water. Nontributary groundwater occurs in several formations in the area, but it is limited in quantity. The Colorado Division of Water Resources puts restrictions as to what groundwater and how much groundwater a particular user can withdraw. However, this water supply problem may not inhibit conventional surface and underground mines or in situ gasification facilities.²

Table 2.2.6.2

Classification of Coal Resources^a in the Denver Region
(Subbituminous and Lignite)

<u>DEPTH OF SEAM</u>			<u>SEAM THICKNESS</u>		
Ft.	10 ⁹ Tons	Percent of Total	Ft.	10 ⁹ Tons	Percent of Total
0-150 ⁵	13	43	2.5-5	14.6	48.9
150-1000	--	--	5-10	14.9	49.7
1000-2000	--	--	> 10	0.4	1.4
2000-3000	--	--			
Unknown ^b	17	57			
Total	30	100.0	Total	30	100.0

<u>SULFUR CONTENT</u>			<u>ASH CONTENT</u>		
Wt. % "as received"	10 ⁹ Tons	Percent of Total	Wt. % "as received"	10 ⁹ Tons	Percent of Total
0-1	30	100	0-5	--	--
1-3	--	--	5-10	--	--
> 3	--	--	> 10	--	--
			Unknown ^b	30	100.0
Total	30	100.0	Total	30	100.0

Notes:

^aNo clear definition is available for the Denver Region that classifies coal resources as Measured, Indicated, or Inferred. Based on the material in Reference 2, it is assumed the resource totals represent Inferred resources.

^b"Unknown" refers to resources not classified into the depth and ash ranges shown.

Sources: References 2,5,7

Water pollution may be another type of problem. Laramie coals are often intimately associated with the Laramie-Fox Hills aquifer. Denver lignites are directly below The Dawson Arkose, a prolific water producing formation, and above sandstones which provide small quantities of water from the lower Denver Formation.

Most of the rocks in the basin are to some degree water bearing. However, due to the large size of the basin and varying structures within the basin, the amounts of water yielded from any one aquifer will vary locally and can vary considerably within a short distance. An important aquifer, Laramie-Fox Hills aquifer, consists of cemented sandstone, which yields varying amounts of water to wells. Wells that fully penetrate the aquifer yield approximately 100 gpm and a few as much as 600 gpm.⁶

The groundwater which has come into contact with the Pierre shale or the coal beds of the Laramie Formation contains large concentrations of dissolved solids, which have a deleterious effect on water quality.⁶

2.2.6.6 Coal Analyses and Limits of Variation

Table 2.2.6.3 presents Denver Region coal analyses by county. The averages have been converted to an "as-received basis" to simplify comparison of these coals with other regions in the report. Most of these samples do not differentiate between Laramie and Denver formation coals, and therefore represent average values for the Denver Region as a whole. The original "dry basis" analyses for the region are presented in Table 2.2.6.4.

The ash analyses for this region consist of three samples taken from the Boulder-Weld field as shown in Table 2.2.6.5.

Laramie Formation coal varies in rank from subbituminous B coal to lignite A. The majority of the Laramie coal contains only minor amounts of sulfur (<1%). There is an average moisture content of 26.0 percent with approximately 11 percent ash in these as-received samples.¹

Highest quality Laramie coal occurs in the Boulder-Weld, Foothills district and Colorado Springs field. Coal averages about 8,400 Btu/lb as received in these samples and ranks as subbituminous B and C in these areas. Within the Boulder-Weld field coal quality decreases from southwest to northeast.²

Denver Formation lignite is brownish-black and weathers, slacks, and disintegrates rapidly. Quality of the lignite varies due to the number and thickness of non-coal partings and the physical character and rank of the pure lignite. Most analyses indicate the lignite ranks as lignite A; however, there are intervals within thick lignite beds which may rank as subbituminous C.

Typical moisture contents for coal within the Denver Formation range from 22 to 40 percent. The heating values can range from 4,000 to 7,500 Btu/lb.²

Table 2.2.6.3

Denver Region Subbituminous and Lignite Proximate Analyses
(as-received basis)^a

County/Bed	Number of Samples	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb
Adams Uncorrelated Average	4	23.7	--	--	6.0	0.3	8675
Range: High Low		35.0 18.9					
Boulder Laramie Tower Average	6	20.5	--	--	3.6	0.4	9985
Range: High Low		21.8 18.7					
Boulder Uncorrelated Average	159	19.1	31.4	43.3	5.9	0.3	9904
Range: High Low		23.3 11.3					
Elbert Uncorrelated	1	32.9	28.1	30.5	8.0	0.5	6283
El Paso Laramie A Average	39	24.3	--	--	5.5	0.3	8705
Range: High Low		26.9 19.2					
Weld Uncorrelated Average	2012	21.2	30.4	43.2	4.9	0.3	9799
Range: High Low		26.2 6.6					

Note:

^aAll analysis averages other than moisture have been converted to an "as-received" basis from the "dry basis" data in reference 5 and presented in Table 2.2.6.5.

Source: Reference 5

Table 2.2.6.4

Denver Region Subbituminous and Lignite Proximate Analyses
(dry basis)

County/Bed	Number of Samples	Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb
Adams Uncorrelated Average	4	--	--	7.9	0.4	11370
Range: High		--	--	11.4	0.6	12220
Low		--	--	4.8	0.4	10740
Boulder Laramie Tower Average	6	--	--	4.5	0.5	12560
Range: High		--	--	4.9	0.6	12800
Low		--	--	4.3	0.4	12410
Boulder Uncorrelated Average	159	38.9	53.7	7.3	0.4	12280
Range: High		41.3	57.9	14.6	0.7	12730
Low		36.3	47.2	4.7	0.2	11110
Elbert Uncorrelated	1	42.2	45.8	12.0	0.7	9430
El Paso Laramie A Average	39	--	--	7.3	0.4	11500
Range: High		--	--	10.5	0.6	13020
Low		--	--	5.2	0.3	10750
Weld Uncorrelated Average	2012	38.7	54.9	6.2	0.4	12460
Range: High		42.9	57.5	10.1	0.9	13210
Low		36.8	49.6	4.4	0.2	11900

Source: Reference 5

Table 2.2.6.5

Average Ash Composition Analysis from the Boulder-Weld Field
(Weight Percent)

Three Samples

	<u>Average</u>
Ash content of coal	8.8
<u>Composition of ash</u>	<u>Wt. %</u>
SiO ₂	45.3
Al ₂ O ₃	11.7
CaO	9.9
MgO	2.0
Na ₂ O	4.2
K ₂ O	.6
Fe ₂ O ₃	4.5
MnO	.026
TiO ₂	.64
P ₂ O ₅	.21
SO ₃	13.1
Cl	0.1

Source: Reference 3

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North Park Region

2.2.7 North Park Region

Located in north-central Colorado, North Park is an intermontane basin bounded by the Colorado-Wyoming border on the north, the Park Range on the west, the Medicine Bow Range on the east, and the Rabbit Ears Range on the south. The North Park Region consists of two fields, the North Park field and the Middle Park field.¹

2.2.7.1 Geology

All the coals found in North Park basin occur in the Coalmont Formation of late Paleocene and Early Eocene ages, which may aggregate as much as 12,000 feet in thickness. The Coalmont consists of terrigenous clastics, carbonaceous shales, and coals laid down in an alluvial basin that subsided as the Rocky Mountains were uplifted in early Tertiary time. Coals were formed in flood basins and swamps between meandering streams. The Coalmont Formation unconformably overlies the marine Pierre Shale.¹

The coal beds in this region often are: 1) highly folded with bed dip in areas like McCallum anticline in excess of 45 degrees; 2) typically faulted; 3) very lenticular; and 4) somewhat upgraded in rank due to the relatively high geothermal gradient in parts of the area.¹

2.2.7.2 Coal Reserves and Mines

Figure 2.2.7.1 is a map of the North Park Region showing the boundaries of the coal field, the areas containing strippable coal, and active surface mines. Two areas that have been extensively mined in the North Park region are the Coalmont district and the McCallum Anticline district.³ Two surface operations are currently operating on the east flank of the McCallum anticline.⁴ These two mines produce subbituminous A coal from 50-60 foot thick beds near the base of the Coalmont Formation, which in the vicinity of the mines, dips from 45° to 60° to the east, creating mining problems.¹

The North Park area has produced 3.7 million tons of coal from a total of 35 mines since the early 1900's. During 1978, the North Park region produced approximately 715,000 short tons of steam coal in the McCallum area.¹

The original demonstrated reserve base for this area has been estimated at 823.51 million short tons. With the reserve base depleted by over 10 million tons, this leaves 813.48 million tons remaining as the reserve base for the North Park Region.³

Figure 2.2.7.1

Map of the North Park Region Showing Strippable Reserve Areas and Active Mines

LEGEND:

North Park Coal Region

Strippable Areas

MINES:

1. Marr Strip Mine

2. Canadian Strip Mine

Source: References 5,8

2.2.7.3 Identified Coal Resources

A total of 28.7 billion tons of coal to 6000 feet in depth have been estimated as resources in the North Park Region.⁹ Approximately 123 million tons of this resource are considered strippable (coal beds at least 2 feet thick, maximum overburden thickness 150 feet).⁵

Table 2.2.7.1 shows the available information on depth, thickness, sulfur, and ash classifications of the identified North Park Region resources. The coal is low in sulfur, with an ash content varying from 3 percent to 13 percent. Bed thickness is usually greater than 10 feet.⁶ The coal is distributed throughout the 0-6000 feet depth range, but percentages falling in the various depth categories have not been estimated.

2.2.7.4 Overburden

The overburden in the North Park Region consists mainly of brown to grey arkosic sandstone and grey, green, and brown carbonaceous shale.⁷ The depth of overburden of two mines ranged from 20 feet to 230 feet due to the steep dips of the seams.⁴

2.2.7.5 Aquifers

Some of the more important aquifers include the valley fill alluvium, North Park Formation, Coalmont Formations, and Precambrian igneous rocks. The Dakota sandstone in the Sundance Formation may yield small quantities of water to wells within a short distance of the outcrop; however, they are normally found at depths too great for recovery.²

Valley fill alluvium is found along most of the river and stream courses within the basin. These deposits, consisting of sand, gravel, clay, and silt up to 80 feet in thickness, yield adequate quantities of water of generally good quality to domestic and stock wells.²

The North Park Formation, up to 2,000 feet thick of calcareous sandstone with some siltstone, clay, volcanic ash and tuff yields water to wells in the northwestern and central parts of North Park. Reported well yields of wells tapping this aquifer are not large, usually less than 50 gpm.²

The Coalmont Formation, 6,000-9,000 feet in thickness is found throughout the central part of North Park. This formation consists of sandstone, shale, conglomerate and coal beds. Yields of wells tapping this aquifer again are not large--less than 10 gpm with the quality of water varying.²

Table 2.2.7.1

Classification of North Park Region Identified Resources^a

<u>DEPTH OF SEAM</u>			<u>SEAM THICKNESS</u>		
Ft.	10 ⁹ Tons	Percent of Total	Ft.	10 ⁹ Tons	Percent of Total
0-150 ⁵	0.123	0.4	2.5-5	.04	.1
0-1000	--	--	5-10	2.5	8.7
1000-2000	--	--	> 10	26.2	91.2
2000-3000	--	--			
Unknown ^b	28.6	99.6			
Total	28.7	100.0	Total	28.7	100.0

<u>SULFUR CONTENT</u>			<u>ASH CONTENT</u>		
Wt. % "as received"	10 ⁹ Tons	Percent of Total	Wt. % "as received"	10 ⁹ Tons	Percent of Total
0-1	28.7	100	0-5	--	--
1-3	--	--	5-10	--	--
3-10	--	--	> 10	--	--
			Unknown ^b	28.7	100.0
Total	28.7	100.0	Total	28.7	100.0

Notes:

^aNorth Park Region Identified resource estimates include coal 2-1/2 feet or more thick to an overburden depth of 6000 feet, which by definition are considered Estimated resources.

^b"Unknown" refers to Identified and Estimated resources not classified into the depth and ash ranges shown.

Sources: References 5,6,9

Precambrian age crystalline rocks found in the central parts of the mountain ranges are an important local source of water. Depending upon whether fractures or fault zones are encountered by the well, the yield of the well will range from a low of less than 1 gpm to 100 gpm. Water obtained from these rocks is usually of good quality.²

2.2.7.6 Coal Analyses and Limits of Variation

Tables 2.2.7.2 and 2.2.7.3 present average coal and ash analyses and statistical limits for a limited number of coal samples from the North Park Region. The moisture content of the samples ranges from 12.0 to 20.2 percent with an average of 15 percent. The volatile matter is approximately 33.8 percent with the fixed carbon average at about 42.5 percent. Ash content also varies considerably showing a range of 2.1 percent to 31.5 percent with an average of 8.7 percent. The heating value ranges from 6,520 Btu/lb to 11,280 Btu/lb; North Park coal is generally ranked as a subbituminous A or B coal. The ash analyses show considerable quantities of SiO_2 and Al_2O_3 but the coals also contain high CaO , SO_3 , and Fe_2O_3 concentrations.

Table 2.2.7.2
Limits of Variation in Proximate and Ultimate Analyses of North Park Region Coal
(as-received basis)

	Number of Samples	Proximate Analysis, Weight Percent				Ultimate Analysis, Weight Percent					Heating Value Btu/lb.	Ash Softening ^c Temp °F
		Moisture	Volatile Matter	Fixed Carbon	Ash	H	C	N	O	S		
Average	17	15.0	33.8	42.5	8.7	5.7	57.6	0.8	26.8	0.4	10,005	2,270
Range: High		20.2	38.3	49.1	31.5	6.0	64.3	1.0	31.7	1.0	11,280	2,520
Low		12.0	29.3	24.7	2.1	4.6	37.8	0.5	24.4	0.2	6,520	2,090
2s limit ^a		4.9	5.74	13.06	14.73	0.73	14.60	0.30	4.71	0.55	2,605	295
Confidence range on average ^b		1.26	1.48	3.36	3.80	0.19	3.75	0.08	2.42	0.28	1,339	99

Notes:

^a"2s limit" equals twice the standard deviation and represents the interval on either side of the average within which 95 percent of the individual values are expected to lie.

^b"Confidence range on average" represents the range around the average within which there is a 95 percent confidence that the true average lies.

^cAsh softening temperature from 11 samples.

Source: Reference 7

Table 2.2.7.3

Limits of Variation in Ash Analyses From North Park Region Coal

		Composition, Weight Percent of Ash											
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	P ₂ O ₅	CaO	MgO	MnO	Na ₂ O	K ₂ O	SO ₃	Cl
Average	21 ^a	39.1	22.6	6.5	1.01	0.58	9.0	1.2	0.05	0.14	0.72	7.9	0.1
Range: High Low 2s limit ^b Confidence range on average ^c		56.0	27.0	12.0	1.8	1.6	22.0	2.12	0.14	0.27	2.40	24.0	0.1
		16.0	15.0	2.2	0.59	0.1	0.3	0.56	0.02	0.09	0.09	0.3	0.1
		22.4	8.5	5.5	0.66	1.0	11.4	0.82	0.09	0.10	1.43	10.4	0.0
		5.1	1.9	1.3	0.15	0.23	2.6	0.19	0.02	0.02	0.33	2.4	0.0

Notes:

^aThese 21 samples include the 17 samples used in Table 2.2.7.3.

^b"2s limit" equals twice the standard deviation and represents the interval on either side of the average within which 95 percent of the individual values are expected to lie.

^c"Confidence range on average" represents the range around the average within which there is a 95 percent confidence that the true average lie.

Source: Reference 7

References - Section 2.2.7

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Green River Basin

2.2.8 Green River Region

The Green River Region is located in southwestern Wyoming and northwestern Colorado. It is comprised of the Sand Wash structural basin of Laramide age, together with the north flank of the Axial Basin uplift which includes the Williams Fork Mountains and forms the south edge of the basin. This perimeter of the Green River region is well defined, except where faulted by the base of the Upper Cretaceous Mesaverde Group. The oldest coals are found in the Iles Formation, lower Mesaverde Group.¹

The Wyoming portion of this region covers 15,400 square miles and is 185 miles wide along the Colorado-Wyoming line. It is divided by the Rock Springs Anticline into the Green River Basin on the west and the Great Divide Basin on the east. The Green River Region is bounded by mountains on all sides except the west where a series of major faults has moved older rocks eastward covering the coal bearing strata. Coal-bearing rocks are exposed only on the basin margin and on the flanks of the Rock Springs Anticline. In most of the central part of the basin, coal-bearing rocks are covered by younger rocks making it difficult to estimate resources.²

There are bituminous coals throughout this region; in fact, two thirds of the Colorado resources in this region are considered bituminous. However, these coals, in some cases, are not readily distinguishable from the subbituminous coals and are included in this report.

2.2.8.1 Geology

In the Colorado portion of the Green River Region, coal-bearing Upper Cretaceous, Paleocene, and Eocene rocks crop out along the Yampa River - Williams Fork Mountain area. This area constitutes the Yampa coal field, the only field in the Colorado portion of the region. The south flank of the Sand Wash basin (sometimes termed Washakie) consists of gently northward dipping sediments that are locally folded, especially in the southeast part of the basin, and complicated by faulting and igneous intrusives of late Tertiary age, which in places have upgraded some of the coals to anthracite.¹

The younger coal-bearing rocks (Lance, Fort Union, and Wasatch Formations) in this part of the region are preserved toward the interior of the basin, away from the outcrops of the Mesaverde on or near where most of the coal mining has taken place.¹

Coal beds in the Wyoming portion of the region occur in the Mesaverde Group and the Lance Formation of Upper Cretaceous age, the Fort

Union Formation of Paleocene age, and the Wasatch Formation of Eocene age. Coals of the Rock Springs Formation of the Mesaverde Group are generally bituminous in rank and have, historically, been the most important. It may not be long, however, before their importance is surpassed by young beds of the Lance, Fort Union, and Wasatch Formations.

2.2.8.2 Coal Reserves and Mines

Figure 2.2.8.1 is a map of the Green River Region showing the boundaries of the coal field, the areas containing strippable reserves (Wyoming) or resources (Colorado), and active subbituminous coal mines. (Bituminous coal mines are also operating in the region, but are not shown.) Estimates of the region's strippable coal quantities (again, reserves in Wyoming, resources in Colorado) are shown in Table 2.2.8.1, along with the criteria utilized by each state. Of Colorado's strippable coal resources, about 200 million tons lie in the Tertiary subregion and 750 million tons lie in the Yampa subregion of the Yampa Field.

Table 2.2.8.1

Strippable Tonnage Estimates and Criteria Used in the Green River Region

State	Strippable Tonnages 10 ⁹ Tons	Ref.	Minimum Thickness, Ft.	Maximum Overburden, Ft.	Maximum Stripping Ratio
Colorado	1.0 ^a	6	2	150	--
Wyoming	<u>1.9^a</u>	13	5	120 ^b	10:1
Total	2.9				

Notes:

^aColorado estimates are for strippable resources; Wyoming estimates are for reserves.

^bExcept where reserves occur in multiple beds or a single thick bed.

Sources: References 6,13

Figure 2.2.8.1

Map of the Green River Region Showing Strippable Areas
And Subbituminous Coal Mines

Source: References 1,2,6,11,12,13,18

* The strippable areas for Wyoming are reserves and the strippable areas for Colorado are resources.

When both underground and surface minable coal beds are considered, the original demonstrated reserve base for the Colorado portion of the Green River region totals 6.68 billion tons (the reserve estimate includes Moffat County in the Uinta Region). This part of the Green River Region has produced almost 90 million tons as of January 1979. The remaining reserve base is given as of 1977 and totals 6.57 billion tons.³

There are three subbituminous coal mines in the Green River Region, as listed in Table 2.2.8.2. (There are mines which contain both bituminous and subbituminous coals. One example is the Edna Strip mine which is not shown as a subbituminous mine, but a subbituminous sample from this mine is in the coal properties section.) Planned subbituminous coal mines are listed in Table 2.2.8.3.

2.2.8.3 Identified Coal Resources

As shown in Table 2.2.8.4, estimated original in-place coal resources in the Wyoming part of the Green River Region total 6.051 billion tons.¹⁷ Total coal resources in the Colorado portion of the Green River may be as much as 57.9 billion tons of which two-thirds are expected to be high volatile C bituminous and one-third subbituminous. This equates to approximately 19.3 billion tons of subbituminous coal up to depths of 6000 feet in the Colorado part of this region.⁵

Table 2.2.8.5 shows that insufficient data exist to classify the Green River Region subbituminous coal resource according to depth, thickness, sulfur content, and ash content. The bed thicknesses of this region usually runs from 2.5 feet up to 10 feet. Most of the coal is low in sulfur though it can reach 5 percent in certain areas. The ash can be typified as usually 5-10 percent although some areas have recorded up to 25 percent ash.⁷

2.2.8.4 Overburden

The overburden in the region consists mainly of poorly consolidated siltstone, sandstone, and shales interspersed with occasional but minor layers of harder sandstone.¹³

2.2.8.5 Aquifers

The western portion of Colorado has limited supplies of available groundwater. Even these available supplies have not been greatly developed due to the topography of the area and the availability of large amounts of surface water. The important aquifers in this area include Valley fill alluvial deposits in the Green River Formation, and the Mesaverde Group.¹⁴

Table 2.2.8.2

Licensed Subbituminous Coal Mines in the Green River Region

Map No.	Company	Mine Name	Type ^a	County	State	Production/ Capacity MTPY
1	Bridger Coal Co.	Jim Bridger	S	Sweetwater	Wyoming	5.449
2	Utah International	Trapper	S	Moffat	Colorado	.346
3	Empire Energy	Eagle #5	U	Moffat	Colorado	.447
	Empire Energy	Eagle #9	U	Moffat	Colorado	.200
	W.R. Grace-Hanna	Hayden Gulch	S	Routt	Colorado	.400

Note:

aS = Surface

U = Underground

Sources: References 8,19,20

Table 2.2.8.3

Planned Subbituminous Coal Mines in the Green River Region

Company	Mine	Type	County	State	Startup Date	Initial Capacity MTPY
Empire Energy	Eagle #7	U	Moffat	Colorado	1982	0.8
Ruby Construction	Sun	U	Routt	Colorado	1980	0.250

Sources: References 19,20

Table 2.2.8.4

Identified Subbituminous Coal Resources^a of the Green River Region, by State

<u>State</u>	<u>Quantity 10⁹ Tons</u>	<u>Ref.</u>
Wyoming	6.051	2
Colorado ^b	<u>19.3</u>	5
Total	25.3	

Notes:

^aIdentified resources include Demonstrated (Measured and Indicated) and Inferred resources 2-1/2 feet or more thick to an overburden depth of 3000 feet.

^bColorado resources include coals to 6000 feet, which by definition are considered Estimated resources.

