Wyoming

COAL

Wyoming State Geological Survey

Public Information Circular No. 44

Nick Jones, Scott Quillinan, and James McClurg

Wyoming State Geological Survey
Ronald C. Surdam, State Geologist

First printing of 1,000 copies by Citizen Printing, Fort Collins, Colorado, November 2009.

Wyoming coal, by Nick R. Jones, Scott Quillinan, and James McClurg.
Wyoming State Geological Survey Public Information Circular No. 44, 2009.
ISBN 1-884589-51-0

Cover photo: Wyoming Powder River Basin coal. *Inset photo (above):* Coal mining in the Powder River Basin. Photos by Meg Ewald.

Illustrations by James R. Rodgers

Wyoming COAL

Wyoming State Geological Survey
Public Information Circular No. 44

Nick Jones, Scott Quillinan, and James McClurg

Table of Contents

What is coal?

Coal is a combustible, dark brown to black, carbonaceous sedimentary rock derived from degraded plant matter called peat that accumulates in wetland environments called mires: bogs, marshes, and swamps. The type of coal that forms depends on the type of plant matter that accumulates. There are two types of coal: humic coal forms from macroscopic (large) vegetation such as trees, sedges, grasses, and shrubs, while sapropelic coal forms from mesoscopic (small) vegetation such as sphagnum moss and algae. Just as a rock is a collection of various minerals, coal is a collection of various macerals (altered remnants of plant matter) (**Table 1**). There are three primary maceral groups: vitrinite (derived from woody tissue, primarily lignin and cellulose), liptinite (derived from waxes and resins), and inertinite (derived from intensely altered and oxidized plant material such as charcoal).

Table 1. Coal macerals and maceral groups

Group	Maceral	Description and source material
Vitrinite[1]	Telinite	Has remnant cellular structure
	Collinite	Has no visible signs of cellular structure
Liptinite[2]	Sporinite	Most common of the liptinie group. Derived from fossil spores and pollen exines
	Cutinite	Cuticle of leaves, young stems
	Resinite	Resins, plant secretions, and exudates
	Alginite	Remains of algae and algal colonies
Inertinite[3]	Micrinite	Very-fine-grained, high-reflectance particles
	Macrinite	Structureless bodies with very high reflectance
	Semifusinite	Degraded cellular structures with a wide range of reflectance
	Fusinite	Oxidized (burned) and degraded cellular structures with the highest reflectance
	Sclerotinite	Ovoid bodies with cellular structure

[1] Coalified woody tissue derived from stems, roots, and vascular tissues of leaves. Most abundant and important maceral group, commonly 50 to 90 percent of the macerals in North American coals. Has a shiny appearance resembling glass.

[2] Derived from resinous and waxy material of plants such as resins, cuticles, spores and pollen exines, and algal remains. Highest hydrogen content of all macerals. Tends to retain original plant form.

[3] Derived presumably from charring of plant tissues; considered the equivalent of charcoal.

Where does coal come from?

Peat-forming wetlands

Mire is the generic term for all wetlands – areas where the water table lies just below, at, or just above the land surface and can vary seasonally in response to flooding or drought. A mire is a mixture of emergent (dry), semi-aquatic (seasonally flooded), and shallow aquatic areas underlain by peat and saturated soil. Mires are classified on the basis of vegetation type and geographic location (**Figure 1**). Free-floating, submergent, emergent, and amphibious vegetation can all occur in a mire (**Figure 2**). Mires are located in small upland catchments (bogs) along creeks and rivers; in depressions along broad flood plains; along the shores of lakes and ponds in the littoral zone (between the high-water mark and the point at which the water is too deep to support rooted aquatic plants); on upper delta plains between active channels; in and landward of the intertidal zone on lower delta plains; in back-beach barrier islands; and along coastal regions of sounds, bays, and lagoons.

In peat-forming mires, plant matter accumulates in successive layers and is altered and preserved. The three types of peat-forming mires are swamps, marshes, and bogs (**Figure 1**). These commonly grade from one type into another and together make up larger, heteroge-

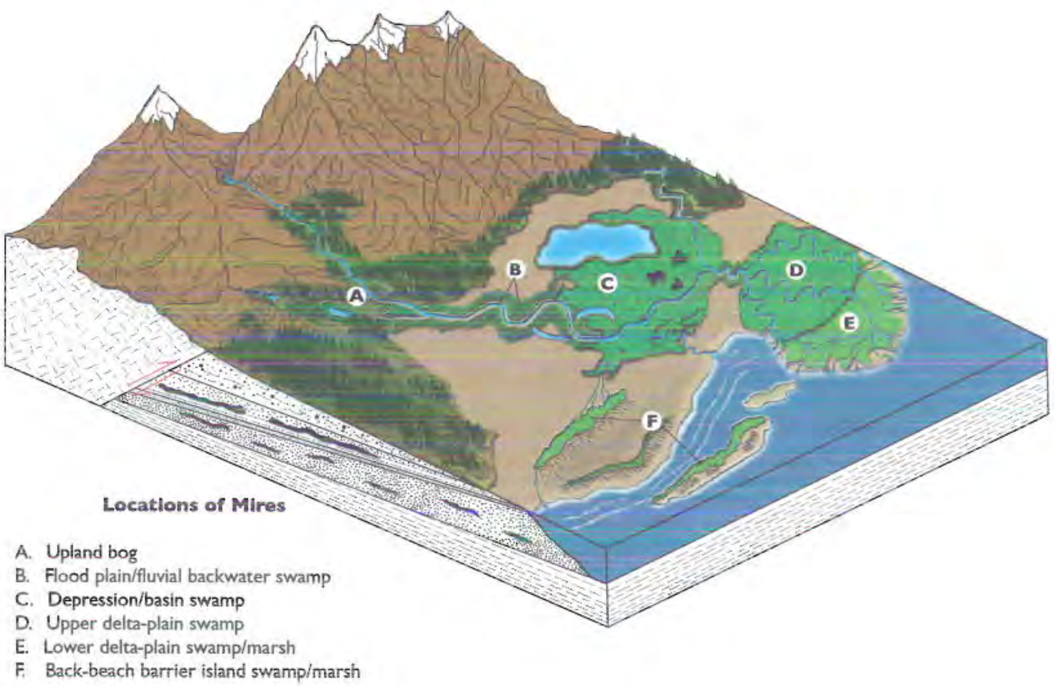


Figure 1. Mire types and locations.