Table 2.2.8.5

Classification of Subbituminous Coal Resources^a in the Green River Area

<u>DEPTH OF SEAM</u>			<u>SEAM THICKNESS</u>		
Ft.	10 ⁹ Tons	Percent of Total	Ft.	10 ⁹ Tons	Percent of Total
0-3000	21.0	83.0	2.5-5	--	--
3000-6000	4.3	17.0	5-10	--	--
			> 10	--	--
			Unknown ^b	25.3	100.0
<hr/>			<hr/>		
Total	25.3	100.0	Total	25.3	100.0
<u>SULFUR CONTENT</u>			<u>ASH CONTENT</u>		
Wt. % "as received"	10 ⁹ Tons	Percent of Total	Wt. % "as received"	10 ⁹ Tons	Percent of Total
0-1	--	--	0-5	--	--
1-3	--	--	5-10	--	--
3-10	--	--	> 10	--	--
Unknown ^c	25.3	100.0	Unknown ^d	25.3	100.0
<hr/>			<hr/>		
Total	25.3	100.0	Total	25.3	100.0

Notes:

^aResources for this region are comprised of Identified resources (coals 2-1/2 feet or more thick to depths of 3000 feet) in Wyoming and Estimated resources (to 6000 feet) for the Colorado portion of the region.

^bSufficient data is not available to classify these resources into thickness range

^cSufficient data is not available to classify these resources into the sulfur content ranges shown. However, analyses results indicate that the vast majority of these coals contain 1 percent or less sulfur, by weight.

^dSufficient data is not available to classify these resources into the ash content ranges shown. However, analyses results indicate that the majority of these coals contain 5-10 percent ash by weight.

Sources: References 2,5,7

There is also limited availability of water resources in Wyoming. The Wasatch Formation is one important source of underground water for this area. The sandstones and conglomerates of this formation are generally porous enough to make them readily absorb and transmit water. This area's groundwater is derived almost wholly from the rain that falls on the surface of the local area.⁴

2.2.8.6 Coal Analyses and Limits of Variation

In Table 2.2.8.6, the individual samples presented have been identified as subbituminous in rank. There were other samples identified as bituminous, and some for which the rank was not designated. These samples were not used for classification.

The heating values of these representative samples range from 9,350 to 11,590 Btu/lb. The exceptionally high moisture content of the coals from the Jim Bridger strip mine account for the lower heating value. The lower ranked subbituminous Tertiary coals of the Green River Region have as received moisture contents between 20 and 30 percent and about equal volatile matter and fixed carbon contents.²

Ash and sulfur contents are characteristically low and are related to the depositional histories of the coals rather than to any differences in rank. Consequently, variation in ash content is quite irregular. As received ash content ranges from a few percent to more than 50 percent in response to the volume of inorganic debris entering the original peat swamp.² Sulfur contents are consistently low although there have been noted exceptions of up to seven percent sulfur in the Wasatch Formation. These coals are not being mined.¹⁵

Table 2.2.8.6

Limits of Variation in Proximate Analyses of Green River Region Coal
(as-received basis)

	Number of Samples	<u>Proximate Analysis, Weight Percent</u>				Ash Softening Temp. °F	Btu/lb
		Moisture	Volatile Matter	Fixed Carbon	Ash		
Yampa Field Average	8	8.0	37.4	45.9	8.8	2461	11,196
Range: High		10.9	39.0	52.3	17.8	2780	12,440
Low		5.7	35.2	41.3	3.0	2140	10,400
2s limit		3.4	2.2	6.0	8.6	435	1,178
Confidence range on average		1.4	0.9	2.5	3.6	182	493

Source: Reference 9

References - Section 2.2.8

1. 1979 Keystone Coal Industry Manual, McGraw Hill Publishing, New York, N.Y. 1979.
2. Glass, Gary B.. Wyoming Coal Fields 1978, The Geological Survey of Wyoming, Public Information Circular No. 9, Laramie, Wyoming, 1978.
3. Boreck, D.L. and D. Keith Murray. Colorado Coal Reserves Depletion Data and Coal Mine Summaries, Colorado Geological Survey Open-File Report 79-1, May 1979.
4. Schell, Elmer M. (editor). Wyoming Geological Association 25th Field Conference Guidebook, 1973, Symposium and Core Seminar on the Geology and Mineral Resources of the Greater Green River Basin, Wyoming Geological Association, 1973.
5. Hornbaker, A.L. and R.D. Holt. 1972 Summary of Coal Resources in Colorado, Colorado Geological Survey, Special Publication No. 3, 1973.
6. Speltz, Charles N. Strippable Coal Resources of Colorado: Location, Tonnage, and Characteristics of Coal and Overburden, U.S. Bureau of Mines, 1976.
7. Anderson, Donald L. The Regional Analysis of the U.S. Electric Power Industry, Vol. 4: Coal Resources in the United States, Battelle Laboratories, BNWL-B-415-V4A, UC-80, April 1975.
8. Dawson, Louise C. and D. Keith Murray. Colorado Coal Directory and Source Book, Colorado Geological Survey, Department of Natural Resources, State of Colorado, Denver, Colorado, 1978.
9. Boreck, Donna L., et al. Colorado Coal Analyses, 1975, (Analysis of 64 Samples Collected in 1975), Colorado Geological Survey, Department of Natural Resources, State of Colorado, Information Series 7, Denver, Colorado, 1977.
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17. Trumbull, James. Coal Fields of the United States, Map Department of the Interior, USGS, 1960.
18. Jones, D.C., and D.K. Murray. Coal Mines of Colorado, Statistical Data, Colo. Geo. Survey Information Series 2, 1976.
19. A Survey of Coal Mining Capacity in the West, U.S. DOE, DOE/RA-0045, January 1980.

Nenana Field

2.2.9 Nenana Field

As with the other Alaskan regions, little information is available on coal resources and properties of the Nenana Coal Field. The distances and lack of accessible transportation between the coal deposits and end users inhibits the immediate exploitation of these coals, except for small, local heating uses. The bulk of material presented here is from USGS Bulletin 1242-B (Barnes, 1967).¹

2.2.9.1 Geology

The Nenana coal field, one of the two producing coal fields of Alaska, extends for about 80 miles along the north flank of the Alaska Range, between the headwaters of the Wood River on the east and the Kantishna River on the west. Tertiary coal-bearing rocks crop out in a discontinuous belt generally ranging from 1 to 30 miles in width. The rocks have been folded and faulted into a series of basins, between which they are either eroded away or covered by younger Tertiary or Quaternary deposits. The coal-bearing formations include a large number of subbituminous coal beds, ranging from a few inches to 60 feet in thickness. The individual coal basins are broken by a few faults and compressed into open folds with moderate to low dips. At the east end of the Healy Creek basin nearly vertical to slightly overturned beds have been measured near the axis of a faulted syncline.

2.2.9.2 Coal Reserves and Mines

Roughly 94 percent of the coal presently mined in Alaska comes from the Nenana field near Healy, Alaska. Figure 2.2.9.1 shows the location of the Nenana field as well as the Susitna and Kenai fields of the Cook Inlet-Susitna Region, discussed in the next section. Coal beds of minable thickness and quality are also shown on Figure 2.2.9.1. The strippable reserve base estimate, and the criteria used to define strippable deposits, are indicated in Table 2.2.9.1.

Table 2.2.9.1

Strippable Subbituminous Reserve Base and Criteria Used in the Nenana Coal Field, Central Alaska

Reserve Base 10 ⁶ Tons	Minimum Seam Thickness Ft.	Stripping Ratio
457	16	4:1

Source: Reference 2

Figure 2.2.9.1

Nenana Field and Cook Inlet-Susitna Subbituminous Regions (Alaska),
Showing Minable Coal Beds

Mining in the Nenana field is largely confined to the south (north dipping) limb of a syncline with the beds dipping less than 45°.

2.2.9.3 Identified Coal Resources

Seven sample areas within the Nenana field and their estimated resources are listed in Table 2.2.9.2. The total resource is further classified according to depth, seam thickness, sulfur content, and ash content in Table 2.2.9.3.

Table 2.2.9.3 shows that almost 70 percent of the Nenana field's identified resources lie within 1000 feet of the surface; about one-tenth of this is considered strippable. The coal is generally found in seams greater than 10 feet thick, has a low sulfur content, and an ash content ranging between 3 and 16 percent by weight on an "as received" basis.

2.2.9.4 Overburden Characteristics

Insufficient information is available to detail the overburden characteristics of the Nenana field.

2.2.9.5 Aquifers

No information has been found concerning the existence and/or characteristics of Central Alaska groundwater.

2.2.9.6 Coal Analyses and Limits of Variation

The coal beds currently mined near Healy have very few shale partings and contain very little bone, and hence need little washing before use. Coals that contain bone, shale, or other rock are stockpiled for washing during the summer months.

Table 2.2.9.4 lists analyses for moisture, volatile matter, carbon, ash, sulfur, and heating value for mine and outcrop samples from the Nenana field. Data are given as ranges; no average or statistical values are available.

Table 2.2.9.2

Identified Resources of Subbituminous Coal in the Nenana Coal Field
Central Alaska Region

Coal District	(Ft.) Overburden	Identified Resources, 10 ⁶ Tons			Total
		Measured	Indicated	Inferred	
Rex Creek	0-1000	--	9.5	113.5	123.0
Tatlanika Creek	0-2000	--	117.4	153.5	270.9
Wood River	0-3000	15.0	45.0	241.0	301.0
California Creek	0-2000	6.0	240.6	511.9	758.5
Lignite Creek	0-3000	266.6	1884.0	1959.3	4109.9
Healy Creek	0-3000	574.0	403.5	385.4	1362.9
Savage River	0-1000	--	--	12.0	12.0
Total		861.6	2700.0	3376.6	6938.2

Source: Reference 1

Table 2.2.9.3

Classification of Nenana Field (Central Alaska) Identified Subbituminous Resources^a

<u>DEPTH OF SEAM</u>			<u>SEAM THICKNESS</u>		
<u>Ft.</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>	<u>Ft.</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>
0-1000	4.79	69.0	2.5-5	.098	1.4
1000-2000	1.45	20.9	5-10	.99	14.3
2000-3000	.70	10.1	> 10	5.85	84.3
<hr/>			<hr/>		
Total	6.94	100.0	Total	6.94	100.0

<u>SULFUR CONTENT</u>			<u>ASH CONTENT</u>		
<u>Wt. % "as received"</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>	<u>Wt. % "as received"</u>	<u>10⁹ Tons</u>	<u>Percent of Total</u>
0-1	6.94	100.0	0-3	--	--
1-3	--	--	3-16	6.94	100.0
3-10	--	--	> 16	--	--
<hr/>			<hr/>		
Total	6.94	100.0	Total	6.94	100.0

Notes:

^aIdentified resources include Measured, Indicated, and Inferred resources 2.5 feet or more thick to an overburden depth of 3000 feet.

Sources: References 1,2

Table 2.2.9.4

Limits of Variation in Proximate Analyses of Nenana Field (Central Alaska) Subbituminous Coal
(as-received basis)

Source of Sample	Proximate Analysis, Weight Percent					Heating Value, Btu/lb.
	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	
- 149- Mine	17.8-27.1	33.2-42.0	27.1-35.3	3.5-13.2	.1-.3	7570-9430
Outcrop	11.7-32.7	31.2-42.9	22.7-36.6	3.3-15.9	.1-.4	6320-10385

Source: Reference 1

References - Section 2.2.9

1. Barnes, F.F. Coal Resources of Alaska, USGS Bulletin 1242-B, 1967.
2. Conwell, C.N. Division of Geological Survey, Dept. of Natural Resources, as cited in the 1979 Keystone Coal Industry Manual.

Susitna Region

2.2.10 Cook Inlet-Susitna Region

The Cook Inlet-Susitna region of south-central Alaska includes the Broad Pass, Susitna, and Kenai subbituminous coal fields. The Susitna field shows the greatest potential for resource development, and is the only field of the three mentioned that is discussed further.

2.2.10.1 Geology

The Susitna coal field is defined as the coal-bearing part of the extensive lowland that lies north of Cook Inlet, between the Talkeetna Mountains on the east and the Alaska Range on the north and west. The coals are found in the Kenai formation, which may be described as non-marine rock of the Tertiary Age (probably Miocene).¹ Most of the potentially valuable coal deposits lie in a 400 square mile area at the southern end of the field, in the basins of the Beluga and Chuitna Rivers. The beds are relatively flat or gently folded, except locally along a few major faults.

2.2.10.2 Coal Reserves and Mines

The Susitna field contains the largest reserve of coal recoverable by strip mining in southern Alaska. In many areas coal beds more than 50 feet thick have less than 120 feet of overburden, which provides a very favorable stripping ratio. The valuable deposits mentioned in part 2.2.10.1 are near the Cook Inlet coast, and although this area is presently undeveloped, private companies are now leasing and exploring the area. The location of the Susitna Region and its minable deposits are shown in Figure 2.2.9.1 in the preceding section. No reserve base estimates for this area are available.

2.2.10.3 Identified Coal Resources

Table 2.2.10.1 presents summary data on six districts within the Susitna field. Of the total identified resource, none is considered in the "measured" category due to the nature of sampling and the estimations used. No estimates of inferred resources were made either because of the general lack of evidence of coal bed continuity beneath covered areas. As the estimates include only coal within half a mile of measured outcrops, the total potential resources of the field may be several times larger than indicated. Table 2.2.10.2 delineates the total resource in terms of depth, seam thickness, sulfur content, and ash content.

All of the resources estimated lie within 1000 feet of the surface. Over 90 percent of the resource is contained in seams greater than 10 feet thick; the coal is a low sulfur coal with an ash content ranging from 2 percent up to 30.5 percent.

Table 2.2.10.1

Identified Resources^a of Subbituminous Coal in the Susitna Coal Field
(Alaska)

District	Overburden	Indicated Resources, 10 ⁶ Tons
Yentna River	0-1000	55.9
Skwentna River	0-1000	123.0
Beluga River	0-1000	260.1
Capps Glacier District	0-1000	405.8
Chuitna River	0-1000	1540.5
Beach Southwest of Tyonek	0-1000	9.4
Total		2394.7

Note:

^aIdentified resources for the Susitna coal field are comprised of Indicated resources 2.5 feet or more thick, and are all located within 1000 feet of the surface.

Source: Reference 2

Table 2.2.10.2

Classification of Susitna Field Identified Subbituminous Coal Resources^a (Alaska)

<u>DEPTH OF SEAM</u>			<u>SEAM THICKNESS</u>		
Ft.	10 ⁹ Tons	Percent of Total	Ft.	10 ⁹ Tons	Percent of Total
0-1000	2.39	100.0	2.5-5	.063	2.7
1000-2000	--	--	5-10	.096	4.0
2000-3000	--	--	> 10	2.23	93.3
Total	2.39	100.0	Total	2.39	100.0

<u>SULFUR CONTENT</u>			<u>ASH CONTENT^b</u>		
Wt. % "as received"	10 ⁹ Tons	Percent of Total	Wt. % "as received"	10 ⁹ Tons	Percent of Total
0-1	2.39	100.0	0-5	--	--
1-3	--	--	5-10	--	--
3-10	--	--	> 10	--	--
			Unknown ^b	2.39	100.0
Total	2.39	100.0	Total	2.39	100.0

Notes:

^aIdentified resources for the Susitna field are comprised of Indicated resources 2.5 feet or more thick, and are all located within 1000 feet of the surface.

^b"Unknown" refers to Identified resources not classified into the ash ranges shown. Reference 2 indicates a range of ash content of 2.0%-30.5%.

Sources: References 1,2

2.2.10.4 Overburden Characteristics

Barnes¹ states that approximately 3400 square miles of coal-bearing rocks in the Susitna coal field lie beneath a mantle of glacial and alluvial deposits.

2.2.10.5 Aquifers

No information is available on the existence and/or characteristics of groundwater in the Susitna coal field.

2.2.10.6 Coal Analyses and Limits of Variation

Table 2.2.10.3 lists the ranges obtained in proximate analyses of Susitna coal samples. No data are available on computed averages and statistical variation.

Table 2.2.10.3

Limits of Variation in Proximate Analyses of Susitna Field Subbituminous Coal (Alaska)
 (as-received basis)

District	Sample	Proximate Analysis, Weight Percent					Heating Value, Btu/lb.
		Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	
Susitna Field	Outcrop	19.7-28.2	30.1-39.9	28.7-40.6	2.0-14.2	.1-.4	8060-9520
Beluga Lake Dist.	Drill Hole	11.3-19.3	27.8-37.9	25.8-34.6	13.3-30.5	--	6290-8890
Beluga Lake Dist.	Trench	24.4	30.1	28.7	16.8	.2	7160

Note:

Based on 60 samples - 44 core samples, 15 outcrop, 1 trench sample.

Source: Reference 2

References - Section 2.2.10

1. Conwell, C.N. Department of Natural Resources, as cited in the 1979 Keystone Coal Industry Manual.
2. Barnes, F.F. Coal Resources of Alaska, USGS Bulletin 1242-B, 1967.

Big Horn Basin

2.2.11 Big Horn Basin

The Big Horn Basin is the third largest coal-bearing region in Wyoming. The region includes portions of Park, Hot Springs, Washakie, and Big Horn counties in northwestern Wyoming just east of Yellowstone National Park. The Basin extends northward into Montana, but the quantity and quality of the Montana coal portion ranks it as a relatively small deposit of bituminous coal and hence is not discussed in this report. Most of the material in this section on the Big Horn Basin is from work by G.B. Glass,¹ Geological Survey of Wyoming.

2.2.11.1 Geology

The geologic history of the Bighorn basin, as recorded in the various rocks outcropping around its outer portion, extends from Middle Cambrian time to the present. All the more important changes in physical geography which took place in the adjoining Bighorn and Rocky Mountain province, from the earliest Cambrian submergence to near the close of Eocene times, are recorded in the rocks of this region. These rocks comprise sedimentary strata several thousand feet in thickness which were originally a part of a much larger area now bordering the Rocky Mountain Front Range. Near the close of the epoch of early Tertiary mountain development, which resulted in the elevation of the Rocky Mountain Range and the Bighorn, Prior, and Owl Creek mountains, the district now comprising the Bighorn basin became surrounded on all sides by high mountain barriers. The elevation of these inclosing ranges probably was greater than it is at present, for subsequent erosion has removed from their summits the softer sedimentary rocks and some of the granitic nucleus.

The sedimentary rocks of the Bighorn basin consist mainly of sandstone, limestone, shale, sand, and gravel, all more or less variable in composition and appearance. The principal materials of which the sedimentary rocks are composed were originally sand, gravel, or calcareous mud derived from the decomposition of older rocks, or chemical precipitates from sea waters.⁵

There are eight coal fields defined in the Big Horn basin; clockwise from the Montana border they are the Silvertip, Garland Basin, South-eastern, Gebo, Grass Creek, Meeteetse, and Oregon Basin (Cody) coal fields.

Structurally, these eight coal fields are on the flanks of a broad syncline bounded on the east by the Bighorn Mountains, on the south by the Owl Creek Mountains, and on the west by the Absaroka Plateau and Beartooth Mountains. To the north, the Bighorn Basin continues into Montana and narrows where it is flanked by the Beartooth and Pryor Mountains before it merges with the Crazy Mountains syncline. Local folding characterizes the marginal areas of the basin where the coal fields are located. These small anticlines and synclines create local dips at various angles to

the overall synclinal structure of the basin. Dips from 15 to 50 degrees are common in these border areas. There are also numerous normal faults on the flanks of the syncline, especially in the northern half of the basin. Most of these faults trend northeast-southwest with vertical displacements up to 250 feet reported.

Although coals are reported in the Cloverly, Frontier, Lance, Willwood, and Tatman Formations, the thicker and more important beds are limited to the Upper Cretaceous Mesaverde and Meeteetse formations and the Paleocene Polecat Bench Formation. Coaly shale and coal are sometimes found associated with the basal sandstones of the Lower Cretaceous Cloverly Formation. Just outside the boundary of the defined coal basin, 8 feet of Cloverly Formation coal was mined. Only thin coals have been found in the Upper Cretaceous Frontier Formation of the Bighorn Basin. Thicknesses over a few inches are seldom mentioned.

Although Upper Cretaceous Mesaverde coals occur throughout the basin, they are thin in the southeastern corner where they seldom exceed 14 inches in thickness. The thickest and most persistent Mesaverde coals are in the southern and southwestern portions of the basin where bed thicknesses range up to 12 feet. More commonly, Mesaverde coals are only 4-6 feet thick, and splitting and rapid thinning of these coals are common.

Apparently coals are distributed throughout the Upper Cretaceous Meeteetse Formation everywhere in the basin, but they are not as thick or as persistent as the older Mesaverde coals. The thicker Meeteetse coal beds coincide with areas where numerous thin coals coalesce into interbedded shale and coal units. These thicker coals commonly range from 4 to 6 feet, although 8 to 11-foot beds have been reported. Because the Meeteetse and Lance Formations in the Bighorn Basin are not always mapped separately, distinction between upper Meeteetse coals and basal Lance coals is often not possible. Of the two formations, however, the Meeteetse Formation normally contains the thicker and more persistent beds of coal.

Where the Upper Cretaceous Lance can be separated from the Meeteetse, it contains only thin coals. These thin coals are usually reported in the top of the formation and are less than 6 inches in thickness. Separation of the Lance from the overlying Polecat Bench Formation is difficult; therefore, the age of the coals near that contact is not always correctly identified.

Polecat Bench (formerly Fort Union) Formation coals are found in all the coal fields of the basin except the Silvertip Coal Field. These Paleocene coals reach their maximum reported thickness in the Grass Creek and Southeastern coal fields where they are as thick as 38 feet and 10 feet respectively. In all cases the thicker and more important coals occur in the lower part of the formation. Interest in the coals of the Polecat Bench Formation has heightened recently as the search for thick, low sulfur coals continues. The shallower dips exhibited by these younger Paleocene coals complement their greater thicknesses.

2.2.11.2 Coal Reserves and Mines

Figure 2.2.11.1 shows the Big Horn Basin subbituminous region and present surface mining operations. Only the Grass Creek field is currently strip mined in the region; the Mayfield bed is being mined where its thickness averages 35 feet throughout a modest 97 acre area.

The remaining strippable reserve base for the Grass Creek field and the Basin as a whole is 18.6 million tons.¹ The criteria used to delineate a "strippable" reserve base in Wyoming are summarized in Table 2.2.11.1.

Table 2.2.11.1

Strippable Coal Reserve Base and Criteria Used in the Big Horn Basin, Wyoming

Demonstrated Coal Reserve Base (Billion Short Tons)	Minimum Coal Bed Thickness (Ft.)	Maximum Overburden- to-Coal Ratio	Maximum Overburden Thickness (Ft.)
0.02	5	10:1	120 ^a

Note:

^aExcept where strata-breaking characteristics appear ideal and coal thickness is more than 20 feet in single or multiple beds.

Sources: References 1,3

Over 50 underground coal mines have been active in the Region's mining history; all are abandoned except one, which is currently inactive. This inactive underground mine and the one operating surface mine are listed in Table 2.2.11.2, along with their respective annual production tonnage, seam thicknesses, and estimated reserve base.

2.2.11.3 Identified Coal Resources

The identified subbituminous coal resources of the Big Horn Basin total 0.56 billion tons. Table 2.2.11.3 classifies the Big Horn Basin coal resources according to depth, seam thickness, sulfur content, and ash content. The tonnages itemized in the table are adjusted slightly

Figure 2.2.11.1

Map of the Big Horn Coal Basin (Subbituminous)
Showing Surface Mineable Deposits and Mines

Table 2.2.11.2

Active and Inactive Subbituminous Coal Mines in the Big Horn Basin

Map No.	Company/Mine Name	Bed/Field	County	State	Type of Mine	Seam Thickness, Ft. (Average)	Estimated Reserve Base 10 ⁶ Tons	Design Capacity 10 ⁶ tons/year	Status
1	Becor/Roncco Mine	Gebo/Gebo	Hot Springs	Wyoming	Underground	6-11 (7)	--	0.001 MTPY	Inactive
2	Northwestern Resources Co./Grass Creek	Polecat Bench/Grass Creek	Hot Springs	Wyoming	Surface	8-38 (35)	18.6	0.7 MTPY	Active
	Total Reserve Base						18.6		

Sources: References 1,2

Table 2.2.11.3

Classification of Big Horn Basin Identified Subbituminous Resources^{a, b}

<u>DEPTH OF SEAM</u>			<u>SEAM THICKNESS</u>		
Ft.	10 ⁹ Tons	Percent of Total	Ft.	10 ⁹ Tons	Percent of Total
0-1000	.39	69.7	2.5-5	.41	73.2
1000-2000	.13	23.2	5-10	.13	23.2
2000-3000	.04	7.1	> 10	.02	3.6
Total	.56	100.0	Total	.56	100.0

<u>SULFUR CONTENT</u>			<u>ASH CONTENT^b</u>		
Wt. % "as received"	10 ⁹ Tons	Percent of Total	Wt. % "as received"	10 ⁹ Tons	Percent of Total
0-1	.54	96.4	0-5	.15	26.8
1-3	.02	3.6	5-10	.22	39.3
3-10	--	--	> 10	.12	21.4
			Unknown ^c	.07	12.5
Total	.56	100.0	Total	.56	100.0

Notes:

^aIdentified resources include Demonstrated (Measured and Indicated) and Inferred resources 2.5 feet or more thick to an overburden depth of 3000 feet.

^bData classified into the range categories shown are taken from reference 4 and include bituminous coal tonnages (approx 3.5% of total). These tonnage totals have been proportionally adjusted to match subbituminous resource totals from other sources.

^c"Unknown" refers to Identified Resources not classified into the ash content ranges shown.

Sources: References 1,4

from reference 4, which included 0.02 billion tons of bituminous coal with the subbituminous coal. Almost 68 percent of the total subbituminous resource in the Big Horn Basin lies within 1000 feet of the surface. The seams are generally less than 10 feet thick, but as stated earlier, the Grass Creek field contains minable beds that average 35 feet thick.

2.2.11.4 Overburden Characteristics

The Big Horn Basin area presents a great variety of topographic forms. Its salient feature is a broad structural valley bordered on nearly all sides by high mountain ranges. The interior of the valley is characterized by high badlands slopes, which terminate in irregular ridges and sharp peaks or are capped by older gravel terraces. Overburden above the Cretaceous and Paleocene coal deposits consists of layered sandstones, shales, and clay. The central downwarp of the Basin is covered by Wasatch and Laramie formation sand, clay and conglomerate, topped with Quaternary deposits of sand, loam, and gravel.⁵

2.2.11.5 Aquifers

The water-bearing formations of the basin are the Cloverly, Tensleep, and Amsden. Of these the Tensleep and Cloverly formations are the most important. The latter consists largely of sandstone and lies several thousand feet from the surface under much of the basin. A number of water-bearing formations outcrop around the outer portion of the basin and extend far up the slopes of the ridges. In their underground beds they lie immediately beneath impervious shales; to this extent the conditions for underground water are favorable, but the dips are generally steep, and the water-bearing formations are carried rapidly to depths too great to be reached by practicable well borings.⁵

The prominent groundwater systems are found in strata below the coal-bearing formations of the basin; however, both water and coal-bearing groups may be encountered around the basin periphery where the steeply-dipping formations outcrop.

2.2.11.6 Coal Analyses and Limits of Variation

Proximate analyses of eighty-five coal samples from three different coal beds within the Big Horn Basin are presented in Table 2.2.11.4. Due to the lack of individual sample data no "2s limit" and "confidence range on the average" calculations are available. Big Horn Basin subbituminous coal, when compared to other subbituminous coals, is low in moisture and ash content; the heating value is consistent and relatively high for its rank.

Table 2.2.11.4

Limits of Variation in Proximate Analyses of Big Horn Subbituminous Coal
(as-received basis)

Coal Bed	Number of Samples	Proximate Analysis, Weight Percent				Weight Percent, Sulfur	Heating Value, Btu/lb
		Moisture	Volatile Matter	Fixed Carbon	Ash		
Regional Average	85	15.1	34.7	44.9	5.3	0.57	10,832
Gebo - Average	69	15.5	34.2	46.0	4.3	0.6	10,970
Range: High Low		17.8	40.3	49.7	9.1	0.8	11,780
		12.4	31.1	43.0	2.3	0.4	10,080
Mayfield - Average	6	12.3	35.6	44.7	7.4	0.4	10,970
Range: High Low		12.8	38.0	48.1	9.4	0.6	11,246
		10.7	34.0	42.2	5.0	0.3	10,730
Meeteetse Formation - Average	10	13.8	38.0	37.3	10.9	0.5	9,800
Range: High Low		15.1	49.7	45.4	16.6	0.7	10,965
		12.8	32.1	23.7	6.5	0.3	7,773

Source: Reference 1

References - Section 2.2.11

1. Glass, G.B. Wyoming Coal Fields, Geological Survey of Wyoming, Public Information Circular No. 9, 1978.
2. Dan Hausel, W., G.B.Glass, and others. Wyoming Mines and Minerals, 1979, Map, Geological Survey of Wyoming.
3. Smith, J.B., M.F. Ayler, C.C. Know, and B.C. Pollard. Strippable Coal Reserves of Wyoming - Location, Tonnage, and Characteristics of Coal and Overburden, USBM IC 8538, 1972.
4. Anderson, D.L. The Regional Analysis of the U.S. Electric Power Industry, Volume 4, Coal Resources in the United States, Batelle Laboratories, BNWL-B-415, V4A, UC80, 1975.
5. Fisher, C.A. Geology and Water Resources of the Big Horn Basin, Wyoming, USGS Professional Paper No. 53, 1906.

2.2.12 Other Regions

Within this section are descriptions of coal fields of lesser importance to development due to their relatively small coal resources, poor quality, or unsuitable mining environment. Because of the less important nature of these deposits, reliable, detailed, and current information is not always available. The deposits are briefly discussed by state, in decreasing order of estimated "other" resources as shown in Table 2.2.12.1.

Table 2.2.12.1

"Other" Identified Low-Rank Coal Resources^a

State	10 ⁹ tons	Ref.
Montana	48.9	13
Colorado	11.9	2
Wyoming	6.82	5
Washington	4.180	13
New Mexico	>1	10
Alaska	0.47	11
Oregon	0.284	13

Notes:

^aAll tonnages are identified resources to 3000 feet deep, except Colorado which includes coal to 6000 feet.

2.2.12.1 Montana

North Central Region

Coal in the North Central Region has been mined from the Eagle Sandstone at several localities, especially along the banks of the Missouri River, where three or four lenticular beds occur in the lower part of the upper member of the Eagle Sandstone. In places, there is as much as 3 feet of clean coal, but it is not persistent. The coal is of subbituminous rank, has a heating value of 9,100 Btu/lb, and contains about 11-1/2 percent ash.

Coal is also found in the Judith River Formation in localities along the Missouri River and northward. In the Milk River field at both Havre and Chinook, one bed ranges from 2-1/2 to 7 feet in thickness, but much of the coal is impure. An analysis of coal on the as-received basis shows a heating value of 8,590 Btu/lb and 10 percent ash.¹

Coal in the Fort Union Formation is preserved locally in down-dropped fault blocks, as at Big Sandy.

Bull Mountain Field

The Bull Mountain coal field occupies the central part of the Bull Mountains basin in the southern part of Musselshell County and the north-eastern part of Yellowstone County. It contains about 1.8 percent of the coal in Montana. The Tongue River Member of the Fort Union Formation underlies the center of the basin, and the Lebo and the Tullock Members of the Fort Union Formation crop out in thin bands around the rim. The basin is a broad, shallow east-west-trending syncline, and the beds dip into it at angles of 1 to 5° on the east, south, and west sides, and as much as 30° on the north side.

Most of the coal in the Bull Mountains basin is in the Tongue River Member, which is about 1,700 feet thick and contains 26 persistent coal beds plus many thin, lenticular beds. Mining has been carried on mostly in the Roundup coal bed, which is 500 feet above the base of the Tongue River Member. This bed is about 6 feet thick in the western part of the basin, decreasing to 4 feet in the eastern part. Heating value on the as-received basis is 11,000 Btu/lb; the coal contains 7.5 percent ash and 0.4 percent sulfur.¹

Other beds that have some potential include the Carpenter bed, where strippable reserves are outlined in the Carpenter Creek area, and the Charter strippable field in the central part of the Bull Mountain field, which is underlain by the Mammoth coal bed, 5 to 14 feet thick. The estimated subbituminous coal resources for the North Central and Bull Mountain Regions are 48.9 billion tons.¹³

2.2.12.2 Colorado

Uinta Region

The Uinta Region is a deep structural basin about 60 miles wide, stretching northwest-southeast for 100 miles in Northwestern Colorado and extending into eastern Utah. Within Colorado, the 6000 square mile basin is lined almost entirely with coal fields. In most of these fields, coal-bearing strata dip moderately to steeply into the basin so the fields are generally quite narrow. Folding has also helped increase the rank of these coals up to high quality coking bituminous and even anthracite. Only one field of the eight in the Uinta Region, the Grand Mesa field, contains quantities of subbituminous coal. An associated outlying field to the south is the Tongue Mesa field, which also contains subbituminous deposits.

Grand Mesa Field

The Grand Mesa field stretches for approximately 50 miles along the southern and southwestern border of the Uinta Basin. Six to eight fairly persistent coal seams in the Paonia Shale have been labeled A through F in ascending order. Beds 7 to 16 feet thick have been reported, although the seams generally range from 4.5 to 14 feet in thickness. Conflicting reports rank these coals as either subbituminous A to high-volatile C bituminous,² or high-volatile C to high-volatile A bituminous coal.³

The total coal resources in place in the Grand Mesa field (to a depth of 6000 feet) are estimated 8.7 billion tons, of which 91 percent (7.9 billion tons) is subbituminous A and the remainder is high-volatile C bituminous.² No strippable coal resource is estimated for the field. Although a number of small deposits can be identified as potentially strippable, their small size and the undesirability of contour mining on steep hillsides discourages their exploitation.

Ranges of Grand Mesa coal analyses are shown in Table 2.2.12.2.

Table 2.2.12.2

Ranges of Analyses of Grand Mesa Field Coals (as received basis)

<u>Weight. Percent</u>			<u>Heating Value, Btu/lb</u>	<u>Ash Fusion temp. °F</u>
<u>Moisture</u>	<u>Ash</u>	<u>Sulfur</u>		
9.8-20.0	2.1-16.1	0.5-1.8	9360-11670	2060-2970

Source: Reference 2

Tongue Mesa Field

The Tongue Mesa field lies about 40 miles southeast of the Grand Mesa field and contains coal correlating with the Fruitland formation of the San Juan Basin and the Paonia Shale of the Grand Mesa field. The principal and most persistent coal bed is the subbituminous B Cimarron, which ranges from 8 to 40 feet in thickness. Ranges of analyses on an "as-received" basis are shown in Table 2.2.12.3.

Table 2.2.12.3

Range of Analyses of Tongue Mesa Field Subbituminous Coal
(as received basis)

Weight Percent			Heating Value, Btu/lb	Ash Fusion Temp. °F
Moisture	Ash	Sulfur		
14.2-16.0	6.7-8.4	0.5-0.9	9350-10220	2450-2480

Source: Reference 2

Coal-bearing strata of the mesa are intensely block-faulted; correlation of coalbeds between drill holes or outcrops is virtually impossible. There is some evidence that many of the outcrops are exposures of large slump or landslide blocks, which give a false picture of the orientation of coalbeds in the mesa. The overall picture of the mesa is further confounded by almost total concealment by heavy vegetation, landslides, volcanic talus, and glacial debris.

Hypothetical resources (to depths of 6000 feet) are estimated as 4 billion tons for the Tongue Mesa field.² No strippable deposits have been outlined, nor is there any intention to surface mine the field in the near future.³

2.2.12.3 Wyoming

Hanna Field

The Hanna Basin, which is approximately 40 miles long (east to west) by 25 miles wide, is extremely deep for its area with 30,000 to 35,000 feet of sediments overlying its crystalline basement. This structural trough is divided into two separate basins by a large northeast trending anticline. The Hanna Basin lies to the northwest of the anticline and the Carbon Basin to the southeast.

Coal seams occur in the Upper Cretaceous Mesaverde Group and the Medicine Bow Formation, with the most significant seams in the Ferris Formation of Upper Cretaceous and Paleocene Age, and the Hanna Formation of Paleocene and Eocene age. There are an estimated 3.8 billion tons of subbituminous coal resources in the Hanna Field, categorized by thickness and overburden depths in Table 2.2.12.4. The range and average of 34 coal samples from the field are listed in Table 2.2.12.5 and show that Hanna Field subbituminous coals average low in moisture content and relatively high in ash and heating content, when compared to other subbituminous coals.

The subbituminous mining activities in the Hanna Field are summarized in Table 2.2.12.6.

Table 2.2.12.4

Original Subbituminous Coal Resources of the Hanna Coal Field
(million short tons)

Coal Thickness	Overburden Thickness, Feet			
	0- 1000	1000- 2000	2000- 3000	0- 3000
2-1/2 - 10 feet	1554.98	753.72	467.94	2776.64
Over 10 feet	751.01	229.56	90.03	<u>1070.60</u>
Total				3847.24

Source: Reference 4

Table 2.2.12.5

Limits of Variation in Proximate Analyses of Hanna Field Subbituminous Coal
(as-received basis)

	Proximate Analysis, Weight Percent					Heating Value, Btu/lb.
	Moisture	Volatile Matter	Fixed Carbon	Ash	Weight Percent, Sulfur	
Average	11.2	35.3	41.1	7.6	.62	10,638
No. of Samples	34	44	44	34	34	34
Range: High	18.9	41.1	49.0	23.8	1.2	11,600
Low	6.3	32.5	34.1	4.4	.26	8,340

Source: Reference 5

Table 2.2.12.6

Active Subbituminous Coal Surface Mines in the Hanna Field

Company	Mine	County	State	1978 Production (10 ⁶ short tons)
Arch Mineral	Seminole 1	Carbon	Wyoming	2.50
Arch Mineral	Seminole 2	Carbon	Wyoming	2.80
Medicine Bow	Medicine Bow	Carbon	Wyoming	3.10
Rosebud Coal Sales	Rosebud	Carbon	Wyoming	2.71 ^a

Notes:

^a1977 production.

Sources: References 14,15

Hams Forks Region

The Hams Fork Coal Region of western Wyoming includes portions of Lincoln, Teton, and Uinta Counties, and is the fifth largest coal-bearing area in the state. The region is unique from other coal-bearing areas in Wyoming because it falls within the Overthrust Belt.

Structurally, the Hams Fork Region is very complex. Folded Paleozoic and Mesozoic rocks are thrust eastward over folded Cretaceous rocks with the younger Cretaceous and Tertiary rocks of the area resting uncomfortably above these older rocks. The coal-bearing rocks of the Hams Fork Region crop out in long narrow belts bounded by major thrust faults or eroded limbs of folds. The U.S. Geological Survey has named four coal fields within the region: the Evanston, Greys River, Kemmerer, and McDougal coal fields. The Kemmerer, Greys River, and McDougal fields are situated within synclinal areas between the various ranges of the region. Coal-bearing rocks within these fields usually dip westward at 16-80 degrees, averaging closer to 25-30 degrees. The more important coals in the region occur in the Upper Cretaceous Frontier and Adaville Formations.

The 2000-2200 feet thick Frontier formation is the oldest principal coal-bearing unit in the Hams Fork Coal Region and consists of alternating shales, sandstones, clays, and coals. Frontier coals in southern Lincoln County and Uinta County are persistent, yet rarely exceed a seam thickness of 6 feet. To date, most Frontier coal production has come from the Kemmerer Coal Field.

The Upper Cretaceous Adaville Formation is the most important coal-bearing formation in the Hams Fork Coal Region. Ranging from 2,900 to 4,500 feet thick, the basal 1,200 feet of interbedded shales, claystones, and sandstones of this formation in the Kemmerer Coal Field contain up to 32 subbituminous coals, many of which are much thicker than other Upper Cretaceous coals in Wyoming. Adaville Formation coals crop out in three elongate basins in the northern, central, and southern portions of the Kemmerer Field over a combined distance of more than 60 miles. Dips in these three basins are generally westward at 17-45 degrees.

The thickest and greatest number of Adaville coal beds occurs in the central basin west of Kemmerer. In that basin, at least eight coals exceed 10 feet in thickness while another seven beds range between 4 feet and 8 feet thick. The thickest bed, the Adaville No. 1, is locally 118 feet thick. In the northern basin, the Adaville coals thin and decrease in number. Little information is available for that area or for the southernmost basin, which also apparently has fewer coals than the central basin.

To date, most Adaville coal production has come from the Kemmerer District of the Kemmerer Coal Field where the Adaville coals have been both deep mined and strip mined. Most of the Adaville production has come

from the Kemmerer Coal Company's open pit mines, which opened on the Adaville No.1 bed in 1950 and on stratigraphically higher Adaville coals in 1963. Presently, there are three active open pit coal mines on the Adaville coals: Kemmerer's Elkol and Sorenson mines and FMC Corporation's Skull Point mine. These three mines are the only active coal mines in the Hams Fork Coal Region.

Tables 2.2.12.7 and 2.2.12.8 show proximate and ash analyses, respectively, of coal samples from the Sorenson mine. Proximate and ultimate analyses of exploratory core samples from Adaville coal beds are shown in Table 2.2.12.9. The undifferentiated samples came from Adaville No. 2 through No. 11 coal beds and indicate an apparent rank of subbituminous B to C. The Adaville No. 1 analyses indicate a rank of the coal as high as subbituminous A.

There are approximately 1.67 billion tons of subbituminous coal resources in the Hams Fork Coal Region.⁵ At least 150 million tons of coal are available along the length of the deposit and from eight seams mined individually by contour stripping at a 4-to-1 stripping ratio. Over 1 billion tons are considered the strippable reserve base, using multiple-bed strip mining to depths of 1400 feet.⁶

Jackson Hole Coal Field

The Jackson Hole Field in Northwestern Wyoming is underlain by minable beds over an area of 700 square miles, immediately east of Grand Teton National Park. Minalbe coals occur in Upper Cretaceous, Paleocene, and Eocene rocks, and are probably subbituminous in rank. No coal mining activity, surface or underground, is underway or planned for this region. The estimated subbituminous coal resource for Jackson Hole Coal Field is 0.12 billion tons.⁵

Rock Creek Coal Field

The Rock Creek Field is southeast of the Hanna Field, and contains an estimated 0.30 billion tons of coal resources within 3000 feet of the surface.⁵ Coal-bearing rocks occur in the Mesaverde Group of Upper Cretaceous age and the Hanna Formation of Paleocene and Eocene age. The thickest and best exposed coals are in the northwestern part of the field. Coal in the field is subbituminous B rank.

Wind River Coal Basin

The Wind River Coal Basin of Central Wyoming includes portions of Fremont and Natrona counties as well as the southeastern part of the Wind River Indian Reservation. This coal-bearing area is the fourth largest in the state and coincides with the topographic and structural basin of

Table 2.2.12.7

Limits of Variation in Proximate Analyses of Subbituminous Coal from the Sorenson Mine, Kemmerer, Wyoming
(as-received basis)

	Number of Samples	Proximate Analysis, Weight Percent				Weight Percent, Sulfur	Heating Value, Btu/lb.
		Moisture	Volatile Matter	Fixed Carbon	Ash		
Average	12	23.33	32.23	40.05	4.38	0.56	9198
Range: High		27.22	33.82	42.72	7.65	1.11	9951
Low		20.50	31.02	37.68	2.95	0.26	8398
2s limit ^a		3.02	1.46	2.36	2.66	0.46	668

Note:

^a"2s limit" equals twice the standard deviation and represents the interval on either side of the average within which 95 percent of the individual values are expected to lie.

Source: Reference 16

Table 2.2.12.8

Limits of Variation in Ash Analyses of Subbituminous Coal from the Sorenson Mine, Kemmerer, Wyoming

	Number of Samples	Composition, Weight Percent of Ash									
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	P ₂ O ₅	CaO	MgO	Na ₂ O	K ₂ O	SO ₃
Average	12	52.6	14.6	12.7	0.4	0.2	6.9	2.3	0.1	0.4	7.9
Range: High		56.1	20.5	29.1	0.5	0.6	10.0	4.6	0.2	0.8	17.2
Low		35.0	7.0	2.8	0.1	0.0	2.5	0.0	0.1	0.0	1.9
2s limit ^a		15.0	7.6	14.8	0.2	0.4	3.8	2.6	0.0	0.4	7.4

Note:

^a"2s limit" equals twice the standard deviation and represents the interval on either side of the average within which 95 percent of the individual values are expected to lie.

Source: Reference 16

Table 2.2.12.9

Limits of Variation in Proximate and Ultimate Analyses of Hams Fork Subbituminous Coal Deposits
(as-received basis)

	Proximate Analysis, Weight Percent				Ultimate Analysis, Weight Percent					Heating Value, Btu/lb.	Ash Softening Temp, °F
	Moisture	Volatile Matter	Fixed Carbon	Ash	H	C	N	O	S		
Adaville No. 1 - Average	20.4	34.5	42.1	3.0	6.3	58.1	0.9	30.2	0.6	10,910	2,370
No. of Samples	25	25	25	25	7	7	7	7	25	25	25
Range: High	22.7	36.6	44.7	5.3	6.6	60.1	0.9	33.6	1.3	10,530	2,660
Low	16.7	33.0	38.8	1.5	6.1	56.0	1.0	27.5	0.5	9,720	2,150
Adaville Beds - Average	21.2	33.9	41.3	3.8	6.1	55.1	1.4	31.8	0.6	9,520	2,100
(undifferentiated)											
No. of Samples	20	20	20	20	18	18	18	18	20	20	20
Range: High	28.6	36.1	44.7	8.9	6.5	60.0	1.5	39.4	1.8	10,510	2,340
Low	15.4	31.1	36.1	3.2	5.9	47.2	0.8	28.2	0.2	7,920	1,980

Source: Reference 5

the same name. There are seven coal fields described in the basin. Counter-clockwise from the basin's northwestern corner, the seven fields are: Muddy Creek, Pilot Butte, Hudson (Lander), Beaver Creek, Big San Draw, Alkali Butte, and Arminto (Powder River).⁵

Structurally, these seven fields lie on the flanks of, or within, a large asymmetrical west-northwest trending syncline which is 125 miles long and 45 miles wide. The Wind River Basin is bounded by the Absaroka Mountains, the Owl Creek Mountains, and the Bighorn Mountains to the north, by the Wind River Mountains to the west and southwest, by Beaver Rim (a north-facing escarpment) to the south, and by the Rattlesnake hills to the southeast.