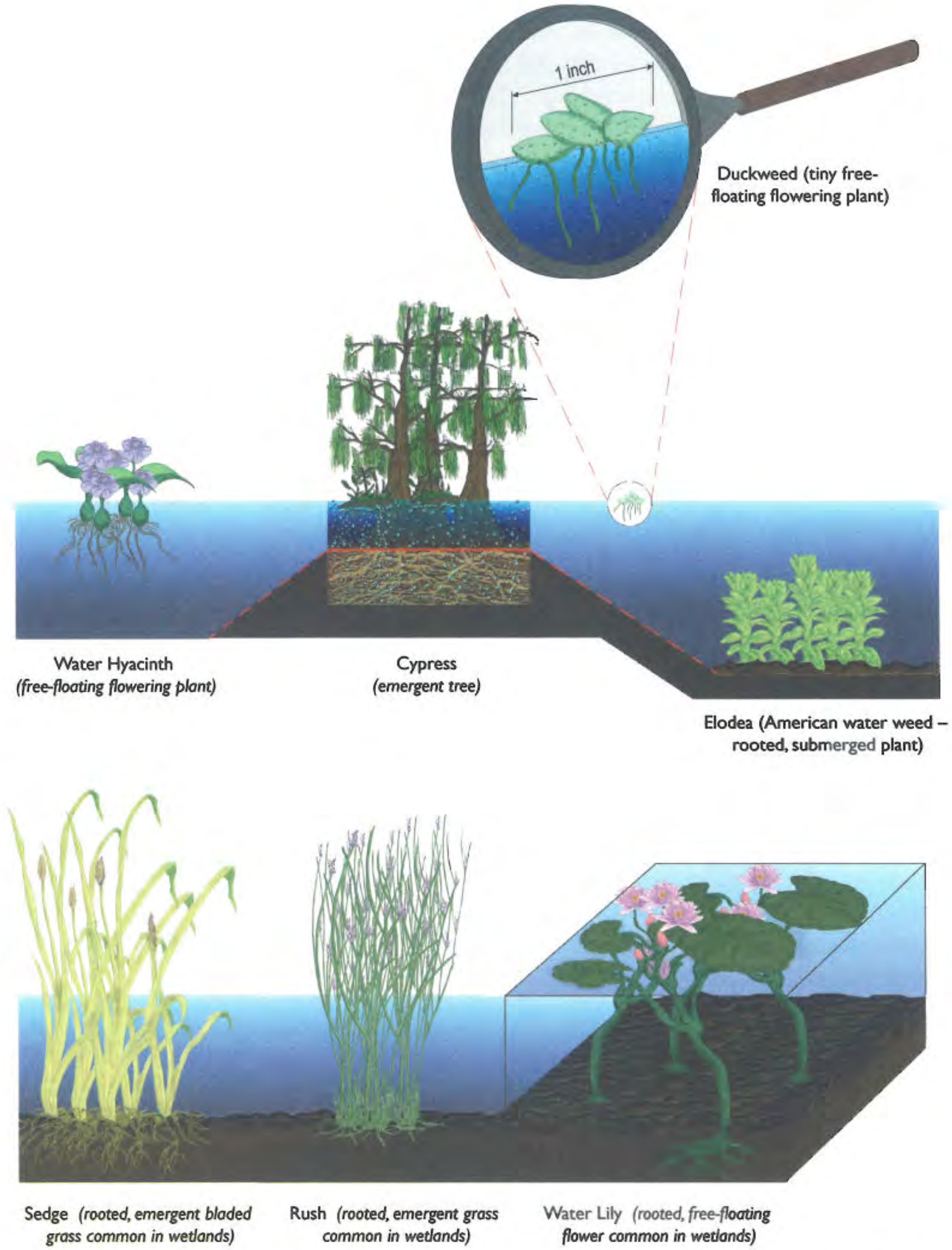


Figure 2. Examples of free-floating, submergent, emergent, and amphibious vegetarian found in mires.

neous wetland systems; as a result, coal beds are generally heterogeneous in thickness and composition. Swamps are flooded deciduous and coniferous forests with saturated soils and semi-aquatic and aquatic areas (shallow lakes with trees). Marshes are semi-aquatic to aquatic areas that support submergent, emergent, and amphibious plant species such as algae, sedges, grasses, and shrubs (flooded prairies). Bogs consist of saturated soils and semi-aquatic areas that support free-floating, submergent, emergent, and amphibious flora such as algae, moss, duckweed, and shrubs. Of the three types of peat-forming mires, swamps have the greatest diversity of wetland and terrestrial plant species.

What is coalification?

The layers of plant matter that accumulate at the bottom of a mire are called peat. Coalification is the slow alteration of that plant matter to coal – it proceeds in two phases. During the first phase, *biogenesis*, biogenic processes convert plant matter into serial forms of peat, culminating in a dark-colored hydrogel called gytta. In the second phase, *thermogenesis*, heat converts gytta into serial ranks of coal.

It is a common misconception that coal forms by compaction of partially degraded organic material due to lithostatic pressure. Although lithostatic pressure does force pore-space closure and the evacuation of free water from buried accumulations of organic matter, lithostatic pressure does not serve to increase the rank of coal during coalification (Tatsch, 1980).

Biogenesis

The vertical stack of accumulated peat (called the peat column) is a sequence of three zones that represent successive levels of aerobic and anaerobic bacterial decay (**Figure 3**). From top to bottom, the zones in a peat column are the fibric zone (little decay, identifiable plant fragments, dense root systems), the humic zone (moderate decay, few identifiable plant fragments), and the sapropelic zone (advanced decay, dominantly microscopic plant fragments). The end product of biogenic processes in these zones is the dark brown to black hydrogel called gytta (see note on gytta, p. 26).

The uppermost few inches of the peat column contains abundant free oxygen that supports aerobic bacteria. Below, little to no free oxygen is available, and anaerobic bacteria take over. During biogenesis, the availability of nutrients in the peat column decreases with depth. The decay produces gases such as hydrogen sulfide (H_2S) and methane (CH_4), and tannic acid. Tannic acid concentration increases during biogenesis, lowering the pH to between 2.5 and 3 and making the water in mires tea-colored to black. As the concentration of acid increases and available nutrients are depleted, conditions in the lower part of the peat column become intolerable to bacteria, and the biogenic process stops.

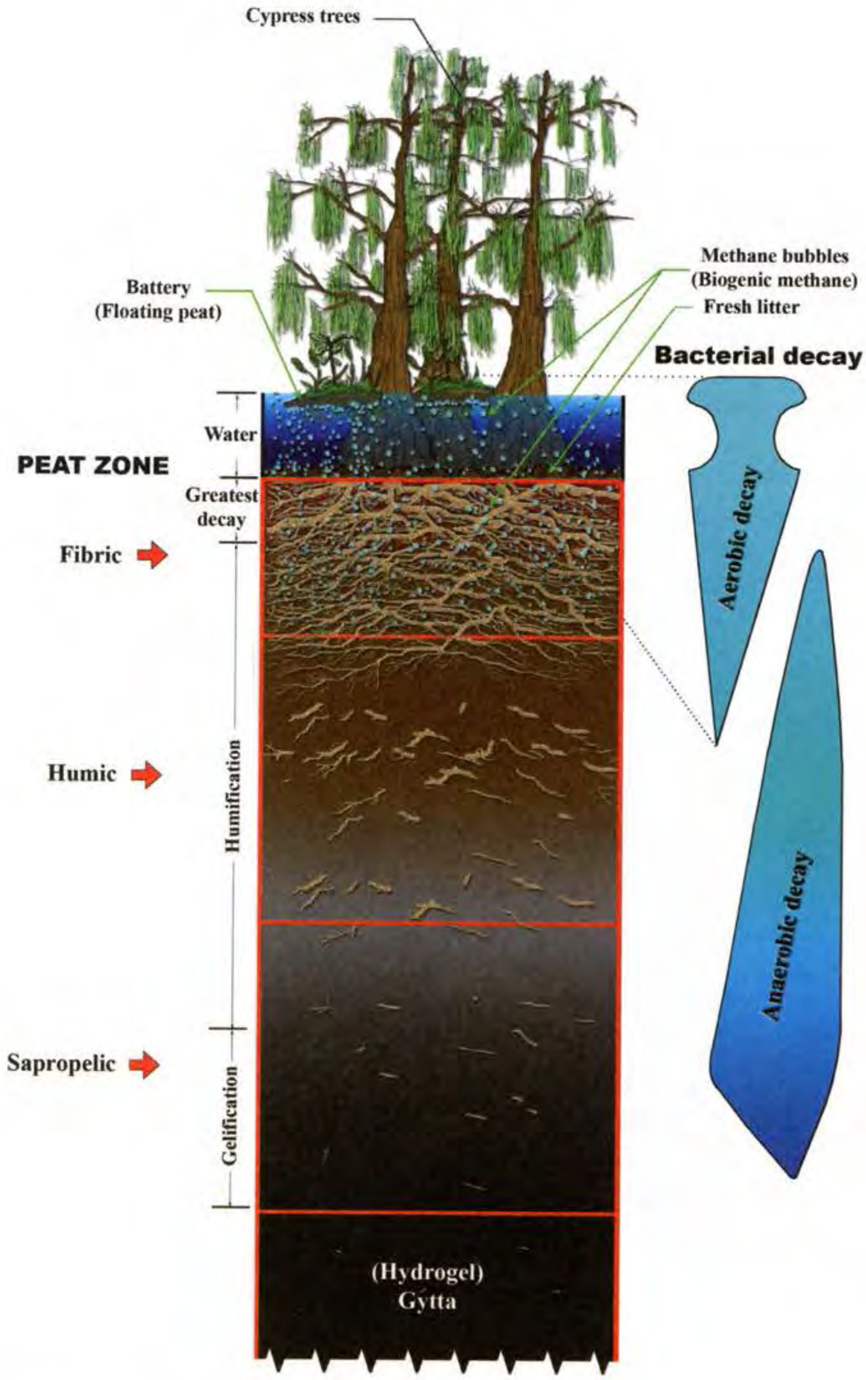


Figure 3. Vertical section of a peat column in a swamp.

The end product of the bacterial reduction of accumulated plant matter is a dark brown to black, semi-amorphous, organic-rich gel called gytta – the precursor to coal. As biogenesis progresses over time, the gytta zone thickens while the thickness of the upper three zones in the peat column remains constant. The thickness of a coal bed directly corresponds to the final thickness of the gytta zone.

Thermogenesis

The second phase of coalification is a heat-driven process called thermogenesis (**Figure 4**), which reduces moisture content and releases gases such as hydrogen, oxygen, nitrogen, and methane. This thermochemical process slowly converts gytta to coal by progressively concentrating available carbon, advancing the coal through sequential levels of *thermal maturation.* Thermal maturation, a measure of how far the coalification process has progressed, is a function of time and temperature. To be converted to coal, gytta must lie buried, normally for millions of years, at temperatures between 150 and 215 degrees Fahrenheit (°F). Such high temperatures result from the natural geothermal gradient of the earth (temperature increases with depth), emplacement of igneous rocks (intrusive and extrusive), and naturally occurring fires in stratigraphically adjacent coal beds.

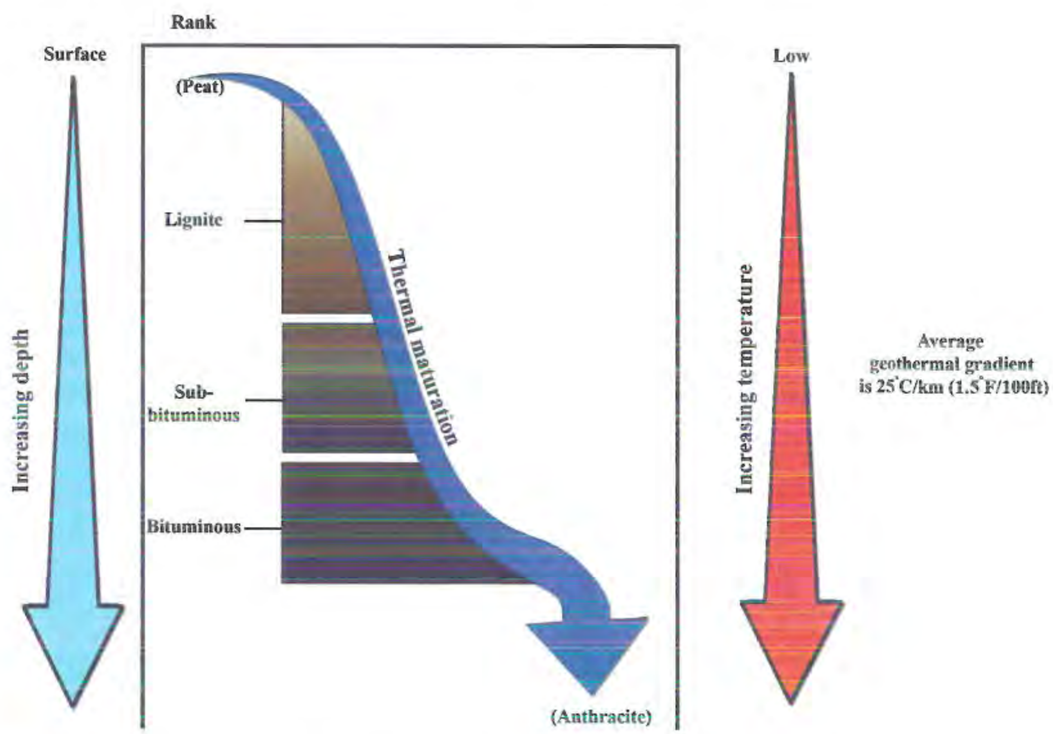


Figure 4. Thermal maturation of coal.

Coal rank and quality

We classify coal in terms of rank and quality. The rank of a coal denotes the level of thermal maturation reached during coalification – the coal's carbon content or heat value. The quality of a coal denotes its content of non-coal matter – volatiles, moisture, sulfur, and ash.

Coal rank

The rank of a coal is a measure of its thermal maturation. Little to no thermal maturation results in the conversion of gytta to a thermoplastic resin called *lignite*, the lowest rank of coal. As thermogenesis continues and the level of thermal maturation increases, the coal is progressively enriched in carbon and increases in rank through subbituminous to bituminous, and finally to anthracite, the highest rank (**Figure 4** and **Figure 5**). No anthracite has been found in Wyoming.

Determination of rank differs for high-rank and low-rank coals (**Figure 5**). The determination of rank for high-rank coal is based on the amount (percent) of fixed carbon in a dry, mineral-matter-free sample. For low-rank coal, the determination is based on heat value – the amount of heat released during combustion of a moist, mineral-matter-free sample, expressed in British thermal units (Btu) per pound of coal. A Btu is defined as the amount

Rank

highest

lowest

Classification			Fixed carbon (%)	Heat value (Btu/lb)	R_0 (%)
Anthracite			92 - 97		2.5 - 5.0
Bituminous	Low Volatile		78 - 85		1.5 - 2.0
Bituminous	Medium Volatile		69 - 77		1.0 - 1.5
Bituminous	High Volatile	A	less than 69	14,000 or more	0.5 - 1.0
Bituminous	High Volatile	B		13,000 - 13,999	0.5 - 1.0
Bituminous	High Volatile	C		11,000 - 12,999	0.5 - 1.0
Brown Coal	Subbituminous	A		11,000 - 12,999	0.4 - 0.5
Brown Coal	Subbituminous	B		9,500 - 10,999	0.4 - 0.5
Brown Coal	Subbituminous	C		8,300 - 9,499	0.4 - 0.5
Brown Coal	Lignite			less than 8,300	0.25 - 0.4
Peat					

Figure 5. Ranks of coal and their properties. R_0 is vitrinite reflectance. Medium volatile bituminous and higher coals are termed *high-rank*. Modified from Karr, 1978, p. 15; Tatch, 1980, p. 10–34.

of heat required to raise the temperature of one pound of water from 63°F degrees to 64°F at atmospheric pressure. A kitchen match produces about one Btu. Coal that produces 8,300 Btu per pound or less is classified as lignite. A heat value between 8,300 and 11,000 indicates subbituminous rank, the first true coal (**Figure 5**). The amount of vitrinite maceral in a coal, as measured by vitrinite reflectance (R_0), also marks its rank – the higher the R_0, the greater the vitrinite content and the more advanced the thermal maturation (**Figure 5**).Wyoming coal ranges in rank from lignite to high-volatile bituminous A.

Coal Quality

Coal quality describes the content of moisture, sulfur, ash, and volatile matter in a coal, and the coal's heat value. The quality of Wyoming coal makes it ideal for use in electric power generation, coal-to-liquids (CTL) and coal-to-syngas conversion technologies, and industrial processes. Across the state and across coal ranks, Wyoming coal averages 0.2 to 1 percent sulfur, 5 to 6 percent ash, less than 30 percent moisture, and 8,300 to 10,000 Btu. **Table 2a** shows properties of Wyoming coal by coal field; **Table 2b** shows coal quality by county. The combination of quantity, quality, and low strip ratios (tons of coal recovered per cubic yard of overburden removed) makes Wyoming coal an ideal energy source.

Coal geology, fields, and resources

Coal geology

Widespread peat-forming wetlands existed in Wyoming during several periods in the state's geologic past. Wyoming's major coal deposits formed during the Cretaceous (138-65 million years ago, mya) and the early Tertiary (65–50 mya). There is little or no evidence of coal in Wyoming from the Carboniferous Period (360–290 mya), a major coal-producing time elsewhere (**Plate 1**).

The oldest documented coal beds in the state occur in the Lower Cretaceous Thermopolis, Cloverly, Lakota, and Fall River formations (136–96 mya). These oldest coals are bituminous in rank, thin (less than 5 feet thick), and discontinuous. Peat deposits that developed in broad floodplains and scattered fluvial systems became these Lower Cretaceous coal beds.

In mid-Cretaceous time, Wyoming was inundated by the Great Western Interior Seaway, a warm, shallow sea that stretched from the Gulf of Mexico to the Arctic Ocean. As the sea transgressed and regressed (the sea level rose and fell) across Wyoming throughout the remainder of the Cretaceous period, coastal marshes, back-barrier swamps, and inter-deltaic wetlands supported numerous narrow, elongate peat deposits (**Figure 1**). Coal beds from this time occur in the Frontier and Adaville formations and in the Rock Springs and Almond members of the Mesaverde Group.