Although coals are reported in the Frontier, Cody, Lance, Fort Union, and Wind River formations, the thicker and more important coals are limited to the Upper Cretaceous Mesaverde and Meeteetse formations. The older formations crop out beyond the margins of the coal basin. The younger Wind River Formation rocks occur in the more central portions of the basin where they overlie the major coal-bearing rocks. The thickest and most persistent Mesaverde coals crop out in the Alkali Butte and Big Sand Draw fields along the southcentral flank of the basin. The Downy coal bed in that area is 28 feet thick; another, the Signor bed, reaches 16.5 feet in thickness. Additionally, the Signor bed remains of minable thickness for more than 6 miles along strike. Although some other coals in these fields reach 4 to 5.5 feet in thickness, there are many coals less than two feet thick.

In the Beaver Creek field, Mesaverde coals are known only from the subsurface. One oil well log in the southern-most part of that field shows 29 coal beds in the Mesaverde. The coals are 2-15 feet thick with an aggregate thickness of about 165 feet in a 1,200-foot interval. Coal resources identified from drill holes in this field are probably indicative of the deeper coal resources underlying the rest of the Wind River Coal Basin.

The Upper Cretaceous Meeteetse Formation is only recognized in the Muddy Creek Coal Field in the northwestern corner of the basin. Meeteetse coals common to that area are nearly as well developed as the Mesaverde coals of the Alkali Butte Field. Meeteetse coals are reportedly up to 16 feet thick, although they average less than four feet.

The Paleocene Fort Union Formation is a minor coal-bearing formation in the Wind River Coal Basin. Fort Union coals are only documented in the southcentral and eastern portions of the basin. Even in those areas, Fort Union coals are uncommon and thin, seldom reaching three feet in thickness. In the southernmost part of the Beaver Creek Field, drill holes show as many as three coals in the Fort Union Formation, but they are only 2-3 feet thick. One prospect in the Arminto field exposed 4.5 feet of Paleocene coal.

The Wind River Coal Basin is estimated to contain 875.66 million tons of identified subbituminous coal resources.⁵ Of this resource, none is considered to be in the strippable reserve category, and there is currently no coal mining activity within the Basin. Table 2.2.12.10 gives the average and range of 40 coal sample analyses from Wind River Basin coals.

Table 2.2.12.10

Limits of Variation in Proximate Analyses of Wind River Basin
Subbituminous Coal
(as received basis)

	Number of Samples	Proximate Analysis, Weight Percent				Weight Heating	
		Moisture	Volatile Matter	Fixed Carbon	Ash	Percent, Sulfur	Value Btu/lb
Average	40	21.0	32.8	40.0	6.2	0.6	9,491
Range: High		26.0	38.1	47.7	11.8	1.3	10,510
Low		14.8	26.0	33.2	2.8	0.3	8,760

Source: Reference 5

2.2.12.4 Washington

There are three major subbituminous and lignite-bearing areas in the state of Washington: 1) Issaquah-Grand Ridge; 2) Kelso-Castle Rock; and 3) Centralia-Chehalis fields.

Issaquah-Grand Ridge

There are four distinct subbituminous coal-bearing areas within the Issaquah-Grand Ridge region: Newcastle-Grand Ridge, Cedar Mountain, Renton, and Tiger Mountain. The Niblock and Taylor areas within the Issaquah-Grand Ridge region contain bituminous coals and will not be discussed here.

The structure of the Newcastle-Grand Ridge area is fairly simple and relatively uniform throughout the coal field. The beds strike eastward from Newcastle to Issaquah where they warp around to a north-northeasterly strike. Dips are generally 30° to 40° but increase to 75° in the Grand Ridge area. The coal beds are in nonmarine rocks of the Puget Group and are probably near the top of the Eocene section. Thicknesses of the coal beds range from several inches up to 17 feet at the Newcastle-Coal Creek mine.

The structure of the Cedar Mountain coal area is a southwest-plunging anticline that has been cut by several northwest-trending faults. One main fault cuts the coal field almost into equal portions, both east and west. Because of poor data, it has not been possible to correlate the seams with any degree of surety from one side of the fault to the other. Total resources in the field are estimated at 66.7 million tons in seams 3.5 to 12 feet thick. The rank of Cedar Mountain coals range from subbituminous A to high-volatile C bituminous.

The coal-bearing rocks in the Renton area occur in the Renton Formation. Folding in the area has been moderate to intense with maximum dips reaching 65°. Several northwest-trending faults, of which two at least appear to be significant in size, cut the coal seams. The coals of the Renton area can be classified as either subbituminous A or high-volatile C bituminous.

Little is known about the geology of the Tiger Mountain coal area. The coal occurs in rocks of the Puget Group. The rocks have been folded and the beds strike northeast and dip about 45° to the northwest. The coal is subbituminous B rank and lies in seams 3 to 6 feet thick.

Total identified resources for the Newcastle-Grand Ridge region are listed for each field in Table 2.2.12.11, and average coal analyses are summarized in Table 2.2.12.12.

Table 2.2.12.11

Identified Resources of the Newcastle-Grand Ridge Coal Field

<u>Coal Area</u>	<u>County</u>	<u>Identified Coal Resources (10⁶ Tons)</u>
Newcastle-Grand Ridge	King	309.6
Cedar Mountain	King	66.7
Renton	King	55.5
Tiger Mountain	King	<u>9.0</u>
Total		440.8

Sources: References 7,8

Table 2.2.12.12

Proximate Analyses of Issaquah-Grand Ridge Area Subbituminous Coals
(Washington)
 (as received basis)

Field	Proximate Analysis, Weight Percent				Weight Percent, Sulfur	Heating Value, Btu/Lb
	Moisture	Volatile Matter	Fixed Carbon	Ash		
Total Issaquah-Grand Ridge Area	14.1	34.1	40.3	11.2	0.63	10,099
Newcastle-Grand Ridge	14.5	33.1	39.2	12.8	0.6	9,801
Cedar Mountain	10.2	36.9	41.0	11.9	0.6	10,751
Renton	14.9	34.4	42.0	8.7	0.7	10,384
Tiger Mountain	19.2	32.5	35.9	12.4	0.2	8,810

Source: Reference 8

Kelso-Castle Rock Area

Coal seams of the Kelso-Castle Rock Area occur in rocks of the Cowlitz Formation of Eocene age and the Toutle Formation of Oligocene age. The coal-bearing rocks in this area are gently folded into broad open northwest-trending anticlines and synclines. Dips of the bed are low, rarely exceeding 25°. The coal ranges in rank from lignite to subbituminous B but is mostly subbituminous C. The Toutle Formation contains only lignite-rank coal.

The identified coal resources of the Kelso-Castle Rock Area are estimated to be 150 million tons of which 24.5 million is considered subbituminous and the remainder is lignite.⁷ Analysis of an "as-received" coal sample from this area is shown in Table 2.2.12.13.

Table 2.2.12.13

Proximate Analysis of Kelso-Castle Rock Lignite
 (as received basis)

Proximate Analyses, Weight Percent				Weight Percent, Sulfur	Heating Value, Btu/Lb
Moisture	Volatile Matter	Fixed Carbon	Ash		
27.9	28.0	27.6	16.5	1.4	6,736

Source: Reference 8

Centralia-Chehalis Area

Coal beds in the Centralia-Chehalis area occur in the Skookumchuck Formation of late Eocene Age. The rocks in the area have been gently folded and faulted with most dips being below 30°. The structural trends are dominately northwest with minor folds trending to the north. The coals range in rank from lignite to subbituminous B but most is subbituminous C.

The Centralia-Chehalis coal field is the largest field in the state and is currently being strip-mined near the town of Centralia. At least 14 coal beds crop out in the district with bed dips ranging from horizontal to vertical. Individual beds range in thickness from a few inches to more than 40 feet; the average thickness is between 6 and 8 feet.

Estimated identified resources for the Centralia-Chehalis Area are 3.69 billion tons of subbituminous coal and lignite. The average, as-received analyses of these coals are listed in Table 2.2.12.14.

Table 2.2.12.14

Proximate Analysis of Centralia-Chehalis Subbituminous Coal
(as received basis)

<u>Proximate Analysis, Weight Percent</u>				<u>Weight Percent, Sulfur</u>	<u>Heating Value, Btu/Lb</u>
<u>Moisture</u>	<u>Volatile Matter</u>	<u>Fixed Carbon</u>	<u>Ash</u>		
24.0	32.1	31.5	11.8	1.8	8,159

Source: Reference 7

2.2.12.5 New Mexico

Datil Mountain Field

The most remote and the least known coal-bearing area in New Mexico is the Datil Mountain field. It covers more than 1000 square miles in Socorro, Catron, and Valencia Counties. The region is composed of rough foothills, mountains, canyons, and mesas, and generally lies in the upper drainage basin of Rio Salado. The remote area is accessible only by secondary ranch roads.

The coal beds are in the lower part of the Mesaverde Group in the Gallup Sandstone and Crevasse Canyon Formation. They crop out on the rugged forested north edges of the Datil, Galinas, and Bear Mountains,

and northward in the mesa and canyon country north of Rio Salado. Datil Mountain coals are considered subbituminous in rank and in most places are less than 3 feet thick, although local lenses are as much as 7 feet thick.⁹

Geologic structure is complicated by faulting, folding, intrusions of igneous masses and by thick, volcanic cover. According to earlier estimates, coal resources may be more than a billion tons for the Datil Mountain field, but no detailed exploration has been done in the area.¹⁰ One coal analysis from the Hot Spot prospect area is shown in Table 2.2.12.15.

Table 2.2.12.15

Proximate Analysis of Datil Mountain Subbituminous Coal
(as received basis)

Proximate Analysis, Weight Percent				Weight Percent, Sulfur	Heating Value, Btu/Lb
Moisture	Volatile Matter	Fixed Carbon	Ash		
3.3	34.8	15.0	10.9	1.12	12,410

Source: Reference 9

2.2.12.6 Alaska

Three coal fields in Alaska not mentioned earlier contain modest quantities of low-rank coal; they are the Kenai, Jarvis Creek, and Broad Pass Fields. These fields are briefly discussed below.

Kenai Coal Field

The Kenai coal field lies on the west side of the Kenai Peninsula, on the lowland between the Kenai Mountains and Cook Inlet. The coal-bearing Kenai Formation of Tertiary age is exposed at many points in the southern part of the lowland, referred to as the Homer district. In the northern part, or Kenai district, bedrock is completely concealed by glacial and alluvial deposits, but the presence of the Kenai Formation was originally inferred from the fact that similar rocks are exposed to the north and west across Cook Inlet. This inference was confirmed when several thousand feet of coal-bearing rocks was penetrated in oil wells in the Swanson River area. Available evidence indicates that overburden is at least several hundred feet thick throughout this district, so any valuable coal deposits that may be present are probably not economically recoverable under present conditions.

The Homer district, which includes the part of the Kenai lowland south of Tustumena Lake, is 1,100 square miles in area and includes the type locality of the Kenai Formation. Beds exposed along the shores of Cook Inlet and Kachemak Bay include at least 5,000 feet of nonmarine sandstone, siltstone, claystone, and coal. They outline a broad structural basin or trough locally modified by gentle folds and by high-angle faults with displacements ranging from a few inches to 80 feet. Included in the exposed section are at least 30 coal beds ranging from 3 to 7 feet in thickness, as well as many thinner beds. Exposures are largely limited to coastal bluffs and the banks of the larger streams. The coal ranges in rank from lignite to subbituminous B, but the greater part is subbituminous C.

Although mining has been attempted in the vicinity of Homer from time to time since 1888, the total production of the field does not exceed a few thousand tons. Estimated coal resources in the Homer district are 318 million tons.¹¹ These estimates include only coal in the indicated category, largely lying within half a mile of the coast. Larger resources are undoubtedly present farther inland, but because of the scarcity of outcrops and the marked lenticularity of the coal beds, no attempt was made to compute tonnages in the inferred category.

Jarvis Creek

The Jarvis Creek coal field lies at the foot of the north flank of the Alaska Range a few miles east of the Delta River. Although geologically it is an eastern extension of the Nenana coal field, geographically it is quite distinct. It is about 16 square miles in area, and the coal-bearing rocks, of Tertiary age, dip 50°-100° around the border of a structural basin. Measured sections include 30 coal beds ranging from 1 foot to 7 feet in thickness, but only a few are more than 2-1/2 feet thick. Analyses show the coal to be subbituminous C in rank and relatively high in ash.

Estimated resources based on a detailed survey are 76.5 million tons.¹¹ A few hundred tons has been produced from one small mine opened in 1958.

Broad Pass Field

The Broad Pass field lies just south of the Divide of the Alaska Range, on the headwaters of the Chulitna River. Coal is known chiefly in two districts, one near Broad Pass Station on The Alaska Railroad and the other on Costello Creek, a northern tributary of the West Fork of the Chulitna. The Coal on Costello Creek is classed as subbituminous and that near Broad Pass Station as lignite. Although the mapped area of coal-bearing rocks is only 7 square miles on Costello Creek and 1-1/2 square

miles near Broad Pass Station, the total area underlain by these rocks probably is much larger, as suggested by the presence of coal outcrops at points farther south on the Chulitna River.

Coal resources on Costello Creek were estimated in 1943 to include 350,000 tons of indicated coal, but most of the remaining coal has since been removed or lost by underground and strip mining. Total reported production, in the period 1940-54, was about 64,000 tons. Resources in the mapped part of the Broad Pass district were estimated in 1944 to be at least 13 million tons; much larger tonnages probably exist in adjoining unmapped areas. Total coal resources for the Broad Pass Coal field are estimated as 63.9 million tons.¹¹ Analyses from these three coal fields are listed in Table 2.2.12.16.

Table 2.2.12.16

Ranges of Proximate Analyses of Jarvis Creek, Broad Pass, and Kenai Coal Fields
(Alaska)
(as received basis)

Field	Sample Type	Proximate Analysis, Weight Percent				Weight Percent, Sulfur	Heating Value, Btu/Lb.
		Moisture	Volatile Matter	Fixed Carbon	Ash		
Jarvis Creek	Outcrop	20.0-23.0	35.1-43.4	24.1-35.3	5.2-13.1	0.3-1.4	7815-9415
Broad Pass	Mine	8.7-18.8	32.0-43.4	23.2-42.2	6.0-21.2	0.3-0.6	7985-10600
Kenai	Outcrop	21.2-27.7	31.2-38.1	24.1-33.7	3.2-22.0	.2- .4	6550-8600
	Mine	16.5-21.6	30.3-38.1	31.2-41.1	9.1-12.1	.3- .4	8380-9020

Source: Reference 11

2.2.12.7 Oregon

The Coos Bay Coal field in Coos County, Oregon, underlies more than 400 square miles of land and water. In the Beaver Hill and South Slough mine areas, where the Beaver Hill bed is known to be steeply dipping, there are an estimated 57 million tons of recoverable reserves.¹² This figure represents half of the coal at least 2.5 feet thick, including deep and steeply dipping coals.

The upper and lower sandstone members of the upper Eocene Coaledo formation are the coal-bearing units of the Coos Bay field. They are folded into a series of north-south trending anticlines and synclines which are highly faulted. The thicknesses of the Coos Bay coal beds range from

less than 1 inch to more than 19 feet, but the average is less than 5 feet. The Beaver Hill bed, the most prominent in the field, averages just under 6 feet in thickness, and its dip falls in the 26 to 45° range. There are many miles of outcrop of the Beaver Hill bed in the South Slough Basin, where the dip ranges from 50 to 80°. In the Beaver Hill mine, the coal averages 5 to 6 feet in thickness, and the dip decreases gradually. It is 45° at the surface; but 3,000 feet downdip it is only 26°.12

Analyses of Coos Bay Field coal samples are presented in Table 2.2.12.17.

Averitt¹³ reports the total subbituminous coal resources for Oregon as 284 million tons.

Table 2.2.12.17

Limits of Variation in Proximate Analyses of Coos Bay Field
Subbituminous Coal
 (as received basis)

	Proximate Analysis, Weight Percent				Ash Softening Temp °F	Heating Value, Btu/Lb.
	Moisture	Volatile Matter	Fixed Carbon	Ash		
Average	16.0	34.5	40.8	8.6	2228	9,888
No. of Samples	5					
Range: High	19.3	36.1	42.8	16.0	2340	10,150
Low	10.1	32.8	37.8	5.4	2070	9,250

Source: Reference 12

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2.3 PROPERTIES AND CHARACTERISTICS

2.3.1 Composition

Coal is not a uniform substance but is instead a mixture of physically distinctive and chemically different organic materials (macerals) and inorganic materials (minerals). The diversity of the original plant materials and the degree of coalification that has affected these materials account for the variability of the organic fraction. For example, most coal seams consist of coal bands (lithotypes) and benches which are sandwiched together in layers and which visually differ from each other by physical structure and luster. In the case of the organic fraction, variations are caused both by differences in original plant matter (inherent) mineral content, and by differences in penetration of (extraneous) minerals into the coal seam from adjacent strata.

Randomly selected samples from layers of coal in a single seam can differ by as much as 30 Hardgrove grindability indices, 0.30 specific gravity points, 20 percentage points of ash, 6 percentage points of dry volatile matter and 10 percentage points of total sulfur.¹ Similar wide variations exist for calorific value, moisture content, and almost any other coal parameter used for comparative purposes. These widely varying compositions greatly affect the preparation and utilization characteristics of coal; however, when coal from a specific mine is utilized in large quantities (as it is in most applications), the wide variations observed on a "micro" scale presumably "average out" in some predictable statistical manner. Nevertheless, the most advantageous use of the coal depends on an understanding of what components are present, how they are distributed in the coal (average values and variability), and how they are concentrated or segregated by various mining and preparation processes.²

Macerals

Macerals are the fragmentary organic remains of plants that, because of their varied plant origins and degree of coalification, form the different lithotypes contained in coals. More simply, coals are composed of organic macerals just as rocks are composed of inorganic minerals. Petrographers have established three primary groups which differ in botanical origin: Vitrinite, exinite, and inertinite.^a

^aThe Europeans have conducted far more extensive petrography studies on "brown coals" than have their U.S. counterparts. The extent to which this work is relevant to U.S. lignite is not clear. The International Commission for Coal Petrology recognizes the following primary maceral groups in the case of brown coals:³

Vitrinites (medium reflectivity) form the humic fraction of coal and are produced by relatively slow alteration of plant cell wall substances. In low-rank coals vitrinites are characterized by a brown color and a woody texture. In bituminous and anthracite coals the vitrinites appear textureless and black with a glassy luster to the unaided eye.

Exinites (lower reflectivity) are derived from waxy secretions such as plant cuticles and spore and pollen exines. The macerals included in the exinite group have names that suggest their plant origins: Sporinite, Cutinite, Alginite, as well as waxes and resins.

Inertinite (higher reflectivity) are those macerals that behave as inert substances on heating and include fusinite, semifusinite, sclerotinite, and micrinite.

These three maceral groups are found together in varying ratios or compositions. Depending on which maceral group dominates the mixture, and on their relative proportions, coals are further classified into various microlithotypes and lithotypes.

The most important maceral group in hard coals of the northern hemisphere is vitrinite. In the Carboniferous coals of northwest Europe, for example, vitrinite amounts to between 60 and 80 percent. Reflectivity and carbon content rise with increasing rank, while the volatile-matter yield falls. On the basis of this data it is impossible by measuring the reflectivity of vitrinite to determine the rank of a coal precisely.³ The same general statements can be made about U.S. coals.⁴

Huminite is the predominant maceral group in brown coals, and is the precursor to vitrinite in hard coal. It is essentially composed of the plant substances cellulose and lignin, and is subdivided into maceral subgroups which differ primarily in their degree of gelification. This in turn influences the crushing behavior, briquetting capacity, and other behavioral properties of the coal.

Liptinite corresponds to the exinite maceral group in hard coal. The liptinite fraction of a brown coal is important for bitumen extraction, montan wax production, tar recovery, and hydrogenation.

Inertinite plays a relatively unimportant role in brown coals, which is not always the case in "hard coals."

In the United States, the majority of coal petrography studies have been directed towards high-rank (coking) coals. The practical applications of this work have so far been limited primarily to the correlation of coking behavior with petrographic properties. The steel industry, for example, is very active in petrography, utilizing the results to select coals, specify blends, and maintain quality control.⁵ Investigators have also found that petrographic composition is an important characteristic affecting coal liquefaction behavior.⁶ However, the correlations between conversion and concentrations of the reactive macerals (which were satisfactory for the higher-ranked coals) did not apply to a subset of western low-rank coals.⁷ Some researchers feel that simple extension of the descriptive procedures used for high-rank coals will be inadequate for the practical application of petrography to low-rank coal utilization.⁸ In some ways, "coal science" applied to low-rank coals in the U.S. is in its infancy.^{9,10}

One significant effort to advance the state-of-the-art of applied coal science in the U.S. has been initiated by R.C. Neavel and co-workers at Exxon. The Baytown Coal Research Laboratory of Exxon Research and Engineering Company offers to qualified investigators a set of well characterized, well preserved coal samples ranging from lignitic to medium volatile bituminous in rank. Sixty-six samples of vitrinite-rich coals with low mineral matter content are being extensively characterized in the Baytown lab. Exxon believes that other investigators might find these samples useful for conducting characterization tests, and is therefore making this offer. The ultimate objective of Exxon's research program is to develop a coal classification system that will allow prediction of responses to processing in combustion, pyrolysis, liquefaction and gasification.¹¹

Table 2.3.1.1 shows some typical values of selected properties of vitrinite macerals in different rank coals. All of the properties listed have an impact on the coal's behavior in extraction, utilization, or conversion processes; the most noticeable properties are the high inherent moisture and oxygen contents of low-rank coal macerals, and their corresponding low heating values. The effects of these properties on technologies for utilization of low-rank coals are discussed throughout Chapter 3; combined with the effects of the unique low-rank coal mineral matter, they provide the justification for a specific, separate R&D program for low-rank coals (see Chapter 7).

P.H. Given and co-workers at Pennsylvania State University have conducted extensive studies of the organic chemistry of coal macerals. From a summary of this work, presented at the 1979 Short Course on Coal Characteristics and Coal Utilization, some interesting points relevant to the functional groups in low-rank coals (the way in which oxygen is combined in the organic structure) can be made:⁴

Table 2.3.1.1

Selected Properties of Vitrinites In Coals of Different Ranks

	<u>Lignite</u>	<u>Subbituminous</u>	<u>Bituminous</u>	<u>Anthracite</u>
Moisture Capacity, Wt.%	40	25	10	< 5
Carbon, Wt.% DMMF	69	74.6	83	94
Hydrogen, Wt.% DMMF	5.0	5.1	5.5	3.0
Oxygen, Wt.% DMMF	24	18.5	10	2.5
Vol. Mat., Wt.% DMMF	53	48	38	6
Aromatic C/Total C	0.7	0.78	0.84	1.0
Density (H ₂ O, g/cc)	1.43	1.39	1.30	1.5
Grindability (Hardgrove)	48	51	61	40
Btu/lb. DMMF	11,600	12,700	14,700	15,200

DMMF = Dry, Mineral-matter-free basis. These are typical values for rank classification. Sulfur and nitrogen are rank-independent and not shown.