Table 2a. Wyoming coal quality by major coal field

Coal field	Rank	Btu	Ash (%)	Sulfur (%)	Moisture (%)	Fixed Carbon (%)	Volatile Matter (%)
Bighorn	High Volatile Bituminous C	10,970	5.85	0.50	13.90	45.35	34.90
	Subbituminous A	9,800	10.90	0.50	13.80	37.30	38.00
Green River	High Volatile Bituminous C	10,832	6.47	0.82	13.20	46.87	33.45
	Subbituminous A	10,000	7.60	0.57	17.50	—	—
	Subbituminous C	8,603	12.15	2.52	21.65	34.75	31.11
Hams Fork	High Volatile Bituminous A	12,875	8.20	1.00	3.20	50.75	37.90
	High Volatile Bituminous A and C	9,635	11.70	2.35	14.30	38.00	36.10
	High Volatile Bituminous B	12,296	6.63	0.46	5.80	49.50	38.03
	High Volatile Bituminous B and C	12,380	6.90	0.90	5.90	47.60	39.60
	High Volatile Bituminous C	12,780	3.60	1.10	5.90	51.00	39.50
	Subbituminous C	9,520	3.80	0.60	21.20	41.30	33.90
Hanna	High Volatile Bituminous C	10,707	7.74	0.82	11.40	43.48	37.44
	Subbituminous A	10,200	6.51	0.94	11.00	43.30	38.50
	Subbituminous C	—	6.98	0.43	12.93	45.15	34.86
Powder River	Subbituminous A	9,750	3.50	0.25	22.60	43.30	30.50
	Subbituminous B	9,390	5.20	0.63	22.03	38.63	34.66
	Subbituminous C	8,162	6.18	0.52	28.60	34.02	31.19

Values averaged from samples collected from 54 coal beds located throughout Wyoming (Glass, 1975).

Table 2b. Wyoming coal quality by county

County	Coal field	Btu	Ash (%)	Sulfur (%)
Campbell	Powder River	8,678	5.14	0.31
Carbon	Hanna/Carbon	10,844	8.00	0.59
Converse	Powder River	8,860	5.39	0.25
Lincoln	Hams Fork	9,940	4.93	0.95
Sweetwater	Green River	9,318	10.33	0.51

Values averaged from data from the Federal Energy Regulatory Commission website (2005; 2006; 2007), as reported by U.S. coal-fired utilities of more than 50 megawatts.

Following the final, northeasterly regression (retreat) of the Great Western Interior Seaway near the end of the Mesozoic, wetland environments developed in flood-plain deposits of the latest Cretaceous Lance, Medicine Bow, Harebell, and Ferris formations.

These wetlands were associated with floodplains along an east-northeast-trending drainage system that stretched from the Fold and Thrust Belt in western Wyoming eastward across the state toward the ancient Cretaceous coastline. During deposition of the Cretaceous Lance Formation and the early Tertiary (Paleocene) Pinyon Conglomerate and Evanston, Hanna, and Fort Union formations, Wyoming was a broad expanse of rivers, lakes, and wetlands. As early as 80 million years ago, the Laramide Orogeny began to compartmentalize the broad flood plain into juvenile basins between uplifts. The peak of Laramide deformation occurred between 65 and 50 million years ago, during the Paleocene. Evidence of exposure of the Precambrian-cored uplifts at approximately 55 million years ago exists as conglomeratic deposits of latest Paleocene and earliest Eocene age that flank the uplifted blocks. During the middle to late Paleocene and early to middle Eocene, a time of major Laramide activity, the thickest coal beds of the entire Rocky Mountain region were created: enough peat accumulated and was coalified to form several coal deposits more than 200 feet thick in the Paleocene Fort Union and Eocene Wasatch formations in the Powder River Basin.

Coal fields

Wyoming has some of the world's largest coal deposits. Coal underlies approximately 53,000 square miles, more than half the area of the state. Wyoming lies within two national coal provinces, the Northern Great Plains Province in the eastern part of the state and the Rocky Mountain Province in the western and most southern parts. Wyoming's basins contain ten major coal fields. Most coal mined in Wyoming is classified as subbituminous A to high-volatile bituminous C. **Figure 6** shows the distribution and rank of minable Wyoming coal.

Coal resources

Three terms define the quantity of coal in the ground: *coal resources* indicates how much coal is in the ground, *coal reserves* indicates how much of that coal is available for mining with current technology, and *recoverable reserves* refers to the amount of coal that we can *actually* recover by mining (Wood et al., 1983). Currently, we estimate Wyoming's coal resources at 1.61 trillion tons – as modified from the conventionally accepted 1.46 trillion-ton estimate of Wood and Bour (1988). During the 120 years from 1868 through 1987, Wyoming produced 1.66 billion tons of coal; during the 20 years from 1988 through 2007, the state produced 5.98 billion tons. Wyoming's total production during the 140 years through 2007 was therefore some 7.64 billion tons of coal.

Recoverable reserves are further split into two categories, *surface recoverable reserves* and *deep recoverable reserves*. Of the 65 billion tons of coal reserves in Wyoming, 46 billion tons are

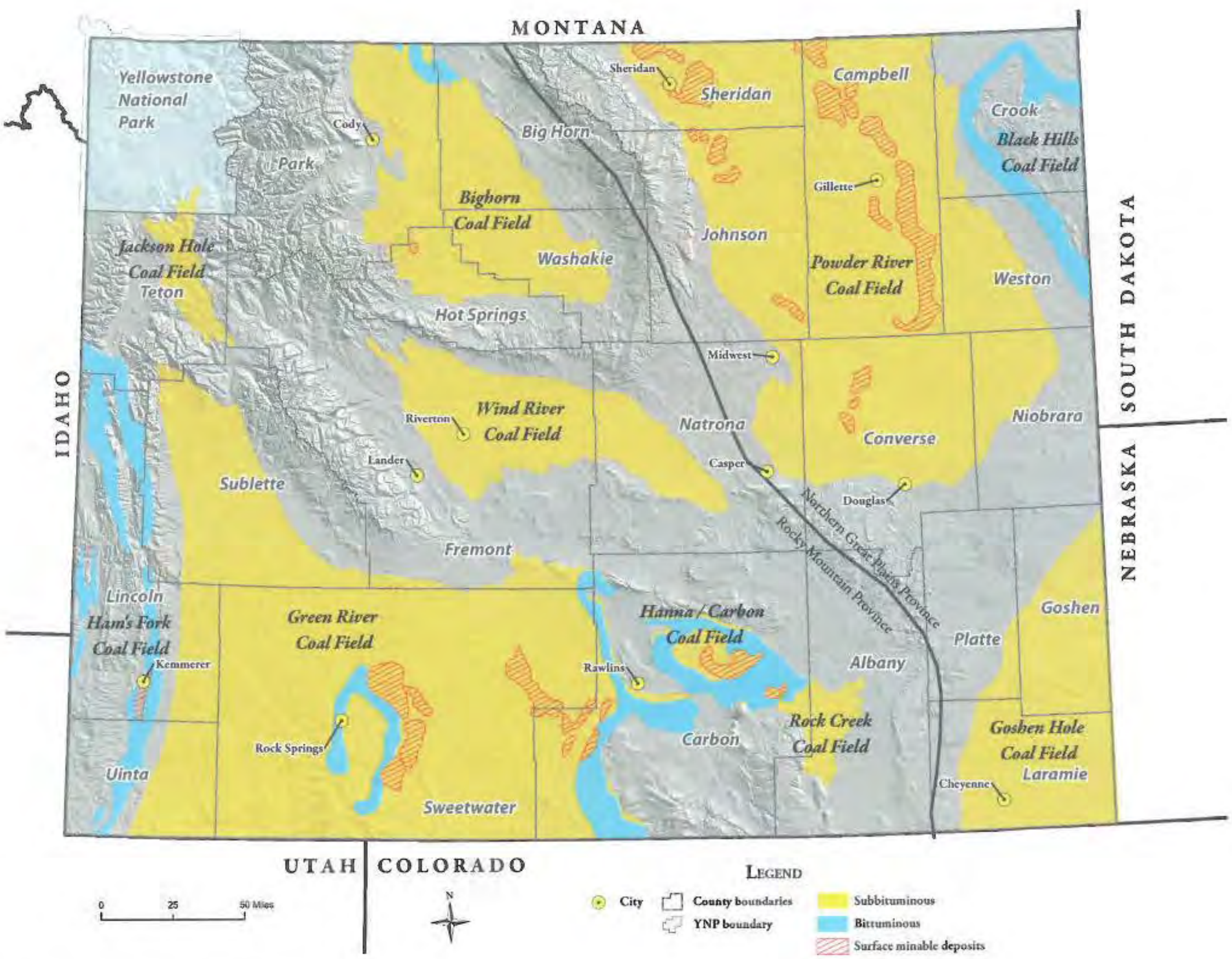


Figure 6. Map of Wyoming coal fields and coal ranks.

classified as recoverable reserves: 23 billion tons as surface recoverable reserves available for surface mining, and 23 billion tons as deep recoverable reserves available for underground mining. Assuming the use of current mining methods and annual production of 500 million tons, the remaining 46 billion tons of recoverable coal reserves in Wyoming will last just into the next century. However, as mining methods and technologies evolve and more coal resources are reclassified as recoverable coal reserves, the state's coal reserves could last an additional hundred years. **Table 3** shows the distribution of coal resources by coal field.

Table 3. Wyoming coal resources by coal field

Coal Field	Resource (MMt)*
Goshen Hole	230
Rock Creek	3,400
Jackson Hole	6,340
Black Hills	7,879
Hanna	22,940
Bighorn	23,475
Hams Fork	49,280
Wind River	81,002
Green River	236,326
Powder River	1,178,626

**MMt, million tons. From Glass, 1997, less production (WSGS). Powder River Basin resource, WSGS.*

Ownership, production, and reclamation

Coal ownership

Coal ownership in Wyoming is divided among private landowners, the State of Wyoming, and the federal government. In the 1900s, the federal government reserved the coal portion of the mineral estate under vast areas of Wyoming. Those wishing to develop these coal reserves may lease the coal. The federal government ceded coal underlying state lands to the State of Wyoming (De Bruin et al., 2004).

The process of acquiring federally-owned coal for mining is called *Lease by Application*. First, an interested party nominates a tract of land containing federally-owned coal: this is called *nomination of a lease*. The U.S. Bureau of Land Management (BLM) then determines fair market value of the coal in the proposed lease area and prepares an Environmental Assessment or an Environmental Impact Statement (EIS) for the area. After successful completion of valuation and review of the EIS, the BLM schedules a competitive sale where interested parties may submit sealed bids for the coal in the lease.

Historic coal production

Coal has been actively mined in Wyoming for more than 130 years. The first commercial coal mines began producing in 1868. By 1900, Wyoming coal production exceeded 3 million tons (MMtons) per year. Coal produced during this period was used primarily as transportation steam-coal for Union Pacific locomotives; the nation also used coal for domestic heating and industrial needs. The earliest coal mines in Wyoming developed concurrently with construction of the transcontinental railroad along the southern corridor of the state. The route for the rail line was selected in part to take advantage of accessible and abundant coal resources.

Wyoming's first commercial mines were the Carbon mines located between Medicine Bow and Hanna in Carbon County. Soon after, the Rock Springs coal mines were established along the western flank of the Rock Springs Uplift in Sweetwater County. As construction of the railroad continued west, mines developed at Diamondville and near Kemmerer in Lincoln County, and near Evanston in Uinta County. During this time, coal from Wyoming fueled the railroad and was shipped east to Nebraska for sale on the open market.

The number of active mines, along with annual coal production, steadily increased during the first half of the twentieth century. Growth in the state's coal industry continued through World War I and the Great Depression, and peaked during World War II. In 1945, more than 100 mines collectively produced nearly 10 MMtons of coal. However, by 1955 the state's coal industry had slowed markedly, and by 1960 annual coal production had dropped to less than 2 MMtons. The decline occurred during the postwar era when coal was no longer needed for the war effort. The railroads' switch from steam locomotives to diesel-electric locomotives compounded the decline.

However, during the 1950s and 1960s, U.S. demand for steam-coal began to grow. In the 1970s, Wyoming began supplying steam-coal to help meet a surge in construction of coal-fired electric power plants throughout the United States. More than 120 new coal-fired power plants began operating between 1950 and 1959, and more than 180 additional coal-fired power plants were built during the following 20 years. Concurrently, coal production in Wyoming doubled every five years between 1960 and 1980. Since 1980, statewide production has nearly doubled every ten years. In 2000, annual production topped 300 MMtons, and in 2005 Wyoming produced 400 MMtons. In 2005 there were approximately 500 active coal-fired electric power plants in the country; Wyoming coal supplied 135 of these.

Rapid growth in the Wyoming coal industry during the latter part of the 1970s resulted from the development of large-scale open-pit surface mines in the Powder River Basin. Development of the abundant coal resources in the Powder River Basin was driven by amendments to the Clean Air Act of 1974 and the energy crisis of the following ten years. The continuous growth of coal production in Wyoming resulted from a growing national demand for low-cost, low-sulfur steam-coal; from technological advances in engineering and mining practice; from large-scale development of mining and rail infrastructure; and from the great abundance of thick, minable coal resources in the Powder River Basin.

Current coal production and electric power generation

Wyoming is the single largest producer of coal in the U.S. – approximately 40 percent of the coal produced domestically each year comes from Wyoming. The state's vast coal resources have been in demand for the last half-century because Wyoming coal is ideal feedstock for electric power generation. Currently, Wyoming coal generates approximately 35 percent of domestically produced electricity. Wyoming's active coal mines are located in Lincoln and Sweetwater counties in the Green River Basin, Carbon County in the Hanna and Carbon basins, and Converse and Campbell counties in the Powder River Basin.

Wyoming power plants consume approximately 5.5 percent of the coal produced in the state. These plants use the heat generated by coal combustion to convert water into steam, which is used to produce electricity. Wyoming is currently home to ten coal-fired power plants – seven located in the Powder River Basin (PRB), one in the Denver Basin, and two in the Green River Basin (GRB) (**Table 4**). These ten plants have an electrical generating capacity of more than 6.0 gigawatts and provide electricity to more than three million customers. Three additional coal-fired power plants (Two Elk II, Dry Fork, and Wygen III) are currently in the permitting process, permitted and awaiting construction, or under construction; the Dry Fork plant should be operational by 2011. The largest power plant in the state is the Jim Bridger plant (**Figure 7**), located 25 miles east of Rock Springs on the Rock Springs Uplift. The Jim Bridger plant, with a generating capacity of 2,120 megawatts, is fed exclusively from the adjacent Black Butte and Jim Bridger coal mines.

Powder River Basin

The most prolific coal-producing area in Wyoming is an elongate zone in the eastern Powder River Basin (PRB), where 7 companies operate 13 active surface coal mines. Mining operations in the PRB use truck-and-shovel and dragline techniques, explosives, and conveyor belt systems to mine and move coal. Companies mine coal from the Upper and Lower Wyodak coal zones in the Tongue River Member of the Paleocene Fort Union Formation. The two main coal beds are the Anderson and the underlying Canyon. Individually, these coal beds are between 30 and 60 feet thick; where the interburden (clastic material separating coal beds) between the two seams is minimal or absent, the coal deposit is between 70 and 100 feet thick. The heat value of Wyodak coal is highest in the southern basin and decreases to the north. Wyodak coals are subbituminous in rank, with heat values between 8,000 and 8,900 Btu per pound, and are low in sulfur (average sulfur content 0.31 percent) and ash (av-

Table 4. Existing and proposed coal-fired power plants in Wyoming
[See map of coal fields, Figure 5. DB, Denver Basin; GRB, Green River Basin; PRB, Powder River Basin; MW, megawatts]

Plant name	Company	Generating capacity (MW)	Basin
Neil Simpson I	Black Hills Power Inc.	22	PRB
Osage	Black Hills Power Inc.	35	PRB
Neil Simpson II	Black Hills Power Inc.	80	PRB
Wygen I	Black Hills Power Inc.	88	PRB
Wygen II	Black Hills Power Inc.	95	PRB
Wygen III *	Black Hills Power Inc.	[110]	PRB
Wyodak	PacifiCorp	362	PRB
Dry Fork Station *	Basin Electric	[385]	PRB
Naughton	PacifiCorp	707	GRB
Two Elk II *	North American Power	[750]	PRB
Dave Johnston	PacifiCorp	816	PRB
Laramie River Station	Basin Electric Power	1,710	DB
Jim Bridger	PacifiCorp	2,120	GRB

** In permitting process, permitted and awaiting construction, or under construction*

Figure 7. The Jim Bridger power plant, southwestern Wyoming. Photo by Nick Jones.

erage ash content 5.14 percent) (**Table 2**). Nearly all coal produced in the PRB is shipped by rail to steam-electric power plants in 39 states, including Wyoming. Presently (2009), eight coal-fired power plants operate in eastern Wyoming, located in Campbell, Converse, Weston, and Platte counties: seven in the PRB and one in the Denver Basin (**Table 4; Figure 8**); they have a combined electrical generation capacity of 3,593 megawatts. A small percentage of Powder River Basin coal is used for industrial purposes in such diverse venues as cement plants, sugar-beet refineries, and bentonite mills.