Source: Reference 9

1. Hydroxyl (OH) content, when expressed as a fraction of total organic matter, shows high correlation with rank parameters. The correlations are even stronger when the data are partitioned into subsets containing Western coal and Interior or Appalachian coal. Hydroxyl groups are important to coal reactivity, in that they are hypothesized to play a role in holding coal molecules together through hydrogen bonds. Dissociation of OH has been observed as one of the first pyrolytic reactions to occur.

2. Carboxyl groups are present in lignite and to a lesser extent in subbituminous coals, but are essentially absent for coals of higher rank. The carboxyl groups in lignites are mostly in salt form; protons have been replaced by metal cations from groundwater, leading to one form of "inherent mineral matter" in low-rank coals.^b

Minerals

Minerals found in coal are classified as either syngenetic or epigenetic.¹³ Syngenetic minerals were included during the biochemical changes associated with coalification, whereas epigenetic minerals were deposited in the cracks and cleats of the coal after the coalification process was complete. The amounts and kinds of minerals found in coal vary widely and naturally depend on the conditions of formation. Table 2.3.1.2 lists some of the more common minerals found in coals.

The most abundant minerals are the alumino silicates, or clay minerals, such as illite, kaolinite, and mixed-layer illite-montmorillonite. Coals in the Denver Region include significant kaolinite partings rich in Al_2O_3 and SiO_2 .²⁰ Clays contain various sites where ion exchange can occur with ions in ground waters. Most clays contain structural -OH groups, which are released as water then the mineral undergoes thermal decomposition (at 500-600°C).

^b"Inorganic" matter occurs in low-rank coal in other forms than that in discrete mineral phases. In a study of the geochemistry of major, minor and trace elements in five lignite drill cores, Miller¹² found that 85-95 percent of the Ca in the coals was present as carboxylate salts, resulting from ion exchange processes between the coal and groundwaters. Major fractions of the Mg, Sr and Na were held in the same way, as were somewhat lesser amounts of Ba, Mn and K. It was inferred that 30-50 percent of the Ti and an appreciable fraction of the Al were present as chelate coordination complexes. Many of the trace elements, such as Y, V and Be, were at least partly held by the organic matter as individual chelated cations. Organic acids had apparently leached Ti from ilmenite ($FeTiO_3$) and extensively changed detrital illite into kaolinite. It is felt that the coal chemist should be aware of these diverse interactions between organic and inorganic matter, which mostly originated in the peat swamp, but whose effects are manifest at the lignitic and subbituminous state of coalification. As coals mature to higher rank, the organic functional groups capable of ion exchange or chelation tend to be eliminated from the organic structures.

Table 2.3.1.2

Minerals Associated With Bituminous Coals

Group	Species	Formula
Shale	Muscovite	$(K, Na, H_2O, Ca)_2 (Al, Mg, Fe, Ti)_4 (Al, Si)_6 O_{20} (OH, F)_4$
	Hydromuscovite	
	Illite	
	Bravaisite	
	Montmorillonite	
Kaolin	Kaolinite	$Al_2(Si_2O_5)(OH)_4$
	Liyesite	
	Metahalloysite	
Sulfide	Pyrite	FeS_2
	Marcasite	
Carbonate	Ankerite	$(Ca, Mg, Fe, Mn) CO_3$
	Ankeritic calcite	
	Ankeritic dolomite	
	Ankeritic chalybite	
Chloride	Sylvine	KCl
	Halite	NaCl
Accessory Minerals	Quartz	SiO_2
	Feldspar	$(K, Na)_2 O \cdot Al_2 O_3 \cdot 6SiO_2$
	Garnet	$3CaO \cdot Al_2 O_3 \cdot 3SiO_2$
	Hornblende	$CaO \cdot 3FeO \cdot 4SiO_2$
	Gypsum	$CaSO_4 \cdot 2H_2O$
	Apatite	$9CaO \cdot 3P_2 O_5 \cdot CaF_2$
	Zircon	$ZrSiO_4$
	Epidote	$4CaO \cdot 3Al_2 O_3 \cdot 6SiO_2 \cdot H_2O$
	Biotite	$K_2 O \cdot MgO \cdot Al_2 O_3 \cdot 3SiO_2 \cdot H_2O$
	Augite	$CaO \cdot MgO \cdot 2SiO_2$
	Prochlorite	$2FeO \cdot 2MgO \cdot Al_2 O_3 \cdot 2SiO_2 \cdot 2H_2O$
	Diaspore	$Al_2 O_3 \cdot H_2O$
	Lepidocrocite	$Fe_2 O_3 \cdot H_2O$
	Magnetite	$Fe_3 O_4$
	Kyanite	$Al_2 O_3 \cdot SiO_2$
	Staurolite	$2FeO \cdot 5Al_2 O_3 \cdot 4SiO_2 \cdot H_2O$
	Topaz	$(AlF)_2 SiO_4$
	Tourmaline	$H_9 Al_3 (BOH)_2 Si_6 O_{18}$
	Hematite	$Fe_2 O_3$
	Penninite	$5MgO \cdot Al_2 O_3 \cdot 3SiO_2 \cdot 2H_2O$

Sources: References 13,14

The carbonate minerals, in general, vary widely in composition because of the extensive solid solution of calcium, magnesium, iron, manganese, and other elements that is possible within them.

Quartz (SiO_2) is present in all coals, and is the only major mineral found in coal that remains inert during high temperature ashing.¹⁷

The remaining common mineral constituents found in coal are iron sulfide (pyrite and marcasite), and sulfates of various cations. Pyrite and marcasite are dimorphs, minerals that are identical in composition (FeS_2), but different in their crystalline structure: Pyrite is cubic and marcasite is orthorhombic.¹⁷ Sulfates are rare in most fresh and unweathered coals, but as the exposed coal dries, both pyrite and marcasite begin to decompose into various phases of iron sulfate minerals. New Mexico studies indicate that the sulfate content in fresh coals depends on some movement of ground water through the coals.

Sulfur occurs in the organic fraction of coal as well. In fact, for low-sulfur (low-rank) coals, the organic sulfur compounds generally comprise one-half to two-thirds of the total sulfur content of the coal. This is indicated in Table 2.3.1.3 which shows data on forms of sulfur in selected low-rank coals. As a general rule, the higher sulfur coals tend to contain a higher ratio of inorganic sulfur forms to organic sulfur than the low-sulfur coals.²²

The total amount of mineral matter in U.S. coals varies considerably, but it is always present in sufficient concentrations to be significant in most coal uses. For low-rank coals in particular, the mineral matter composition causes well-known ash fouling and scaling problems in conventional combustion practices, yet also offers the potential for post-combustion SO_2 control. These characteristic process effects and others are discussed in detail throughout Volume 3.

Ash

Ash is the mineral residue remaining after complete combustion of coal. It is related to mineral matter, but is different in chemical composition from, and found in less quantity than, the original mineral matter. The heat of combustion induces changes in the mineral portion of coal, such as loss of water of constitution by silicate minerals, loss of carbon dioxide from carbonate minerals, oxidation of iron pyrites to iron oxide, and fixation of oxides of sulfur by bases such as calcium and magnesium.¹⁶ Ash consists mainly of compounds of silicon, aluminum, iron, calcium, magnesium, and sodium with smaller quantities of phosphorus, titanium, potassium, and a number of trace elements. Analyses of ash are commonly reported as oxides; however, they may actually occur in the ash as a mixture of silicates, oxides, and sulfates.

Table 2.3.1.3

Sulfur Contents and Forms of Sulfur of Selected Low-Rank Coals

State	Total Sulfur (Wt. Percent)	Forms of Sulfur, Wt. Percent of Total Sulfur			Ref.
		Sulfates	Pyrite and Marcasite	Organic	
North Dakota	0.61	4.4	33.8	61.8	15
Wyoming	<1.0	3-5	25-29	70-72	21
Montana					
Decker Field	0.41	2.7	21.4	75.9	26
Foster Creek	0.66	3.8	47.3	48.9	
Ashland	0.26	5.5	15.7	78.8	
Colorado					
Canon City	0.78	1.3	28.7	70.0	24
Denver	0.31	3.2	24.5	72.3	
Green River	0.59	2.8	8.7	88.5	
North Park	0.40	4.8	36.4	58.8	
Arkansas	0.58	3.9	28.5	67.6	25
New Mexico					
Upper Menefee	0.84	19.8	11.0	69.2	22

Note:

The total sulfur percentages do not necessarily reflect overall averages for each state or region; they are merely averages of specific samples that have been analyzed for the various sulfur forms.

Table 2.3.1.4 shows average values and ranges of concentration of the primary constituents of ash from coal samples of different rank. It should be noted that the average values do not necessarily represent "typical" values for any specific type of coal, because of the very wide variations that exist. Despite the wide variations, certain trends as a function of rank are typically observed, and are reflected in the averages.^C Low-rank coal ashes generally have higher proportions of the alkali components CaO, MgO, Na₂O, and SO₃. The acidic components SiO₂ and Al₂O₃ are more prominent in the higher-rank coals. Fe₂O₃ apparently does not follow any definite pattern in relation to rank.¹⁵

Trace Elements

The term "trace elements" is applied to elements that are present in concentrations of 0.1 percent (1000 ppm) or less. Elements present in amounts greater than 0.1 percent are often called minor and major elements according to increasing concentrations. Although they represent a very small fraction of the total composition of coals, trace elements are important in the behavior of coals during conversion processes. Some elements are highly volatile and present a potential health and environmental hazard; others may actually promote conversion reactions by acting as catalysts.¹⁸

Tables 2.3.1.5 and 2.3.1.6 summarize trace element contents in coals from various regions throughout the U.S. Concentrations of mercury, lead, and zinc are highest in the Eastern Interior region; the lowest concentrations for all hazardous elements listed (except for zinc and cadmium) are found in the Powder River Region.

Moisture

The largest single inert in low-rank coals is moisture. Moisture content of as-mined subbituminous coal may be as high as 35 percent, but averages around 23 percent. Lignites contain even higher moisture percentages - as high as 43 percent in North Dakota samples and 64 percent in Alabama, with a gross national average around 33 percent. Most of the moisture in a typical shipment of Eastern bituminous coal is surface

^CStrictly speaking, the rank of coal expresses only the degree to which geologic alteration processes (metamorphism) have affected the properties of the organic substances. In this sense, rank classification is independent of inorganic content; nevertheless, U.S. low-rank coals do exhibit characteristic differences from high-rank coals in their mineral matter content and therefore in their ash properties. This is apparently a coincidental or indirect relationship caused by the respective geologic ages and geographic locations of the U.S. low-rank coals and high-rank coals.^{9,15}

Table 2.3.1.4

Limits and Averages of Ash Composition For Various U.S. Coals

	Anthracite				Bituminous				Subbituminous				Lignite			
	Low	High	Average	No. Of Samples	Low	High	Average	No. Of Samples	Low	High	Average	No. Of Samples	Low	High	Average	No. Of Samples
Ash, percent of MF coal	10.2	25.8	17.4		4.0	18.5	8.6		--	--	--		--	--	9.9	
Analysis, percent of Ash								135								444
SiO ₂	47.7	67.7	55.2	29	9.3	69.6	48.2		15.2	52.8	38.2	124	6.3	39.4	19.7	
Al ₂ O ₃	24.7	43.5	34.0	29	5.6	41.7	24.9		9.0	27.6	20.6	124	4.2	26.1	11.1	
Fe ₂ O ₃	2.1	10.2	6.3	29	3.8	84.2	14.9		3.3	31.5	9.8	124	0.9	34.3	9.1	
TiO ₂	1.0	1.8	1.3	9	0.1	2.5	1.10		0.1	2.1	0.8	124	0.0	0.8	0.4	
P ₂ O ₅	0.1	0.1	0.1	6	--	--	--		0.0	2.2	0.4	124	0.0	1.1	0.3	
CaO	0.2	3.7	1.0	29	0.2	36.7	6.6		10.5	52.6	19.5	124	12.4	52.0	24.6	
MgO	0.0	1.2	0.6	29	0.4	6.3	1.7		1.4	9.0	5.4	124	2.8	13.6	6.9	
Na ₂ O	--	--	--		0.0	7.6	1.2		0.1	10.4	2.0	124	0.1	27.8	6.5	
K ₂ O	--	--	--		0.1	6.0	1.5		0.0	1.1	0.3	124	0.0	1.3	0.4	
SO ₃	0.0	2.0	0.7	27	--	--	--		12.9	20.5	15.9	20	8.3	32.0	19.5	
AST, °F	2350	3000	2817	23	1940	2930	2355		1940	2730	2189	124	1970	2730	2290	

Sources: Anthracite: Reference 28
 Bituminous: Reference 23
 Subbituminous: Reference 29
 Lignite: Reference 15

Table 2.3.1.5

Trace Element Content of American Coals (ppm in coal)

Element	Region			
	Northern Great Plains	Western Interior	Eastern Interior	Appalachian
Beryllium	1.5	1.1	2.5	2.5
Boron	116	33	96	25
Titanium	591	250	450	340
Vanadium	16	18	35	21
Chromium	7	13	20	13
Cobalt	2.7	4.6	3.8	5.1
Nickel	7.2	14	15	14
Copper	15	11	11	15
Zinc	59	108	44	7.6
Gallium	5.5	2.0	4.1	4.9
Germanium	1.6	5.9	13	5.8
Molybdenum	1.7	3.1	4.3	3.5
Tin	0.9	1.3	1.5	0.4
Yttrium	13	7.4	7.7	14
Lanthanum	9.5	6.5	5.1	9.4

Source: Reference 19

Table 2.3.1.6

Distribution of Environmentally Hazardous Trace Elements (ppm in coal)

Element	Region			
	Powder River Basin	Western Interior	Eastern Interior	Appalachian
Antimony	0.67	3.5	1.3	1.2
Arsenic	3	16	14	18
Beryllium	7	2	1.8	2.0
Cadmium	2.1	20	2.3	0.2
Mercury	0.1	0.13	0.19	0.16
Lead	7.2		34	12
Selenium	0.73	5.7	2.5	5.1
Zinc	33		250	13

Source: Reference 19

moisture from the underground mine or the preparation plant, which can be readily removed by conventional mechanical and thermal drying techniques. In contrast, the moisture is inherent in the lignites and subbituminous coals, partly trapped in pores and capillaries, and partly as bound water within the molecular structure of the coal. Mechanical drying methods cannot remove it, but finely crushed lignites will air-dry very rapidly in ambient conditions and in thermal drying processes. Because much of the moisture in low-rank coals is associated with the coal structure itself, moisture reduction changes the structure from a tough, resilient gel-like particle to a weak, friable, fragile particle. Dried lignite slacks readily and becomes much more reactive to oxygen, hence more susceptible to spontaneous heating.

2.3.2 Physical Properties/Behavior

Various physical and behavioral coal properties are briefly discussed here, with special attention given to comparing low-rank coal characteristics to other U.S. coals. The effects of these properties on coal processing technologies are discussed in detail throughout Chapter 3.

Specific gravity. Because coal contains many pores and capillaries within its structure, the value obtained for specific gravity depends on the dilatometric fluid used. The specific gravity of pure coal (macerals only), measured in water, ranges from 1.23 to 1.72, and increases with rank from lignite to anthracite. Within any rank, wet coal has a higher apparent specific gravity than a dry sample, and an increase in ash content corresponds to an increase in specific gravity.²

Grindability. The grindability of coals is a composite physical property that encompasses other specific properties such as hardness, strength, tenacity, and fracture. Grindability is generally related to rank, and more specifically to the volatile matter content: Medium- and low-volatile groups are decidedly easier to grind than high-volatile bituminous and subbituminous coals.² Table 2.3.2.1 lists the grindability values for some representative American coals; the relationship between volatile matter and grindability appears more pronounced among the higher-ranked Eastern coals than in the Western coals. The Hardgrove grindability index values obtained from lignite samples have been shown to vary in a characteristic manner as moisture is removed from the lignite. More importantly, the index values for lignite correlate poorly with the performance of actual mills.²⁷

Friability. The tendency toward breakage on handling, termed "friability," is affected by several coal characteristics such as toughness, elasticity, fracture characteristics, and strength. Highly friable coals result in increased surface area, allowing for more rapid oxidation which causes loss in quality and a greater chance of spontaneous ignition. Although a relationship does exist between the friability and rank of

Table 2.3.2.1

Grindability Indexes of Some American Coals

State	Bed Or Location	Hardgrove Grindability Index	Rank
Pennsylvania	Lower Kittanning	109	Low-Vol. Bit.
	Lower Freeport	92	Med-Vol. Bit.
	Upper Freeport	65	Hi-Vol. Bit.
West Virginia	Pocahontas No.3	96	Med-Vol. Bit.
	Sewell	86	Med-Vol. Bit.
	Powellton	58	Hi-Vol. Bit.
Virginia	Raven	98	Med-Vol. Bit.
	Upper Banner	84	Hi-Vol. Bit.
	Morris	43	Hi-Vol. Bit.
Illinois	No. 5	63	Hi-Vol. Bit.
	No. 6	57	Hi-Vol. Bit.
	No. 7	56	Hi-Vol. Bit.
Alabama	Black Creek	44	Hi-Vol. Bit.
Utah	Castle Gate	47	Hi-Vol. Bit.
New Mexico	Newcomb Upper Menefee	58	Subbit. A
	Bisti Fruitland	56	Subbit. A
	Navajo Fruitland	52	Subbit. B
Wyoming	Western Wyoming	54	Bit. & Subbit.
	North Central Wyoming	49	Bit. & Subbit.
	Southern Wyoming	49	Bit. & Subbit.
	Northeastern Wyoming	45	Bit., Subbit. & Lignite

Source: References 2, 21, 22

coals, it is only a general one, since coals of the same rank exhibit wide variations in friability. However, lignites tend to be the least friable of all coals; friability increases with rank up to low-volatile bituminous coals, then decreases in anthracites (see Table 2.3.2.2). The low index of friability for low-rank coals is more than offset by the tendency of these coals to disintegrate by slacking during moisture loss. Bituminous coals are affected only slightly by weathering.

Table 2.3.2.2

Average Friability Values of Different Ranks of Coal

Rank of Coal	Number of Tests	Friability (percent)
Anthracite	37	33
Low-Volatile bituminous	27	70
High-Volatile bituminous	87	43
Subbituminous A	40	30
Subbituminous B	29	20
Lignite	16	12

Source: Reference 2

Abrasiveness. Coal handling equipment suffers definite wear from the abrasive nature of the coal. Experience in operating pulverized fuel power plants has demonstrated that some coals are much more abrasive than others. However, abrasive wear is attributable more to the impurities in coal than to the coal itself, regardless of rank. Therefore, a well-cleaned and prepared coal will show a more consistent and lower level of abrasiveness.² Many low-rank coals contain very little extraneous mineral matter (silica) as mined, thus reducing their abrasiveness in comparison to bituminous coals.

Caking. Caking, or agglomerating, coals are usually bituminous in rank. When heated in a furnace, they pass through a plastic phase during which individual pieces fuse together. Low-rank coals do not have this property, and are termed non-agglomerating, or non-caking coals. Many coal utilization processes are affected by the caking behavior of the coal feedstock, as discussed in Chapter 3.

Ash Fusion Temperature. This property is most important in the design and operation of furnaces and gasifiers. As coal ash melts, it first softens and, as temperature increases, gradually becomes a viscous liquid (molten slag). The process is a complex combination of chemical reaction, solution, and melting. The melting process may differ according to the atmosphere, the rate of heating, and the length of time a temperature level is maintained.²³ Three characteristic temperatures are generally reported in ash fusibility studies: the initial deformation temperature, the softening temperature and the fluid temperature. Single point values for these three temperatures are listed for various low-rank coal samples in Table 2.3.2.3. These values should not be considered typical of a given type of coal; a very wide range (1900-2700°F) of ash softening temperatures is typically observed for different samples from any specific coal seam.

Correlations have been developed which are reasonably successful in predicting ash softening temperatures as a function of ash composition. Two parameters used in these correlations are the basic constituent ratio (numerator = $\text{Fe}_2\text{O}_3 + \text{CaO} + \text{MgO} + \text{Na}_2\text{O} + \text{K}_2\text{O}$; denominator = numerator + $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{TiO}_2$) and the dolomite ratio (numerator = $\text{CaO} + \text{MgO}$; denominator = numerator + $\text{Fe}_2\text{O}_3 + \text{Na}_2\text{O} + \text{K}_2\text{O}$). Low-rank coals tend to have basic constituent ratios greater than 0.5, and ash softening temperatures that increase with increasing ratios. Bituminous coals tend to have basic constituent ratios less than 0.5, and ash softening temperatures that increase with decreasing basic constituent ratio. Minimum ash softening temperatures tend to occur at a BC ratio of about 0.5. The best correlations for predicting fusibility of ash from Fort Union Region lignites do not utilize these ratios, but instead utilize statistical regression coefficients applied to each of the constituent concentrations. GFETC studies show that addition of SiO_2 to lignite ash markedly reduces the ash softening temperature; addition of calcium and magnesium oxides markedly increases it.²³

Table 2.3.2.3

Ash Fusion Temperatures for Various U.S. Coals

State	Formation/ Bed	Rank	Initial Deformation	Softening	Fluid
Colorado	Green River Region, Yampa Field	Sub/bituminous	2397	2461	2555
	Canon City Field	Subbituminous	2350	2433	2560
	North Park Field	Subbituminous	2216	2270	2329
N. Dakota	Northern Great Plains Province	Lignite	--	2290	--
Texas	Wilcox	Lignite	2174	2280	2385
	Yegua	Lignite	2133	2211	2380
Alabama	Wilcox	Lignite	2691	2762	2871
Arkansas	--	Lignite	2344	2418	2455
New Mexico	Upper Menefee	Subbituminous	2653	2667	2737
	Mesaverde	Subbituminous	2463	--	--
	Fruitland	Subbituminous	2441	2562	2750
Montana	Westmoorhead	Subbituminous	2342	2392	2438
	Colstrip	Subbituminous	2175	2220	2269
	Broadus	Subbituminous	2242	2287	2332
135 Samples of bituminous coals			--	2355	--

Sources: References 6,15,22,24,25,26

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2.4 WATER RESOURCES

2.4.1 Introduction

In the western United States, the adequacy of a water source is dependent on several factors, including the average quantity of water available at the intended source, the variability of supply over time, the manner in which the water is appropriated, the quality of the water, and the environmental and social implications involved in altering the hydrologic regime.¹ In this section on water resources, all the above aspects will be evaluated except for the social and environmental implications.