Green River Basin

Wyoming's second most productive coal area is the Green River Basin (GRB), where three companies operate three mines: the Jim Bridger mine (surface, high-wall, and underground); the Black Butte mine (surface); and the Kemmerer mine (surface). At present the GRB hosts the only active high-wall miner and underground long-wall and continuous miners in the state. Two of the three mines active in the GRB are captive coal mines: they supply coal directly to adjacent coal-fired power plants. Together, the two plants can generate 2,827 MW (**Table 4; Figure 8**).

The Jim Bridger underground mine, located in Sweetwater County north of Point of Rocks, uses a long-wall miner in its underground operations and a high-wall miner in its surface operations. The main producing coal bed is the Deadman coal bed in the Tertiary Fort Union Formation. The Deadman coal is between 12 and 30 feet thick; the main coal bed splits to the south and east into five thinner beds, coal beds D1 through D5. These five coal deposits south of the Jim Bridger mine were mapped by H.W. Roehler in 1979 as, from top to bottom, the Leaf, Big Burn or Nuttal, Hail, Washout, and Little Valley coal beds (Glass, 1982). The average heat value of coal produced from the Jim Bridger operations is approximately 9,200 Btu per pound, average sulfur content is 0.58 percent, and average ash content is 11.59 percent. Coal produced at this mine directly supplies the adjacent coal-fired Jim Bridger power plant, the largest coal-fired power plant in Wyoming.

The Black Butte mine, also located in Sweetwater County, lies south of Interstate 80 and east of Point of Rocks. There are nine minable Upper Cretaceous coal beds at the Black Butte coal mine, five in the Lance Formation and four in the underlying Almond Formation. Coals in the Lance Formation are, from youngest to oldest, the Overland, Gibralter, Black Butte, Maxwell, and Hall coal beds. The four coal beds in the Almond Formation compose the Almond coal group; they are, from youngest to oldest, the A2, A3, A4, and Lebar coal beds. The average heat value of coal produced at this mine is approximately 9,400 Btu per pound, average sulfur content is 0.44 percent, and average ash content is 9.03 percent. Coal produced at the Black Butte coal mine is used in Wyoming at the Jim Bridger power plant and is also shipped to Utah and Nevada to generate electricity.

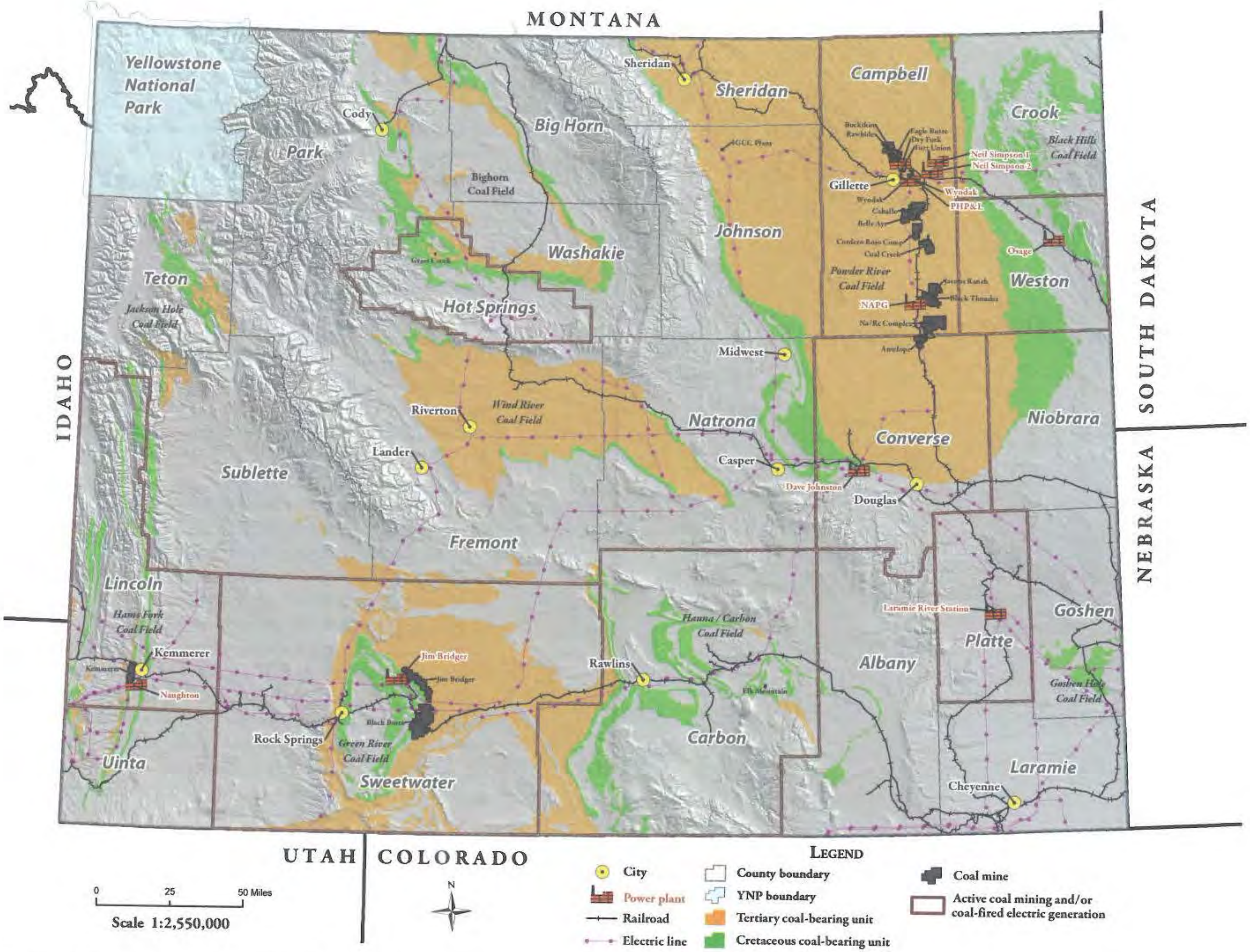


Figure 8. Map showing coal-related activity in Wyoming.

The Kemmerer mine is located in the Hams Fork Coal Field west of Kemmerer (and Diamondville), in Lincoln County. The main producing coal bed at the Kemmerer mine is the Adaville No. 1 in the Upper Cretaceous Adaville Formation. The Adaville No.1 coal bed is between 30 and 88 feet thick. The average heat value of the coal produced at the Kemmerer mine is approximately 9,900 Btu per pound, average sulfur content is 0.96 percent, and average ash content is 4.93 percent. Coal produced at this mine primarily supplies the adjacent Naughton power plant (**Table 4; Figure 8**). This coal is also used for industrial purposes at cement and trona processing plants.

Hanna and Carbon basins

The oldest coal-producing areas in Wyoming are the Hanna Basin and adjacent Carbon Basin in eastern Carbon County. Coal production in the Hanna Basin ceased in 2004, ending 136 years of continuous coal operations. However, in 2006 a new surface coal mine, the Elk Mountain/Saddleback mine, opened in the Carbon Basin to supply a planned coal-to-liquids (CTL) plant. The CTL plant will produce approximately 10,000 barrels per day of low-sulfur transportation fuel, just as Hanna produced coal for steam locomotives more than a century ago. The Elk Mountain/Saddleback operation currently mines the Johnson coal bed in the Tertiary Hanna Formation. This coal bed has an apparent rank of bituminous, with an approximate heat value of 10,600 Btu per pound, and has less than 1 percent sulfur and less than 7.5 percent ash.