In most areas of the West, both surface water and groundwater supplies must be evaluated as potential sources for water-intensive coal extraction or utilization projects. Surface water is usually measured in acre-feet per year;^a it can also be quantified by runoff rates, usually measured in cubic feet per second.^b Groundwater is usually measured in acre-feet or in terms of flow rates obtained from wells, using units of gallons per minute (gpm). The quality of water resources can be just as important as the quantity which is available. When describing water quality, the salinity of the surface waters refers to their content of soluble salts which include mainly chlorides, sulfates, and bicarbonates of calcium, magnesium, and sodium. Salinity is often measured in terms of total dissolved solids (TDS) in units of milligrams per liter (mg/l) without further identifying the levels of specific constituents. The TDS content classification is shown in Table 2.4.1.1.¹

Although there may be adequate water supplies generated in one area and the quality is determined to be acceptable or evaluated not to be harmed, competing uses and legal constraints can severely curtail that water's availability. The major current use of water throughout the western regions is agriculture. Irrigation is by far the largest water use in the West, accounting for an average of 70-80 percent of total present depletion. The net depletion comes from evaporation and transpiration losses, seepage into the deep groundwater system, and water incorporation into growing plants.⁴ Other competing water uses include municipal and industrial sectors, reservoirs, and industries which are self-supplied.

Legal constraints involved in water use can also preclude the use of water in certain areas. Water rights are a major part of this legal system. They are considered property, and can be bought and sold as such. State surface water rights are usually controlled under one

^aOne acre-foot (AF) of water is that volume of water which will cover a one-acre area one foot deep, or about 325,000 gallons.²

^bRunoff is an indicator of a region's water resources, but it should not be used alone as a measure of water sufficiency.¹

Table 2.4.1.1

TDS Content Classification

<u>Class</u>	<u>TDS, mg/l</u>
Fresh	<1000
Slightly Saline	1000-3000
Moderately Saline	3000-10,000
Very Saline	10,000-30,000
Briny	>35,000

Source: Reference 3

of two systems, appropriation or riparian, or can sometimes be a mixture of both. In general, the states in the West have adopted the appropriation system of water rights. In this system, water rights are given priorities dependent on the seniority of the right and independently of the location of the water use with respect to its source. Usually the only requirement regarding the use of the water once the water right is confirmed is the need to put the water to "beneficial use."

The states in the East adopted the riparian system of water rights. The basis for this system lay in the concept that the rights to use the waters of non-navigable streams were held by owners of the land adjacent to the stream.⁵ There is also another principle involved, the idea of "reasonable use." This idea is relatively ill-defined and in many cases understood to mean that the use of the water is permissible so long as no other user of the water is harmed. The riparian system is clearly the result of experience gained from areas in which water is relatively plentiful.⁴ Most of the states containing major low-rank coal resources are under the appropriation system. There are a few states, however, which use a combination of the systems, such as North Dakota and Texas.^{4,6}

The groundwater system is different in its legal characteristics from the surface water. Groundwater is generally considered part of the land and, therefore, the property of the landowner rather than the public.⁵

In general any water supply strategy must consider a number of sources and the consequences of development from among the alternatives. Included typically among the possible water sources are unused and unappropriated surface waters, groundwater, the purchase of surface and

groundwater rights, the development of adequate storage facilities, and the possibilities of conjunctive use and water transfers over long distances.

The water resources have been identified in the following subsections by the applicable geographic areas which contain low-rank coal regions. Where specific coal or lignite regions' water resources could be distinguished from its geographic basin, this additional detailed information is summarized as well.

Conclusions on Water Supply Availability

It appears that actual water use other than for energy will be considerably less than the total available surface water supply. Of the remaining water, however, significant quantities may already be legally committed to other uses, or may be required for instream flow uses. In many cases, therefore, water to meet energy requirements will have to be acquired through the purchase of existing rights; diverted from major interstate rivers and piped to the point of intended use; developed from groundwater reserves; or a combination of these.⁴

The results of some investigations indicate that future energy-related water requirements will be most easily accommodated for those plant sites located along the mainstems of the major rivers and in areas where the level of competing use is projected to be small relative to overall water availability. Some sub-regions in both the Upper Missouri River Basin and Upper Colorado River Basin which will have some water availability include:

1. Yellowstone River Mainstem
2. Missouri River Mainstem
3. North Platte River
4. Upper Green River
5. Upper Colorado Mainstem

Although overall water availability is generally favorable within these regions, individual sites may be located considerable distances away from the water sources and require major water delivery development.⁴

On the other hand, in several areas of the Upper Missouri River Basin and Upper Colorado River Basin, future water needs for types of energy development will be difficult to meet from the available sources within the region without major disruptions to the present water use structure. Some of the most readily developable coal reserves in the Powder River and Fort Union coal formations of northeast Wyoming and western South Dakota are located in regions with these characteristics. These sub-regions include:

1. Tongue-Rosebud
2. Powder River
3. Belle Fourche - Cheyenne
4. Heart Cannonball

In these regions, the energy-related water requirements probably can best be met by trans-basin diversions from more adequate supplies outside the regions.⁴

In assessing water availability for lignite development in Texas, both the magnitude of the water resource and the total demand placed on that resource must be evaluated. Agricultural demands have already exceeded the renewable supply in some areas of Texas such as the High Plains and the Winter Garden area in the Southern part of the Nueces River Basin. Also, much of the available surface water in the State has already been legally claimed through the issuance of water rights permits, which all major users of surface waters in Texas must obtain from the Texas Water Rights Commission.³⁵

The South, except for central and western Texas, is generally considered to be an area rich in water resources. However, there are several basins with actual or potential water supply problems. Groundwater in the High Plains area comes from the Ogallala aquifer, the level of which is dropping because of excessive water use. Water availability problems also exist in the Carrizo aquifer of south Texas. Many municipalities, Corpus Christi, for example, have water supply problems that are increasing in severity. A large portion of irrigated agriculture may have to be retired and the water rights transferred if anticipated growth is to occur in other economic sectors.⁴⁰

In general, it seems that water in Texas will be made available for energy through three routes: additional surface development, transfer of existing water rights, and increased use of groundwater, either directly or indirectly through displacement of competing surface-water demands.⁴¹

2.4.2 Upper Missouri River Basin

The Upper Missouri River Basin, on the eastern slopes of the Rocky Mountains, contains eight of the low-rank coal regions identified in the preceding sections including: Fort Union, North Central, Bull Mountain, Big Horn, Wind River, Powder River, Hanna, and Rock Creek Regions. (See Figure 2.4.2.1.)

This basin has two major sub-regions with respect to climate: 1) the mountainous regions of western Montana and central Wyoming, and 2) the flat plains of the rest of the region. The mountainous regions receive annual rainfall up to 40 inches and generate most of the runoff within the basin. The flat plains area of the rest of the basin has an annual precipitation ranging from about 12 to 24 inches.⁴ With most of the precipitation in the basin occurring as snowfall, most of the annual runoff occurs in late spring as the snowpack melts. This creates short periods of high stream flows and recharges the alluvial groundwater system. From late summer through winter there is very little natural surface runoff. Annual evaporation rates range from 28 inches at the higher elevations to about 44 inches on the plains.⁷ The geographic variability of the precipitation of the Upper Missouri River Basin is shown in Figure 2.4.2.2.

Figure 2.4.2.1

Low-Rank Coal Areas in the Upper Missouri River Basin

Source: Reference 4

Figure 2.4.2.2

Average Annual Precipitation in the Upper Missouri River Basin

(Contours of Precipitation in Inches)

Source: Reference 4

Also important to the assessment of water resources are the evaporation rates of lakes in the regions. These are shown in Figure 2.4.2.3.

Surface Water Resources

Most of the annual runoff produced in the Upper Missouri River Basin originates in the mountainous headwaters of the Upper Missouri River Mainstem and Yellowstone River Mainstem in western Montana and Wyoming. The Yellowstone River Basin is of special interest because much of the most easily retrievable coal is located within its drainage including the Fort Union Region in Montana and Wyoming, and the Bull Mountain, Big Horn and Wind River fields. The Yellowstone Basin covers a drainage area of about 70,000 square miles which is divided nearly equally between Montana and Wyoming.⁴ At the confluence of the Yellowstone and Missouri Rivers, the Yellowstone River yields an annual flow of about 9.5 million acre-feet/year which is 22 percent more than the average flow of the Missouri, although it drains 14 percent less area.⁸ The Yellowstone River receives more than half of its total yield from waters rising in the mountain ranges upstream of Billings, Montana, and the majority of the remaining yield from Wind-Bighorn River Basin. The total water yields on a sub-regional basis for the Upper Missouri River Basin are shown in Table 2.4.2.1. (The sub-regions are shown in Figure 2.4.2.4.)

The seasonal distribution of runoff varies throughout the basin with most of the annual runoff occurring in the spring and early summer due to melting of the accumulated snowpack. The largest variation in flow is evidenced in streams in the plains regions where very high flows are typically experienced during the short spring melt season, but where flows often diminish to zero at times during the year because of depletions and little rainfall input. As a result, numerous storage reservoirs have been built over the years to retain the spring runoff for use during the remainder of the year. This has been particularly important to the development of the region's agricultural base.

Within the Yellowstone River portion of the basin, the reservoirs are located primarily on the tributaries in northern Wyoming and southeastern Montana in the Fort Union lignite and Powder River coal regions. The mainstem of the Yellowstone is presently unregulated and is valued as one of the few remaining major free-flowing rivers in the west. It is doubtful that any future impoundments on the mainstream would be allowed.⁴

The Missouri River mainstem is highly regulated by a series of large multipurpose reservoirs built and operated by the Bureau of Reclamation and the U.S. Army Corps and Engineers. These are listed in Table 2.4.2.2.

A more recent assessment indicates that in Lake Sakakawea alone, there are 24 million acre-feet of water waiting for agricultural and industrial development (by way of comparison a 440-MW electrical generation plant requires about 17,000 acre-feet of water per year).¹¹

Figure 2.4.2.3

Average Annual Lake Evaporation in the Upper Missouri River Basin

(Contours of Evaporation in Inches)

Source: Reference 4

Table 2.4.2.1

Average Annual Water Yield - Upper Missouri Basin

Sub-Region	Coal Regions w/in Sub-Region	Drainage Area (Sq.Mi.)	Average Water Yield in Sub-Region (AF/year)	Average Area Yield (AF/Year/Sq.Mi.)
Tongue-Rosebud	Bighorn Powder River	6,660	467,000	70
Powder	Powder River Wind River	13,420	501,900	37
Yellowstone Mainstem	Fort Union Bull Mountain Big Horn Wind River	50,040	10,488,100	210
Belle Fourche- Cheyenne (Wyoming Only)	Powder River	11,000	182,400	17
Heart-Cannonball	Fort Union	7,620	337,500	44
Upper Missouri Mainstem	Fort Union North Central	185,840	23,625,000	127
North Platte	Hanna Rock Creek	26,660	1,223,100	46

Source: Reference 9,10

Figure 2.4.2.4

Sub-Basin Boundaries and Rivers in the Upper Missouri River Basin

Source: Reference 4

Table 2.4.2.2

Reservoirs in Missouri River Mainstem

<u>Reservoir</u>	<u>Location</u>	<u>Active Storage, AF</u>
Fort Peck	Montana	10,900,000
Lake Sakakawea	North Dakota	13,400,000
Oahe	North and South Dakota	13,700,000

Source: Reference 4

The quality of surface waters in the Upper Missouri River Basin may be categorized as being from good to excellent and suitable for most uses. In general the highest quality water is found at the headwaters of the streams near the mountain divides. As the flow progresses downstream, the quality generally deteriorates somewhat due to a variety of natural processes such as erosion and leaching, and man made influences such as agricultural practices and waste discharges. Throughout the region, except in a few localized areas, the quality is satisfactory for most irrigation, stock watering, recreation, fish and wildlife, and municipal and industrial purposes.⁴

Water quality in the headwaters of the Yellowstone and Missouri River Basin is generally excellent with only localized or seasonal problems involving sedimentation, heavy metals and acidity.⁸ In the lower reaches of these basins near the confluence of the Yellowstone with the Missouri, median TDS and sulfate concentrations sometimes exceed recommended guidelines of 500 mg/l and 250 mg/l for drinking water during the low flow period from November to April. These levels are not, however, high enough to interfere with the most beneficial uses of water in the mainstems.⁴

Water quality in the eastern Wyoming and western North Dakota tributaries (Fort Union and Powder River coal regions) is somewhat poorer since their flows are derived mainly from rainfall or groundwater rather than snowmelt. For example, the dissolved solids at the mouth of the Yellowstone range from 230 mg/l to 660 mg/l with an average of 460 mg/l, while solids in the Powder River at Moorhead, Montana average 1550 mg/l with a range of 680 to 4080 mg/l.¹²

Groundwater

Shallow aquifers are present throughout much of the Upper Missouri Basin except in the Bighorn Mountains and Black Hills, where the older Madison Limestone and associated carbonate rocks are exposed. These

aquifers generally vary in depth from the surface to a few thousand feet. Most existing wells are less than 300 feet deep, although some alluvial wells less than 100 feet deep yield as much as 500 gpm.¹³ Most present shallow aquifer wells yield less than 50 gpm, but this appears to be a limitation related to typical water requirements rather than the capacities of the aquifers.⁴ Available data indicates that the sandstone units and associated coal beds in the Fox-Hills-Hill Creek-Fort Union-Wasatch sequences may yield up to 500 gpm in appropriately constructed individual wells.⁴

The Madison aquifer underlies most of the Northern Great Plains coal region except for the Bighorn, Pryor, and Snowy mountains and the Black Hills where it is exposed or absent. Varying in depth from about 5,000 feet in the coal region of Montana to about 10,000 feet in portions of the Powder River Basin in Wyoming, this aquifer has produced a few high yielding wells yielding up to several thousand gallons per minute. However, yields are highly variable, and since the cost involved in tapping this source is so great, data on the potential of the Madison are presently quite limited. Significant studies are presently being carried out by the U.S. Geological Survey.⁴

The Madison aquifer shows very good water quality considering its depth. Dissolved solids in this aquifer vary from less than 1,000 mg/l near the Black Hills to about 2,000 mg/l throughout the Powder River Basin, but it is known to exceed 100,000 mg/l in some areas of western North Dakota.⁹ In general, salinity increases with depth beneath the surface.

Low-Rank Coal Regions

More specific water resource information for some of the coal regions within the Upper Missouri Basin is presented below.

Fort Union Region

The average precipitation in the Fort Union Region is 15 inches per year with most of the rainfall occurring during the spring and summer.¹⁴ During the spring months the stream flows peak with the snow melts, while during the months of January and February the stream flows are at their lowest. In this region, average open water surface evaporation is 36 inches per year in North Dakota and 38 inches per year in Montana.¹⁴

Recorded surface runoff characteristics of some rivers in the Fort Union Region are given in Table 2.4.2.3.

Groundwater in the Fort Union Region is available from alluvial and deep aquifers. The principal alluvial aquifers are located along the main rivers and their tributaries and have yields ranging up to 500 gal/min. Large amounts of water are stored in these alluvial aquifers. For example, almost 2 million acre-feet are stored in the alluvial aquifers of the Yellowstone and Little Missouri rivers. Some of the deep aquifers are the coal seams. Yields from these aquifers in Montana and North Dakota range up to 400 gal/min. Groundwater is used as a water supply for many towns and rural homes.^{17,18}

Table 2.4.2.3

Recorded Surface Runoff Characteristics of Rivers at Selected Points in the
Fort Union Region (cubic feet per second)

River and Location	Average Discharge	Maximum Discharge	Minimum Discharge
Missouri, near Culbertson, Montana	10,300	78,200	575
Yellowstone, near Sidney, Montana	13,030	159,000	570
Little Missouri, at Marmarth, North Dakota	343	45,000	0
Knife, near Hazen, North Dakota	183	35,300	0
Cannonball, near Breien, North Dakota	247	94,800	0

Sources: References 15,16

Surface waters in the Fort Union Region have either sodium bicarbonate or sodium sulfate as the predominant constituent in their dissolved solids. The TDS range from 300-500 mg/l in the larger rivers and up to 2000 mg/l in the tributaries, with relatively high average sediment concentrations exceeding 10,000 mg/l in some of the tributaries.¹⁷

The ground waters of the alluvial and deep aquifers are also of the sodium bicarbonate or sodium sulfate type, with TDS ranging from 500 mg/l to 6,000 mg/l.¹

Powder River Region

Water supply in the Powder River Region is similar to that in the Fort Union Region, with major supplies provided by the Yellowstone and Bighorn Rivers. During extended periods, however, the tributaries have negligible or zero flows. The rainflow and snowfall in this region average, respectively, about 14 and 36 inches per year, with rainfall heaviest in the spring and early summer.¹⁴ During the early spring and summer, snowmelt produces the largest annual stream flows while the lowest stream flows occur during late fall and winter. In the Powder River Region the average annual open surface evaporation is 38 inches per year in Montana and 42 inches per year in Wyoming.¹⁴

The recorded surface runoff characteristics of some rivers at selected points are given in Table 2.4.2.4.

Table 2.4.2.4

Recorded Surface Runoff Characteristics of Rivers at Selected Points in the Fort Union Region (cubic feet per second)

<u>River and Location</u>	<u>Average Discharge</u>	<u>Maximum Discharge</u>	<u>Minimum Discharge</u>
Yellowstone, at Miles City, Montana	11,330	96,300	966
Yellowstone, at Billings, Montana	6,858	66,100	430
Tongue, at Miles City, Montana	423	13,300	0
Bighorn, at Bighorn, Montana*	3,851	26,200	275
Powder, at Arvada, Wyoming	272	100,000	0

*Regulated by storage facilities.

Sources: References 15,19

Several of the groundwater aquifers in the Powder River Region have yields ranging from 5 to 500 gal/min. The Madison limestone aquifer, as described earlier, has produced well yields to 9,500 gal/min.^{17,18}

The major consumptive use of surface water in the Powder River Region is for irrigation. Average TDS range from less than 250 mg/l in the Yellowstone River to over 700 mg/l in the Bighorn River. The average annual sediment concentrations of some of the smaller tributaries can exceed 15,000 mg/l.¹

Competing Water Use and Projected Availability

Present water use of the Upper Missouri River Basin is shown in Table 2.4.2.5. In the Upper Missouri Basin an estimated 80 percent is committed to agricultural purposes. Some portions of this basin contain good water availability (western Montana, Upper Yellowstone, and south-central Montana); however, in other portions of the Yellowstone River Basin and Belle Fourche-Cheyenne Basin (where some of the most easily retrievable coal reserves are located) water is already in short supply. Within each of the major tributaries, various interstate compacts define how much of the available supplies may be used within each state, allowing for reservations recognized prior to the compact date. Each state's share is then allocated according to existing appropriation rights.

Table 2.4.2.5

Present Water Use - Upper Missouri Basin
(Depletions - Acre-Feet/Year)

<u>Sub-Region</u>	<u>Irrigation</u>	<u>Municipal, Industrial, Rural, Domestic</u>	<u>Industrial</u> *	<u>Reservoir Evaporation</u>	<u>Total</u>
Tongue-Rosebud	187,200	5,000	1,600	8,000	201,800
Powder	181,600	4,400	1,600	29,000	216,700
Yellowstone Mainstem	1,561,200	79,400	24,600	331,900	1,997,100
Belle Fourche-Cheyenne (Wyoming Only)	6,000	2,000	3,000	31,000	41,000
Heart-Cannonball	24,300	6,500	2,400	8,000	41,200
Upper Missouri Mainstem (To Oahe Dam)	1,335,300	159,600 (including all industrial)		1,445,000	2,939,900
North Platte (Wyoming Only)	574,000	7,000	9,000	177,000	766,000

* Water is self-supplied.

Sources: References 9,20,21,22,23

An indication of the net water supply that could be expected to be available for energy production without the transfer or acquisition of existing water rights from present uses for the Upper Missouri River Basin is given in Table 2.4.2.6.

Other estimates have been made of the water supply and the projected water needs of the Upper Missouri River Basin and the Yellowstone River sub-basin, both of which include the Fort Union and Powder River Regions. The main conclusion from a U.S. Department of the Interior study is that there is sufficient water in the Upper Missouri River Basin to meet all projected needs and uses to the year 2000 including a high degree of energy development.¹ According to that study, approximately 21.8 million acre-feet/year of water would be available in 2000 compared to a projected need of 4 million acre-feet/year.

In the Yellowstone River Basin, a major tributary of the Missouri, approximately 8.8 million acre-feet are available with a projected need of 1.3 million acre-feet/year.²⁵ The Northern Great Plains Research Project has indicated that the Missouri mainstream reservoirs could yield at least 2 million acre-feet/year for industrial use in the Fort Union Region.²⁶

As previously noted, there is sufficient water in the Upper Missouri River Basin to meet future energy needs. In the Yellowstone River Basin, however, and in the Powder River Region, there is a problem of distributing the water from the source to the mine-plant complexes because of the large distances involved. Estimates are that approximately 1 million acre-feet/year could be made available in this region to support energy development without the need to build new storage facilities.²⁶

Water Rights

Wyoming

The Appropriation System is used in Wyoming exclusively for water administration. The Wyoming State Engineer is the person responsible for handling this procedure, and for ensuring that all water is used in accordance with set priorities and conditions.

There is rank ordering of the beneficial uses in Wyoming, indicating which categories of use are preferred over others. Agriculture, the use consuming the greatest amount of water, is relatively low on the list, as domestic, municipal, steam power plants, transportation, and industrial uses of water are preferred to it. The meaning of preference in beneficial uses is simply that transfers from a use lower on the list to a use higher on the list are more easily handled and encouraged than other types of transfers, and in some cases, preferred uses may condemn the rights put to inferior use. In fact, almost any use to which water is put that benefits somebody in the slightest way is considered a beneficial one. An important exception to this is instream flow which at present is not considered a beneficial use.

Table 2.4.2.6

Projected Future Water Availability Year 2000 - Upper Missouri Basin
(1000 AF/YR)

<u>Sub-Region^a</u>	<u>Annual Water Supply</u>			<u>Water Use and Commitments</u>				<u>Net Water Availability</u>
	<u>Natural Yield</u>	<u>Depleted Inflow</u>	<u>Imports</u>	<u>Total Supply</u>	<u>Projected Depletions</u>	<u>Instream Flows</u>	<u>Exports</u>	
Tongue-Rosebud	467	0	0	467	382	148	0	(63)
Powder	502	0	0	502	386	162	0	(46)
Yellowstone Mainstem	10,488	0	0	10,488	2,270	4,070	0	4,148
Belle Fourche-Cheyenne	182	0	0	182	88	75	0	19
Heart-Cannonball	338	0	0	338	89	138	0	111
North Platte	1,223	520	10	1,753	1,181	501	0	71

^a No use or supply projections were made for the Upper Missouri Mainstem sub-region because it is anticipated that the abundant water supply available in the Fort Peck Reservoir and Lake Sakakawea and Oahe will be more than adequate to meet the energy and all other water needs of that area into the future.⁴

Sources: References 20,22,24

Because most of the water is presently in agricultural use, and agricultural uses are so low on the list of preferred uses, most of the water transfers would probably come from agricultural-industrial transfers if no new water supplies are developed. Agricultural water is, in some cases, tied to the land upon which it is used. It may therefore be necessary to purchase the land in order to acquire the water.

Because of the time requirement for the perfection of completion of decrees, there are relatively few permits for the construction of diversion facilities which are still outstanding, i.e., being completed. Thus, a dynamic, rapidly changing situation exists currently in the Wyoming water resources picture with respect to the availability of presently undeveloped and undecreed water.⁴

Montana

Montana has, since 1973, a permit system for the orderly management of its water rights. Before 1973, even though Montana followed the appropriation doctrine, there existed no centralized water management and administration authority in Montana. Water rights were only erratically, if at all, recorded at local county courthouses, and there was no legal requirement to have them recorded.

Generally, water must be diverted for beneficial use, which, in Montana, has a broad definition. The use of water for slurry pipelines exporting coal from Montana, however, is not a beneficial use, by act of the Montana Legislature. Instream water use, on the other hand, is recognized as a beneficial use in Montana. Transfers of water with respect to use, location, and ownership are permitted if Department of Natural Resources and Conservation approval is obtained. Groundwater is, in general, handled in much the same manner as surface water.⁴

North Dakota

The water administration system of North Dakota incorporates aspects of both the appropriation doctrine and the riparian code. Originally riparian rights were the water law of the State; in 1955 the State Legislature enacted the irrigation code which is the basis of the current appropriation doctrine. It recognizes the riparian rights which were established before 1955, e.g., rights belonging to those who owned land adjacent to the water body, and in keeping with the "reasonable use" requirement.

To appropriate water, an application for appropriation is made to the State Engineer. If water is available and the approval is not "contrary to the public interest," the permit is approved, and a completion time is set. The final license is issued after inspection by the State Engineer for the amount of water actually applied to beneficial use. The actual beneficial use is the basis and measure of the water right. Transfers can take place with the approval of the State Engineer.⁴

2.4.3 Upper Colorado River Basin

The Upper Colorado River Basin covers a region on the western slope of the Continental Divide that is located further south than the Missouri Basin. The four coal regions associated with this basin are the Green River Region, Hams Fork Region, North Park Region, and San Juan Basin. (See Figure 2.4.3.1.)

Surface Water

Throughout the basin annual precipitation varies from lows of eight inches at numerous locations to a maximum of 40 inches at higher elevations in portions of northeastern Utah. Most of the annual surface runoff results from melting mountain snowpacks in the spring and early summer with much lower flows occurring the remainder of the year. Annual evaporation rates over most of the basin are quite high, ranging from 32 inches to over 54 inches.⁷ The geographic variability of the precipitation of the Upper Colorado River Basin is shown in Figure 2.4.3.2.

Also important to the assessment of water resources are the evaporation rates of the lakes. These are shown in Figure 2.4.3.3.

Most of the runoff produced in the Upper Colorado River originates in the western slope mountain headwaters of the basin in Colorado. The mainstem of the Colorado River and two of its major tributaries, the Green River and the San Juan River, drain portions of the headwaters, but the Colorado produces by far the most runoff. Although the Green River Basin drains about 44,000 square miles or about 70 percent more area than the Colorado River above their junction, the Colorado yields about 25 percent more water. Much of the remainder of the basin at lower elevations has an arid to semi-arid climate and produces very little additional yield. Rainfall water yields range to over 20 inches in the high mountain regions, but consist of less than 0.5 inches over most of the basin.⁴ Total water yields on a sub-regional basis are shown in Table 2.4.3.1. (The sub-regions are shown in Figure 2.4.3.4.)

The seasonal variability of runoff is also a very significant aspect of the overall water resources situation in the Upper Colorado River Basin. Most of the annual runoff occurs during the late spring as a result of melting snow. During the remainder of the year, most of the smaller tributary streams receive little additional rainfall input and flows frequently diminish to zero. Because agriculture has long been an important part of the region's economy, water resource management systems have been developed over the years to more evenly distribute the excess spring runoff over the year, particularly during the growing season. These systems include storage reservoirs, flow diversions, and a variety of irrigation works. The result is that the Upper Colorado Basin has become one of the most highly regulated river systems in the country.⁴

Figure 2.4.3.1

Low-Rank Coal Areas in the Upper Colorado River Basin

Source: Reference 4

Figure 2.4.3.2

Average Annual Precipitation in the Upper Colorado River Basin

(Contours of Precipitation in Inches)

Source: Reference 4

Figure 2.4.3.3

Average Annual Lake Evaporation in the Upper Colorado River Basin

(Contours of Evaporation in Inches)

Source: Reference 4

Table 2.4.3.1

Average Annual Water Yield - Upper Colorado River Basin

Sub-Region	Coal Regions Within Sub-Regions	Drainage Area (Sq.Mi.)	Average Water Yield in Sub-Region (AF/year)	Average Area Yield (AF/Year/Sq.Mi.)
Upper Green River Basin	Green River Hams Fork	14,300	1,926,000	135
Lower Green River Basin	Green River North Park	29,700	3,534,000	119
Upper Colorado Mainstem	North Park	26,000	6,838,000	263
Lower Colorado Mainstem	--	20,500	451,000	22
San Juan Basin	San Juan Basin	23,000	2,387,000	104

Sources: References 3,9,10,27

Figure 2.4.3.4

Sub-Basin Boundaries and Rivers in the Upper Colorado River Basin

Source: Reference 4

The major storage reservoirs in the Colorado Basin are included in Table 2.4.3.2. Although these facilities and a number of significant flow diversions make more water available along the major interstate rivers than can presently be used, a specific set of legal considerations govern how the water may be used.

Table 2.4.3.2

Reservoirs in the Upper Colorado Basin

Reservoir	Location	Active Storage, AF
Fontenelle	Green River, Wyoming	190,000
Flaming Gorge	Green River, Wyoming-Utah	3,749,000
Blue Mesa	Gunnison River, Colorado	830,000
Navajo	San Juan River, New Mexico	1,696,000
Lake Powell	Colorado River, Utah-Arizona	25,002,000

Source: Reference 4

Water quality is a more significant issue in the Upper Colorado River Basin than in the Upper Missouri Basin. Although the water in the upper reaches of the major streams is of high quality, the quality deteriorates as the water moves downstream. By far the most significant water quality concern in the basin is mineral pollution or salinity measured as total dissolved solids.

As water flows downstream in the Colorado River Basin, salt concentrations increase due to a variety of natural and man-made influences. Throughout most of the length of the river, salinity has been increasing with time. The factors that cause the salinity problems in the basin can be classified into two basic categories. These may be referred to as salt loading and salt concentrating effects. Salt loading refers to the addition of mineral salts into a stream from natural sources (runoff, springs, etc.) or man-made causes such as industrial wastes or leaching of salts from soils during irrigation. Salt concentrating effects involve no change in the amount of salt present, but result in higher concentrations as a consequence of removal of water from the stream system through consumptive use, or transfers of high quality water out of the basin.⁴

The salinity problem is presently most severe in the lower Colorado Basin. Annual economic losses have been estimated at \$230,000 per mg/l increase in salinity at Imperial Dam just above the Mexican border.²⁸ Although the problem is less critical in the Upper Colorado Basin, changes in water use here can effect salinity levels in both the upper basin's streams and in the lower Colorado River.

Surface water quality in the Upper Colorado Basin will be an important consideration for future energy development for two reasons. The presence of high concentrations of certain salts may be a factor affecting the feasibility of using various sources as a water supply source for energy conversion, and therefore may be a siting consideration. At the same time, the consumption of high quality supplies in the upper basin region may reduce the dilution water available and therefore increase salinity downstream.

Groundwater

The aquifers that underlie the Upper Colorado River Region consist mostly of consolidated and semi-consolidated sedimentary strata with unconsolidated alluvial deposits along reaches of major stream valleys. The Department of Interior has estimated that the volume of recoverable groundwater within 200 feet of the surface is about 38 million acre-feet. This is nearly three times the active storage in all of the surface reservoirs in the Colorado River System. The amount stored in the deeper rocks is several times that within the initial 200 feet zone. It is also estimated that about 4 million acre-feet of groundwater recharge occurs annually from rainfall, principally in the higher mountains and plateaus where rainfall is the highest.^{3,4}

Although the total volume of recoverable groundwater storage is great, the water cannot always be obtained at the desired rates in all places. About 85 percent of the stored groundwater occurs in sedimentary rocks which have relatively low permeability and yield water slowly. Wells yielding more than 50 gpm generally can be expected only in areas consisting of permeable alluvium, which account for only 5 percent of the groundwater reserves.⁴

Low-Rank Coal Regions

The water characteristics of the individual low-rank coal regions within the Upper Colorado River Basin are presented below.

San Juan River Basin

The Four Corners Region which contains the San Juan Basin is quite arid. The San Juan and Little Colorado rivers are the principal rivers in the region. Precipitation ranges from 8 to 12 in/yr, with most of it coming mainly from heavy thunderstorms.¹⁴ The peak flows of the San Juan River occur as a result of snow melt and thunderstorms, while the peak

flow of the Little Colorado River is from direct surface runoff augmented by springs. The highest stream flows are in the spring and the lowest flows in early summer and winter. The annual average evaporation from open water surfaces is 46 in/yr in the San Juan Basin in New Mexico.

Recorded surface runoff characteristics of a number of the major rivers in the Four Corners Region are shown in Table 2.4.3.3. As in many parts of the West, the river flows are highly variable even with the regulation of some of the rivers. The flows of the San Juan River are stabilized by the Navajo Reservoir with a capacity of over 1.7 million acre-feet.¹

Table 2.4.3.3

Recorded Surface Runoff Characteristics of Rivers at Selected Points in the Four Corners Region (cubic feet per second)

River and Location	Average Discharge	Maximum Discharge	Minimum Discharge
Little Colorado, near Cameron, Arizona	201	24,900	0
San Juan, at Farmington, New Mexico	2,425	68,000	14
Animas, at Farmington, New Mexico	922	25,000	1
San Juan, near Carracas, Colorado	605	9,730	5

Sources: Reference 29,30

In the San Juan River Basin, there are a number of major aquifers. In some cases, well yields greater than 500 gal/min have been obtained.¹⁷

Water quality varies not only because of varying flow conditions but because of industrial use and agricultural runoff. The San Juan River near Farmington contains moderate amounts of hardness (about 100 mg/l as CaCO_3), bicarbonate (about 120 mg/l as CaCO_3), and sulfate (about 120 mg/l as CaCO_3), with an average annual total dissolved solids concentration and suspended solids concentration, each of about 300 mg/l. The concentrations of the same constituents in the Little Colorado River are about twice those of the San Juan River. The total dissolved solids content of some of the groundwater in the San Juan Basin is greater than 1,000 mg/l.¹⁷

Green River Formation

In the Green River Formation, water is generally available from underground water sources as well as from large rivers of the Upper Colorado River Basin. Precipitation varies from 24 inches per year in the higher elevations of Colorado to 7 inches per year in Wyoming. Snowfall accounts for most of the precipitation. The average annual open water surface evaporation is about 36 inches per year in Colorado and about 42 inches per year in Wyoming.¹

Table 2.4.3.4 lists the principal rivers and tributaries in the Green River Formation and their recorded surface runoff characteristics. The highest runoffs occur in the spring and early summer as a result of snowmelt, with smaller flows the rest of the year.

Significant quantities of groundwater are believed to be in the Piceance Creek Basin of Colorado. Estimates of water in storage in the deep aquifers in the Piceance Creek Basin range from 2.5 to 25 million acre-feet.^{32,33}

Table 2.4.3.4

Recorded Surface Runoff Characteristics of Rivers at Selected Points in the
Green River Formation (cubic feet per second)

River and Location	Average Discharge	Maximum Discharge	Minimum Discharge
Colorado River, at Hot Sulphur Springs, Colorado	201	2,500	44
Colorado River, near Colorad- Utah State Line	5,345	33,000	1,570
Gunnison River, near Grand Junction, Colorado	2,072	12,000	500
Green River, near Green River, Wyoming	1,584	10,900	245
Green River, at Green River, Utah	5,811	29,500	1,180
Yampa River, at Steamboat Springs, Colorado	421	4,080	45
White River, near Meeker, Colorado	540	4,010	25

Source: Reference 31

Groundwater is also available from shallower alluvial aquifers that are much smaller in areal extent than deep aquifers. Recharge to the aquifers occurs mainly as a result of snowmelt along the margins of the basin. Groundwater flows from the margins of the basin to the central part of the basin.³² The surface water and groundwater systems are hydraulically connected so that if a large quantity of groundwater is withdrawn from an aquifer, flow in neighboring streams could be decreased or possibly reduced to zero.

Increasing salinity in the Colorado River is considered the most serious water quality problem.³⁴ The average salinity varies from less than 50 mg/l in the headwaters of the Colorado River to about 660 mg/l near Cisco, Utah, and to 610 mg/l at Lee Ferry, Arizona.^{17,34} The dissolved solids concentration of groundwater in the Green River Formation ranges from 250 to over 60,000 mg/l, with the lower values occurring in the edges of the Piceance Basin, where hardness and bicarbonate ions predominate, and the higher values in the center of the basin, where sodium and bicarbonate ions predominate.

Competing Water Uses and Project Availability

In the Upper Colorado River Basin, agriculture accounts for the major current consumption of the water supply. The reservoirs that make this water available for use, however, also cause significant depletions through evaporation. In Table 2.4.3.5 present water use for the Upper Colorado River Basin is given.

An indication of the net water supply that could be expected to be available for energy production without the transfer or acquisition of existing water rights from present uses for the Upper Colorado River Basin is given in Table 2.4.3.6.

Under terms of the Colorado River Compact and the Upper Colorado River Basin Compact, New Mexico is allocated 11 percent of the water available in the Upper Colorado River Basin after 50,000 acre-feet/year is deducted for the Arizona allocation. The New Mexico entitlement ranges from 645,000 acre-feet/year to 726,000 acre-feet/year, according to different estimates.²⁸ Other estimates conclude present water allocations total 566,000 acre-feet/year and include a present use of 251,000 acre-feet/year and a future use of 226,000 acre-feet/year for a Navajo Indian Reservation project now under construction. In addition, 20,000 acre-feet/year have been contracted for steam-electric power generation and 44,000 acre-feet/year have been contracted from the Navajo Reservoir for coal gasification plants to be constructed in the future, for a total water allocation of 630,000 acre-feet/year.²⁸ This leaves an additional 23,000 to 101,000 acre-feet/year of water available for future energy development, or with the 44,000 acre-feet/year contracted for gasification, a total of 67,000 to 145,000 acre-feet/year. There may also be the possibility of obtaining water presently included in the Navajo allocation. However, the scarcity of surface water may still pose a serious constraint on the development of energy related industry in the Four Corners Region.¹

Table 2.4.3.5

Present Water Use - Upper Colorado Basin
(Depletions - Acre-Feet/Year)

<u>Sub-Basin</u>	<u>Irrigation</u>	<u>Municipal Industrial, Rural, Domestic</u>	<u>Industrial</u>	<u>Reservoir Evaporation</u>	<u>Other¹</u>	<u>Total</u>
Upper Green	242,000	12,000	16,000	26,000	--	296,000
Lower Green	550,000	6,000	28,000	31,000	154,000	769,000
Upper Mainstem	775,000	15,000	13,000	79,000	194,000	1,096,000
Lower Mainstem	33,000	1,500	1,500	2,000	--	38,000
San Juan	286,000	11,500	31,500	95,000	48,000	472,000

¹ Other losses are consumptive conveyance losses and evaporation attributed to recreation, wildlife, and wetlands.

Source: References 9,20,22

Table 2.4.3.6

Projected Future Water Availability - Upper Colorado Basin
(1000 AF/YR)

<u>Sub-Region</u>	<u>Annual Water Supply</u>				<u>Water Use and Commitments</u>				<u>Net Water Availability</u>
	<u>Natural Yield</u>	<u>Depleted Inflow</u>	<u>Imports</u>	<u>Total Supply</u>	<u>Projected Depletions</u>	<u>Instream Flows</u>	<u>Exports</u>	<u>Total Use</u>	
Upper Green	1,926	0	0	1,926	618	960	10	1,588	338
Lower Green	3,534	1,300	0	4,834	1,191	2,400	112	3,703	1,129
Upper Mainstem	6,838	0	0	6,838	1,753	3,400	620	5,773	1,065
Lower Mainstem	451	9,298	0	9,749	101	4,900	0	5,001	4,748
San Juan	2,387	0	130	2,517	1,100	1,260	113	2,473	44

Source: References 9,20,22

The rivers in the Green River Formation are part of the Upper Colorado River Basin. After 50,000 acre-feet/year is given to Arizona, the remaining water is apportioned to the states in the Upper Colorado River Basin about as follows: Colorado - 52 percent; Utah - 23 percent; and Wyoming - 14 percent.²⁸ Based on an assumed water supply of 5.8 million acre-feet/year, the following estimates have been made for total water that could be made available for energy development:

Colorado	90,000 acre-feet/year
Utah	128,000 acre-feet/year
Wyoming	233,000 acre-feet/year

Additional water would be available if there were transfers from existing uses.

Water Rights

Colorado

Colorado has a unique form of the appropriation system in which the judiciary is incorporated in the administration and establishment of water rights. The Colorado State Engineer is responsible for the enforcement of the decisions made in the Water Court System.

Transfers in ownership, location, and point of use are made through the courts; with the primary factor under consideration being that other users, both senior and junior, are not adversely affected. Actual beneficial use is the basis, measure, and limit of the water right.

Groundwater tributary to a surface stream is administered in the same manner as surface water. The State Engineer exercises control of groundwater that is non-tributary to surface waters, i.e., deep aquifer systems, to a much greater extent.⁴

New Mexico

The State Engineer of New Mexico plays a dominant role in the administration of the water of the State. The Appropriation doctrine is followed in New Mexico, with actual beneficial use as the basis, measure, and limit of the right to divert and use water. Generally, the State Engineer handles the entire procedure of water rights administration and establishment, from permit application to final adjudication of the water right, including hearings and protests from existing water users. The decisions of the State Engineer may be appealed to the appropriate district court; in fact, that is rarely done. Transfers are handled by the State Engineer in essentially the same manner as described above for the establishment of new water rights.⁴

2.4.4. Texas

The lignite-bearing areas of Texas have been divided into three "climatic regions," as shown on Figure 2.4.4.1. The East Texas region covers the lignite-bearing areas of the Sulphur Creek, Cypress Creek, Sabine River, and Neches River Basin; the Central Texas region consists of the lignite-bearing areas of the Trinity, Brazos, and Colorado River basins; and the South Texas region includes areas of the Guadalupe, San Antonio, and Nueces.³⁵ Annual precipitation averages for the three regions increase from a low of 18 inches in the south to over 48 inches in the east. Figure 2.4.4.2 illustrates the average precipitation levels for these climatic regions as well as the entire state.

East Texas

Annual rainfall in this area averages more than 45 inches; therefore, runoff is usually high. The combined annual average flow of the four East Texas rivers, as they cross the lignite-bearing regions, is over 6 million acre-feet/year.³⁵ However, since these basins have relatively small drainage areas within and above the lignite-bearing regions, stream flow is highly dependent on localized rainfall patterns. During periods of drought, both the Sulphur and Cypress Creeks have ceased to flow, and flow in the Sabine and Neches Rivers in these areas was reduced to a mere trickle. However, surface water is available in this area by impoundment of streams in order to develop a dependable supply. Unappropriated water still exists in these basins, but developers must be cautious not to infringe upon existing water rights.³⁵

Surface water availability has been increased by numerous reservoirs presently in existence or under construction. There is over 15 million acre-feet of water storage capacity within the major reservoirs of the East Texas region. These impoundments are listed in Table 2.4.4.1.

Groundwater is available from the Carrizo-Wilcox, Queen City, Sparta, and other minor aquifers in the lignite-bearing area. The sustainable yield of these aquifers approximates 250,000 acre-feet/year according to recent Texas Water Development Board estimates. Therefore these aquifers represent another viable water source. Evaluation of these aquifers must be made on an individual basis, however, since competition for groundwater sources is already high in some areas. Figures 2.4.4.3 and 2.4.4.4 indicate the location of the major and minor aquifers for East Texas as well as the rest of the State.

Present water use in the East Texas region is shown in Table 2.2.4.2. Manufacturing uses account for about 65 percent of the total water consumption, while only 6 percent goes for crop irrigation and one percent for mining operations. In Table 2.2.4.3, the authorized use of water for mining accounts for a negligible percentage of the total use. Over 65 percent is authorized for industrial operations.

Figure 2.4.4.1

Climatic Region in the Lignite-Bearing Areas of Texas

Figure 2.4.4.2

Mean Annual Precipitation in Texas

Legend:

Contours of precipitation
in inches

Dotted area represents the
three climatic zones of the
Texas lignite-bearing areas

Source: Modified from Reference 38

Table 2.4.4.1

Major Reservoirs Existing and Under Construction in the
East Texas Climatological Region

<u>River Basin</u>	<u>Reservoir</u>	<u>Allocated Storage Capacity (thousands of acre-feet)</u>	
Cypress	Cypress Springs	72.8	
	Monticello	40.1	
	Bob Sandlin	213.4	
	Welsh	23.6	
	Ellison Creek	24.7	
	Johnson Creek	10.1	
	Lake O'Pines	842.1	
	Caddo	129.0	
			1355.8
Sulphur	Cooper	441.4	
	Sulphur Springs	14.2	
	River Crest	7.0	
	Wright Patman	2654.3	
			3116.9
Sabine	Tawakoni	936.2	
	Holbrook	8.0	
	Lake Fork	675.8	
	Quitman	7.4	
	Hawkins	11.9	
	Winnsboro	8.1	
	Gladewater	7.0	
	Cherokee	46.7	
	Martin	77.6	
	Murvaul	45.8	
	Toledo Bend	4477.0	
			6301.5
Neches	Athens	32.8	
	Palestine	411.8	
	Jacksonville	30.5	
	Tyler	80.9	
	Striker	27.0	
	Nacogdoches	41.1	
	Pinkston	7.4	
	Kurth	16.2	
	Sam Rayburn	3997.6	
	Steinhagen	94.2	
			4739.5
	East Texas Region Total		15513.7

Figure 2.4.4.3

Major Aquifers of Texas

Source: Reference 35

Figure 2.4.4.4

Minor Aquifers of Texas

Source: Reference 35

Table 2.4.4.2
Present Water Use, East Texas Climatological Region (1974)
 (10³ acre-feet)

Basin	Municipal	Livestock	Manufacturing	Steam- Electric Power	Irrigation	Mining	Total
Cypress	12.3	4.7	154.8	10.6	0.3	1.3	184.0
Sulphur	22.4	8.9	29.7	0.2	0.0	0.5	61.7
Sabine	45.2	12.1	84.7	3.7	10.1	2.2	158.0
Neches	57.4	11.9	194.7	6.3	36.0	3.9	310.2
Totals	137.3	37.6	463.9	20.8	46.4	7.9	713.9

Source: Reference 38

Table 2.4.4.3
Authorized Water Use, East Texas Climatological Region
 (10³ acre-feet)

Basin	Municipal	Industrial	Irrigation	Mining	Hydroelectric	Recreation	Total
Cypress	107.1	255.9	7.1	0.7	0.0	7.2	378.0
Sulphur	181.6	167.1	2.2	0.0	0.0	6.5	357.4
Sabine	501.1	1284.9	153.9	0.7	0.0	62.8	2003.4
Neches	478.2	1886.2	217.7	0.1	0.0	29.4	2611.6
Totals	1268.0	3554.1	380.9	1.5	0.0	105.9	5350.4

Source: Reference 38

Central Texas

Average annual rainfall in this area ranges from 35 to 45 inches. Because of the large drainage areas above the lignite-bearing regions in the Trinity, Brazos, and Colorado basins, streamflow is not as highly dependent on local rainfall as it is in East Texas. Nonetheless, flows during prolonged drought periods are greatly reduced. Reservoir development does help to maintain some streamflow during these dry periods. The lignite-bearing zones of the Central Texas region have a total reservoir capacity of over 8 million acre-feet, as shown in Table 2.4.4.4. Much of the surface water in these three basins is already committed through existing water permits in the area. Those wishing to develop a surface-water source for a lignite operation in Central Texas may find they must purchase water from existing permit holders in the area.³⁵ Present and authorized water use patterns for this area are listed in Tables 2.4.4.5 and 2.4.4.6, respectively. Groundwater is available from the Carrizo-Wilcox, Queen City, and Sparta aquifers and from local alluvial deposits. Recent estimates by the Texas Water Development Board place the sustainable yield of aquifers in the Central Texas lignite-bearing area at approximately 250,000 acre-feet/ year.³⁵ However, as in the East Texas area, the availability of groundwater at each site must be closely evaluated on an individual basis.