Future coal production and new uses

Wyoming coal production could increase to nearly 500 million tons per year by 2015. However, future regulatory constraints on carbon emissions, increasing use and development of solar and wind power technologies, and a potential upturn in nuclear power production could together keep Wyoming coal production from surpassing this level. In the future, a growing percentage of Wyoming coal could be converted into transportation fuels and synthetic natural gas (syngas) through clean-coal conversion processes, including coal-to-liquids (CTL) and coal-to-syngas (CTG). However, coal-based electrical generation will continue to play a significant role well into the future. It is likely that new coal-fired power plants will be sited closer to their sources of coal, as described under *Coal by wire* on page 23. This will require significant additions to the existing electric power transmission infrastructure, but will boost efficiency in power transmission and reduce transportation costs (cost of power transmission vs. cost of transporting coal) and diesel fuel consumption. Also, upgrading the power transmission infrastructure will allow increasing integration of electric power generated from renewable resources.

Reclamation

Mine reclamation was mandated in 1977 when Congress passed the Surface Mining Control and Reclamation Act (SMCRA). The SMCRA is a set of formal guidelines that requires coal developers to include methods in their mine plans for reclaiming areas after they are mined through. Reclamation is defined as returning the mined area to its original contours, vegetation, and use. A mine permit agreement requires a mining company to post bond or to make a deposit to the State of Wyoming that guarantees proper reclamation of mined areas. The Wyoming Game and Fish Department awards its annual *Mine Reclamation and Wildlife Stewardship Award* to a select few mining operations that have implemented outstanding reclamation and preserved or created wildlife habitat. The award is highly sought after by Wyoming's coal producers. Between 1998 and 2005, seven mines and two companies that operate in Wyoming received the award.

Coal distribution and coal-based power

Coal distribution and customers

Wyoming producers ship coal to 38 states outside Wyoming, as well as within the state, primarily by rail (**Figure 9**). The Burlington Northern Santa Fe and Union Pacific railroads together transport approximately 95 percent of the state's produced coal to 135 coal-fired power plants located throughout the country. The other 5 percent of production is used to fuel the ten power plants in Wyoming and, in small quantities, for industrial purposes and stoker coal at concrete, wallboard, and sugar beet processing plants.

Coal by wire

Under the concept of *coal-by-wire,* Wyoming would export electricity rather than coal: electricity would be generated very near the source of coal and transmitted to distant markets. In addition to being a net exporter of coal, Wyoming could also become an important provider of electricity: in the future, a growing percentage of Wyoming coal could supply a fleet of new Wyoming coal-fired power plants. Five proposed long-distance, high-voltage power transmission lines that would originate in Wyoming and carry electricity to distant markets are in various stages of planning; they are listed in **Table 5**. These transmission lines would originate in the PRB and carry wind power in addition to coal-fired power.

The Wyoming coal industry in 2008

The coal industry in Wyoming (in 2008) consists of nine mining companies that together operate seventeen surface mines and one underground mine (**Figure 8**). Coal from these mines is sold to power plants located in 39 states (**Figure 9** shows 2006 data, the latest available). Wyoming coal is also sold and distributed on the international coal market: Wyoming currently exports between 5 and 7 million tons of coal per year internationally, mostly to Canada.

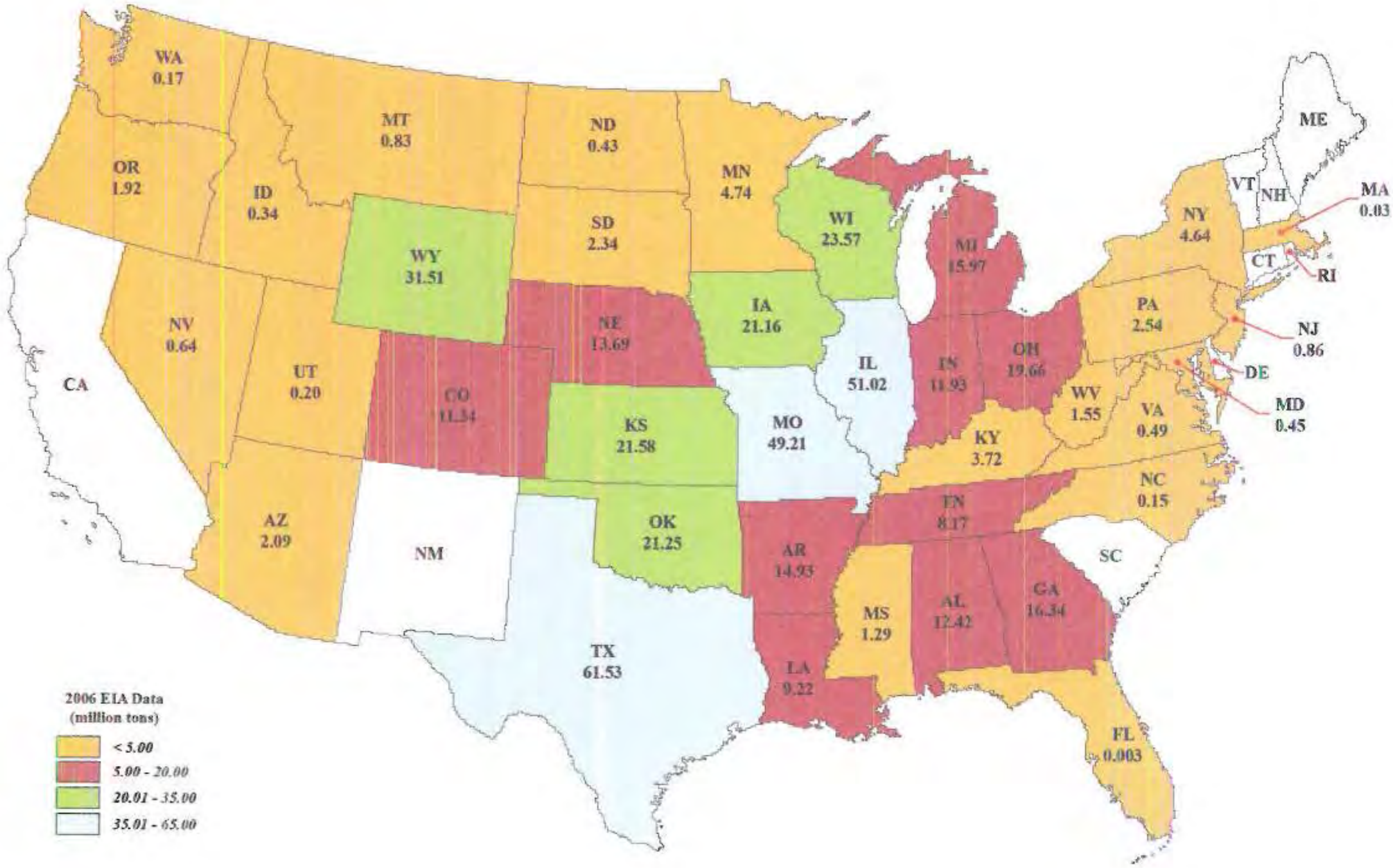


Figure 9. Map showing the national distribution of Wyoming coal in 2006, according to Energy Information Administration data.

Table 5. Proposed interstate power transmission lines
[A.C., alternating current; D.C., direct current]

Line name	Kilowatts	Type	Planned initial service date	Service routes
Gateway West	230/500[1]	A.C.	2014	Wyoming-Idaho
Wyoming-Colorado Intertie	345	A.C.	2013	Wyoming-Colorado
Gateway South	500	A.C.	2014	Wyoming-Utah-Nevada
TransWest Express	500	D.C.	2015	Wyoming-Arizona
High Plains Express	500/500[1]	A.C.	n.a.[2]	Wyoming-Colorado-New Mexico-Arizona

[1]These corridors carry two separate lines.
[2]Initial service date currently (2009) unplanned.