South Texas

Average annual rainfall in the lignite-bearing areas of the Guadalupe, San Antonio, and Nueces River basins varies from 20 inches in the southwestern part of Nueces River basin to over 30 inches in the Guadalupe River basin. Spring flow helps to sustain the streamflow of the Guadalupe River, but because of the small drainage areas of these three basins in and above the lignite-bearing areas and the low rainfall, the average annual combined flow of these three rivers scarcely equals that of the Colorado River alone as it crosses the lignite outcrop belts. Current and future surface water supplies in South Texas are already heavily committed to beneficial uses; little water remains to be appropriated for lignite development. Therefore, those wishing to locate a lignite-fueled facility in South Texas will most likely have to acquire surface water from an existing permit holder or develop groundwater sources.³⁵

Table 2.4.4.7 lists the five major impoundments in the South Texas region, which total a surface water storage capacity of 300,000 acre-feet. This quantity represents less than half the present water usage for this area, of which 80 percent is used for crop irrigation. See Tables 2.4.4.8 and 2.4.4.9 for actual and authorized water consumption patterns.

Groundwater is available in the northern part of the region, but irrigators in the Winter Garden area of the Nueces River basin are already withdrawing water from the Carrizo-Wilcox aquifer at a rate

Table 2.4.4.4

Major Reservoirs Existing and Under Construction in the
Central Texas Climatological Region (Lignite Bearing Areas)

River Basin	Reservoir	Allocated Storage Capacity (10 ³ acre-feet)	
Brazos (Zones 4 and 5)	Proctor	374.2	
	Stillhouse Hollow	630.4	
	Belton	1097.6	
	North Fork	130.8	
	Granger	244.2	
	Alcoa	14.8	
	Somerville	507.5	
	Bryan Utilities	15.2	
	Campus Creek	8.6	
	Limestone	217.5	
	Mexia	10.0	
		<u>3250.8</u>	
Colorado (Zone 3)	Eagle Lake	9.6	
	Cedar Creek	71.4	
	Bastrop	16.6	
	Walter E. Long	33.9	
	Austin	21.0	
	Travis	1954.0	
	Lyndon B. Johnson	138.5	
	Inks	17.5	
	Buchanan	992.0	
		<u>3254.5</u>	
Trinity (Zone 2)	Fairfield	50.6	
	Houston County	19.5	
	Livingston	1750.0	
		<u>1820.1</u>	
	Central Texas Region Total (Lignite bearing Areas)		<u>8325.4</u>

Source: Reference 38

Table 2.4.4.5
Present Water Use, Central Texas Climatological Region (Lignite Bearing Areas) 1974
(10³ acre-feet)

Basin	Municipal	Livestock	Manufacturing	Steam- Electric Power	Irrigation	Mining	Total
Trinity (Zone 2)	11.3	3.3	1.3	12.9	1.8	1.8	37.4
Brazos (Zones 4 and 5)	72.3	26.2	13.0	4.1	77.8	2.9	196.3
Colorado (Zone 3)	83.8	13.6	10.1	14.3	96.3	3.9	222.0
Totals	167.4	48.1	24.4	31.3	175.9	8.6	455.7

Source: Reference 38

Table 2.4.4.6
Authorized Water Use, Central Texas Climatological Region (Lignite Bearing Areas)
(10³ acre-feet)

Basin	Municipal	Industrial	Irrigation	Mining	Hydroelectric	Recreation	Total
Trinity (Zone 2)	214.4	17.6	21.5	0.0	10.7	0.0	264.2
Brazos (Zones 4 and 5)	386.7	1414.7	474.6	3.3	0.0	22.5	2301.8
Colorado (Zone 3)	56.5	526.3	173.5	5.8	5790.7	6.1	8558.9
Totals	657.6	1558.6	1669.6	9.1	5801.4	28.6	11124.9

Source: Reference 38

Table 2.4.4.7

Major Reservoirs Existing and Under Construction in the
South Texas Climatological Region (Lignite Bearing Areas)

River Basin	Reservoir	Allocated Storage Capacity (10 ³ acre-feet)	
Guadalupe	Dunlap	5.0	
	McQueeney	5.0	
	H-4	<u>6.5</u>	16.5
Nueces	Upper Nueces	7.6	
	Corpus Christi	<u>278.2</u>	285.8
	South Texas Region Total (Lignite bearing Areas)		302.3

Source: Reference 38

Table 2.4.4.8
Present Water Use, South Texas Climatological Region (Lignite Bearing Areas) 1974
(10³ acre-feet)

Basin	Municipal	Livestock	Manufacturing	Steam- Electric Power	Irrigation	Mining	Total
Guadalupe (Zone 2)	18.7	8.2	32.0	7.0	7.6	1.0	74.5
San Antonio (Zone 2)	6.3	3.5	0.3	0.0	19.6	0.2	29.9
Nueces	20.0	16.4	3.2	3.8	465.2	1.6	510.2
Totals	45.0	28.1	35.5	10.8	492.4	2.8	614.6

Source: Reference 38

Table 2.4.4.9
Authorized Water Use, South Texas Climatological Region (Lignite Bearing Areas)
(10³ acre-feet)

Basin	Municipal	Industrial	Irrigation	Mining	Hydroelectric	Recreation	Total
Guadalupe (Zone 2)	21.0	895.7	93.5	0.1	8771.1	2.1	9783.5
San Antonio (Zone 2)	1.5	48.9	89.2	0.0	75.0	4.6	219.2
Nueces	290.7	258.9	355.0	20.0	20.5	30.8	975.9
Totals	313.2	1203.5	537.7	20.1	8866.6	37.5	10978.6

Source: Reference 38

greater than that at which the aquifer is being recharged. Therefore, groundwater supplies in the South Texas area, though available, must be evaluated with caution.

Competing Water Use and Projected Availability

In the southerly basins of Texas, a high percent of total demand goes for irrigation. Towards the north, where the bulk of the higher quality lignite is found, manufacturing and municipal uses predominate. In the central portion, municipal and agricultural uses generally dominate the total demand. Mining uses vary little of the total water supply.⁶

Given that little, if any, surface water remains to be appropriated in Texas, new energy industries will have to obtain most of their surface water needs either by contract from large reservoirs or by purchase and conversion of water rights. It appears likely that the net result of this trend will be the transfer of water out of agricultural use and into the higher priority industrial use.⁶

Both riparian and appropriative rights may, with administration approval, be severed from the lands on which the water was originally used, and sold to other persons for use on other lands.³⁶ Riparian rights, however, remain limited to domestic, livestock, and irrigation use. Appropriative rights may be converted to a new beneficial use, if approved by the Water Commission.

In general, where surface supplies and usage are relatively large, groundwater use is small, and vice versa. Irrigation use is concentrated in the southwestern part of the trend, and virtually no groundwater is now used for steam-electric power generation. With institutional and economic constraints on surface-water development increasing and with potential additional pressure on surface water from freshwater inflow allocations, the relative proportion of the total water demand that is met by groundwater is likely to increase.⁶

Groundwater is considered a property right, and can be taken without limit from under the land on which it is found. It can likewise be freely sold or transported for any beneficial purpose. Currently, the only means of controlling pumpage rates is by the formation of a Groundwater Conservation District. This process is complex and must be approved by a regional election. Consequently, only a few have been formed in the High Plains and in areas near Houston affected by subsidence and saltwater intrusion.

The result of this lack of regulation has been the development of widespread depletion problems. In the Lignite Belt, the Carrizo and the Trinity Group Aquifers have already been affected. Increased drawdown increases pumping costs, and may also result in quality problems.³⁷ Over the long run, uncontrolled pumpage depletes long-term storage and reduces future availability to the amount that is recharged each year.

Given its essentially unregulated status, groundwater offers a limited "cushion" in the event that surface water supplies are constrained. Those users which would suffer most would be those whose groundwater is completely depleted, or whose pumping costs were increased by drawdown beyond the point where economic returns justify the cost. Agriculture is likely to be the most strongly affected.

In addition to existing and projected demands for surface water, two potentially large additional demands could further stress water availability; freshwater inflows to bays and estuaries, and transfers of water to the High Plains irrigated agricultural region.

Some quantity of freshwater inflow is required to sustain ecosystem productivity in bays and estuaries. Regulatory agencies are now required to evaluate water withdrawals and reservoir regulation with respect to ecological effects on the estuaries. The data base for this evaluation, however, is only in the formative stages. The Texas Department of Water Resources (TDWR)^a has been charged by the Legislature to prepare a detailed report on estuarine freshwater inflow requirements by December of 1979. Once these inflows are quantified, they must be reserved from other uses. The Legislature will determine what priorities these inflows will have relative to other uses. In order to assure these inflows, the state may have to condemn and purchase existing rights, or condition their use on maintenance of required instream flows.

The rapid depletion of the Ogallala Aquifer, the source of irrigation water for the highly productive High Plains area, is a growing concern to water planners. Attempts to plan an interstate diversion of water from the Mississippi have already been made and discarded because of the extremely high cost and potential inequities of cost distribution. Potential imports from Arkansas are currently being discussed,³⁸ but plans are far from consummation. Thus, it is not unreasonable to consider the possibility that planners might turn to East Texas as a possible source of water for the High Plains.

The economic stakes may be very high. The High Plains supplies 20 percent of the nation's cotton, 25 percent of its grain sorghum and 5 percent of its wheat. Demand for these commodities is relatively inelastic, such that a decrease in supply is met with a more than proportional increase in price. Without imports of water, TDWR calculates that irrigated acreage will have declined by more than 40 percent in the year 2000.³⁸ The economic impacts of such a reduction in productivity could be felt nationwide. The amounts of water needed to avert it total to millions of acre-feet annually.

^aOn September 1, 1977, the Texas Water Rights Commission Quality Board and the Texas Water Development Board were consolidated into a single agency, the Texas Department of Water Resources.

The High Plains situation potentially affects lignite in two ways. First, about three-fourths of the runoff in Texas originates in the eastern quarter of the state,³⁹ making it a prime potential candidate for intra-state transfers. Second, very large amounts of electric power would be needed to raise the needed millions of acre-feet of water several thousand feet in elevation between East Texas and West Texas. This need would also apply to water from outside the state. The result would not only be potentially larger demands on lignite to generate the power, but significant increases in cooling water demand as well.⁶

Water Rights

Texas currently recognizes both riparian and appropriative water rights. Riparian rights are limited a "reasonable use" of the base flow of streams. The use of riparian rights is generally limited to domestic use, livestock watering, and irrigation.³⁶ Appropriative rights apply to flood flows, and base flows not under riparian rights. Statutory priorities were established by Wagstaff Act of 1931, giving the order in which needs for different beneficial uses are to be met in appropriating these supplies. These are, in order:

1. Municipal supply
2. Industry and manufacturing, including nonhydroelectric power generation
3. Irrigation
4. Mining oil and gas extraction
5. Hydroelectric power
6. Navigation
7. Recreation and pleasure⁶

These priorities are to be applied in cases of dispute and during water shortages. They do not affect the granting of permits which are not contested. The key concept behind these priorities, and reflected throughout the body of case law, appears to be that water should be allocated to the most economically efficient uses, after basic domestic needs have been met.

Water impounded by reservoirs is appropriated to the operator of the reservoir in the same manner as direct withdrawals. Viewed in the aggregate, authorizations for municipal uses comprise the largest proportion in existing reservoirs followed by industry, irrigation and mining. The operator of a reservoir is free to contract with individuals to supply needs without the authorized beneficial use categories, at a price mutually agreed upon.⁶

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35. Hoffman, H.W. Jr. "Water for Lignite Development in Texas," From Proceedings Gulf Coast Lignite Conference: Geology, Utilization, and Environmental Aspects, Report of Investigations No. 90, Bureau of Economic Geology, University of Texas, Austin, Texas, 1978.

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36. Hutchins, W.A. Water Rights Laws in the Nineteen Western States, Misc. Publ. No. 1206 Natural Resource Economics Division, Economic Research Service, U.S. Department of Agriculture, U.S. Government Printing Office, Washington, D.C., 3 Volumes, 1977, as cited in Reference 6.
37. McNeely, J.G. and R.D. Lacewell. Surface Water Development in Texas, Texas A&M University, Agricultural Experiment Station, 1977, as cited in Reference 6.
38. Texas Water Development Board. Continuing Water Resources Planning and Development for Texas, Austin, Texas, May 1977.
39. Texas Water Development Board. Texas Water Plan, 4 Vols., Austin, Texas, 1968, as cited in Reference 6.
40. Argonne National Laboratory et. al. An Assessment of National Consequences of Increased Coal Utilization, U.S. Department of Energy, Office of the Assistant Secretary for Environment, Office of Technology Impacts, Division of Technology Assessments, Washington, D.C., February 1979.
41. Radian Corporation. An Integrated Assessment of Texas Lignite Development, Volume II - Technical Analysis, Texas Energy Advisory Council, Report No. ES-011, April 1979.

2.5 SELECTED REFERENCES

The following publications are particularly informative on the subjects of: 1) regional occurrence of low-rank coal deposits; 2) properties and characteristics of low-rank coals; and 3) water resources associated with the major U.S. low-rank coal deposits, respectively. Many other publications, as listed under References at the end of each section, provide data on specific subjects within these technical areas.

2.5.1 Regional Occurrence (Section 2.2)

1. Averitt, Paul. Coal Resources of the United States, January 1, 1974, USGS Bulletin 1412, 1975.

Probably the most frequently cited reference for coal resource quantities and distribution in the United States. Besides tonnage estimates, this bulletin includes: an extensive glossary of coal resource terms; peat resources; production information; and a detailed index for easy location of specific material. Over 250 references are cited in this report, which provides a condensed listing of most publications relevant to state-specific coal resources.

2. Demonstrated Coal Reserve Base of the United States on January 1, 1976, USBM Mineral Industry Survey, 1977.

Although small in terms of number of pages, this paper is filled with various tables delineating the coal reserve base according to rank, mining method, and state.

3. Sondreal, E.A., W.R. Kube, and J.L. Elder. Analysis of the Northern Great Plains Province Lignites and Their Ash: A Study of Variability, USBM RI 7158, 1968.

This report presents empirical results from over 400 lignite sample analyses in North Dakota and Montana. Fusion properties, trace elements, and compositional breakdowns of both lignite and its ash are discussed here. Statistical calculations of standard deviation and confidence ranges are included with the averaged properties of lignite and lignite ash.

4. Matson, R.E., and J.W. Blumer. Quality and Reserves of Strippable Coal, Selected Deposits, Southeastern Montana, Montana Bureau of Mines and Geology, Bulletin 91, 1973.

Quality and quantity of strippable subbituminous and lignite coal in 32 deposits are described, and distribution is shown on 46 plates. Proximate analyses, forms of sulfur, calorific values, and major ash constituents of the coal samples are tabulated. The report presents vast amounts of drill hole data, but unfortunately includes no worthwhile summarization of coal properties.

5. Glass, Gary B. Wyoming Coal Fields, 1978, Geological Survey of Wyoming, Public Info. Circular No. 9, 1978.
Every coal seam in the state of Wyoming is discussed in this report. The information emphasizes the geologic nature of the deposits more than their potential minability. However, proximate analyses of almost all deposits are included.
6. Shomaker, John W., Edward C. Beaumont, and Frank E. Kottlowski. Strippable Low Sulfur Coal Resources of the San Juan Basin In New Mexico and Colorado, New Mexico State Bureau of Mines and Mineral Resources, Memoir 25, 1971.
A concise and complete reference for the San Juan Region's coal deposits is not easy to locate. This paper comes close to clarifying the rank and in-place resources of the region, but much more information is needed to fully assess the deposits here. Detailed core sample analyses are presented, but the report lacks a comprehensive summary of composition averages and other significant coal characteristics.
7. Barnes, F.F. Coal Resources of Alaska, USGS Bulletin 1242-B, 1967.
Little material on reliable coal resource estimates has been published since this report by Barnes. Resources are delineated into depth categories and composition (proximate analysis).
8. Kaiser, W.R. Texas Lignite: Near-Surface and Deep-Basin Resources, Bureau of Economic Geology, RI No. 79, University of Texas, Austin, 1974.
Revised estimates of lignite resources in Texas are only part of this comprehensive report. Geologic histories, compositional analyses, and detailed maps of various deposits are also included, making this paper the primary reference for Texas lignite.
9. Kirkham, Robert M., and L.R. Ladwig. Coal Resources of the Denver and Cheyenne Basins, Colorado, Colorado Geological Survey, Department of Natural Resources, Denver, Resource Series 5, 1979.
This recent publication presents a part of the first-year findings from a 2.5-year study of the environmental impacts of energy-resource development in the Denver and Cheyenne Basins of Colorado. Three main topics are covered: geologic deposition history of the coal deposits; coal mining history; and resource estimates for the Basins. More reliable estimates of the in-place resources are needed for fair tonnage comparisons with deposits in other regions.

10. Proceedings, Gulf Coast Lignite Conference: Geology, Utilization, and Environmental Aspects, W.R. Kaiser, editor, U.S. DOE CONF-7606131, RI No. 90, 1978.

Presents 29 papers addressing progress and problems associated with lignite utilization.

11. Gulf Coast Lignites Conference, Proceedings, Houston, Texas, May 17-19, 1978.

This collection of papers focuses specifically on the lignite deposits of the Gulf Coast states. Four sessions were organized for the meeting, and the presentations are categorized under the following topics: state-by-state review of lignite deposits; mining; utilization; and regulatory and environmental overview.

2.5.2 Properties and Characteristics (Section 2.3)

1. International Handbook of Coal Petrography, Supplement to the 2nd Edition, published by the Centre National de la Recherche Scientifique, Paris, France, for the International Commission for Coal Petrology, 1971.

A highly technical scientific volume that describes coal petrographic nomenclature and characteristics. The format is designed for reference use, with individual sections clearly outlined and sub-headed.

2. Given, P.H. The Organic Chemistry of Coal Macerals, presented at the Short Course on Coal Characteristics and Coal Utilization, Pennsylvania State University, University Park, PA., October 22-26, 1979.

This paper presents an easily read and thorough discussion of coal macerals. The report is sectioned into nine chapters that include the following topics: the Heterogeneity of Coals; aromaticity, and various testing and measurement techniques; functional groups; some chemical reactions of coals (depolymerization, oxidation, pyrolysis); solvent extraction; molecular structure; mineral matter and coal chemistry.

3. Neavel, R.C. Coal Structure and Coal Science: Overview and Recommendations, presented at the ACS Symposium on Coal Structure, Honolulu, Hawaii, April 2-6, 1978, ACS Division of Fuel Chemistry, Preprints, V. 24, No. 1, pp. 73-77.

Neavel proposes that coal classification procedures should be revamped to include both coal type (proportions of various macerals and minerals) and rank (stage of metamorphic development). The paper contains a brief discussion of coal's depositional characteristics followed by a lengthy justification of his proposal. He points out that the relationships between coal properties and process responses are more complex than presently described, and much more needs to be learned in the field of basic coal science.

4. Sondreal, E.A., and R.C. Ellman. Fusibility of Ash from Lignite and its Correlation with Ash Composition, GFERC/RI-75-1, ERDA (DOE), 1975.

Fusibility of Northern Great Plains lignite ash was correlated with the oxide constituents in a 10-component analysis. The correlations developed establish methods and guidelines for predicting the fusibility of ash in these coals and adjusting it for boiler fuel use or other conversion processes. Tests were performed to determine the effects on fusibility temperature caused by adding various materials.

2.5.3 Water Resources (Section 2.4)

1. Probst, Ronald F., and Harris Gold. Water in Synthetic Fuel Production, The Technology and Alternatives, The MIT Press, Cambridge, MA., 1978.

This book is designed as a guide to understanding the role water plays in synthetic fuel production and includes the basic concepts underlying water usage and water treatment in this context. Chapter headings include: coal and shale conversion fundamentals; cooling fundamentals; gas, liquid, and solid fuel production; mining, disposal, and other water uses; water treatment; and resources and water requirements.

2. Gold, Harris, and David J. Goldstein. Water-Related Environmental Effects in Fuel Conversion, Volumes I and II, U.S. EPA, EPA-600/7-78-197, October 1978.

The report gives results of an examination of water-related effects that can be expected from siting conversion plants in the major U.S. coal- and oil-shale bearing regions. Regional water supplies and demands are reviewed in detail and presented in an easily-read format. Water requirements for various processes are also discussed. Volume II consists of 15 appendices covering detailed calculations for each conversion process water needs, as well as additional water requirements and availability.

3. Continuing Water Resources Planning and Development for Texas, Phase I, Draft, Volumes I and II, Texas Water Development Board, Austin, May 1977.

This two-volume report is the renewal of a comprehensive long-range continuing planning process which presents an analysis of current water development and use in Texas along with new projections of future water needs of the state through the year 2030. It identifies major water and water-related problems, identified actions currently underway to provide for part of Texas' present and future water needs, and presents a preliminary draft plan of development, including alternatives, for meeting water supply and water-related needs in parts of the state through the year 2000.

4. VanDerwalker, J.G. (Program Manager). Effects of Coal Development in the Northern Great Plains, Northern Great Plains Resources Program, Denver, Colorado, April 1975.

A multi-agency, multi-publication program prepared by seven work groups representing Montana, Wyoming, North Dakota, South Dakota, Nebraska, the Environmental Protection Agency, the Department of Agriculture, and the Department of Interior. Publications resulting from the program fall into the following categories: 1) regional geology, 2) mineral and fuel resources; 3) water resources, 4) land and wildlife resources; 5) effects of economic development on all resources and on air quality; 6) socio-economic and cultural development of the region; and 7) national energy considerations.