There are two types of reported coal sales, contract sales and spot market sales. A contract coal sale is an agreement between a coal producer and a coal customer that guarantees delivery of a specified amount of coal (tonnage) at an agreed-upon price per ton that meets specified criteria for heat value (Btu per pound) and coal quality. Contract coal agreements are either long-term (more than 5 years) or short-term (5 years or fewer). Spot coal sales are transactions involving available tonnages of coal not obligated under contract. This coal may cost several dollars per ton more or less than contracted coal, depending on demand.

Within the U.S. coal market, Wyoming coal is separated into two categories based on heat value: 8,400 Btu-per-pound coal and 8,800 Btu-per-pound coal. Of all the coal produced and sold in the U.S., Wyoming coal is the most affordable on the basis of price per million Btu (MMBtu), delivered. Since 1999, Wyoming coal has accounted for more than 30 percent of total annual U.S. coal production, and in 2007 it accounted for 40 percent of total U.S. production. During that period, the price of Wyoming coal increased by 61.6 percent from an annual average of $1.12 per MMBtu in 1999 to $1.81 per MMBtu in 2007 (Federal Energy Regulatory Commission, 1999–2007). Most of this increase resulted from higher fuel prices and significant capital investment by the Union Pacific and Burlington Northern Santa Fe railroads to increase rail capacity and infrastructure in the Powder River Basin. The greatest year-to-year increase, 23.4 percent, occurred between 2004 and 2005.

In 2007, the coal industry in Wyoming directly supported more than 6,000 jobs. Each job in mining supported at least three jobs not directly supported by mining (Wyoming Coal Information Committee, 2007). In addition to supporting jobs directly and indirectly, Wyoming coal producers generated approximately $744 million in revenue for the state in 2006

(Wyoming Coal Information Committee, 2007). This revenue was *(1)* monies returned to the state as Wyoming's share of federal mineral royalties, lease bonus payments, and abandoned mine lands (AML) disbursements paid to the federal government; *(2)* additional state income from state mineral royalties and rents, severance taxes, and part of sales and use taxes; and *(3)* county income from ad valorem taxes (production and property) and part of sales and use taxes.

Recent studies and assessments of the coal market by the Wyoming Bureau of Land Management, U.S. Geological Survey, U.S. Energy Information Agency, and Wyoming State Geological Survey predict that the coal industry will continue to play a vital role in this state's economy well into the next century. These forecasts are based on available coal resources and a growing U.S. demand for energy. Despite bumps in the economic road, the industry will remain robust and will sustain jobs related to mineral extraction, handling, and transport; reclamation; maintenance; and clerical, administrative, and scientific disciplines.

Note on gytta

Also gyttja; mud or ooze in Swedish; in technical usage since 1862: a typically black sediment, rich in organic matter, deposited in productive lakes (Simpson and Weiner, vol. VI, p. 986). Used currently by European coal petrologists for an amorphous maceral, "gelenite." Used here for the complex hydrophilic gel that is the end product of the biogenesis of peat and the precursor of coal.

References

De Bruin, R.H., Lyman, R.M., Jones, R.W., and Cook, L.W., 2004, Coalbed methane in Wyoming: Wyoming State Geological Survey Information Pamphlet No. 7, second edition.

Energy Information Administration website, 2008, 1984–2007 coal production data; accessed 2008 —
http://www.eia.doe.gov/fuelcoal.html
[Coal production tables: current weekly production estimates, current monthly production estimates, weekly revised estimates, monthly revised estimates] —
http://www.eia.doe.gov/cneaf/coal/weekly/weekly_html/archmonth.html

Federal Energy Regulatory Commission website, 1999–2007, Cost and quality of fuels for electric plants, FERC form 423; accessed 2008 —
http://www.ferc.gov/docs-filing/eforms.asp
[no longer available online]

Glass, G.B., 1975, Analysis and measured sections of 54 Wyoming coal samples (collected 1974): Geological Survey of Wyoming Report of Investigations 11, 219 p.

Glass, G.B., 1982, Coal deposits of Wyoming: Wyoming State Geological Survey Reprint 39, 56 p. [Reprinted from the Wyoming Geological Association Thirty-second Annual Field Conference Guidebook, 1981, p. 181–236.]

Glass, G.B., 1997, Coal geology of Wyoming: Wyoming State Geological Survey Reprint No. 63, 21 p. [Reprinted from Keystone Coal Industry Manual, 1997]

Jones, N.R., 2008, Coal bed nomenclature and distribution, *in* Copeland, D.A., and Ewald, M.L., eds., Water associated with coal beds in Wyoming's Powder River Basin – Geology, hydrology, and water quality: Wyoming State Geological Survey Exploration Memoir No. 2, p. 45–94.

Karr, C., Jr., ed., 1978, Analytical methods for coal and coal products, vol. 1: New York, Academic Press, 580 p.

Simpson, J.A., and Weiner, E.S.C., preparers, 1989, The Oxford English Dictionary, 2nd edition: Oxford, Clarendon Press, vol. VI, 1143 p.

Tatsch, J.H., 1980, Coal deposits – Origin, evolution, and present characteristics: Sudbury, Mass., Edward Arnold, 590 p.

Ting, F.T.C., 1978, Petrographic techniques in coal analysis., *in* Karr, C., Jr., ed., Analytical methods for coal and coal products, vol. 1: New York, Academic Press., p. 3–25.

Wilfrid, Francis., 1954, Coal – Its formation and composition: London, Edward Arnold, 567 p.

Wood, G.H., Jr., and Bour, W.V., III, 1988, Coal map of North America: U.S. Geological Survey Special Geologic Map, scale 1:5,000,000, 2 sheets, and pamphlet, 44 p.

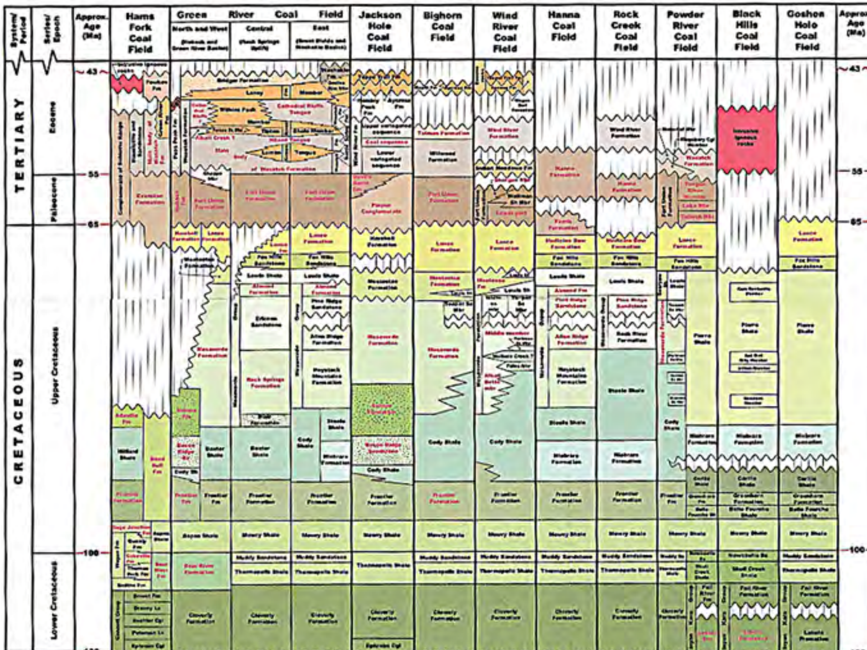
Wood, G.H., Jr., Kehn, T.M., Carter, M.D., and Culbertson, W.C., 1983, Coal resource classification system of the U.S. Geological Survey: U.S. Geological Survey Circular 891, 65 p.

Wyoming Coal Information Committee, 2007, A concise guide to Wyoming coal 2007: Cheyenne, Wyoming Mining Association, 8 p.

ISBN 1-884589-51-0
WSGS-PIC44-09

WYOMING STATE GEOLOGICAL SURVEY
Ronald C. Surdam, State Geologist
Laramie, Wyoming

Principal coal-bearing and related stratigraphic units in Wyoming



EXPLANATION

Symbols

Abbreviations used

Gp Group
Fm Formation
Mbr Member
mbr informal member
T Tongue
Ls Limestone
Cgl Conglomerate
Ss Sandstone
ss sandstone
Sh Shale
Ma Millions of years before present
YNP Yellowstone National Park

Acknowledgements

References

Location map of Wyoming coal fields