BLM

Final Mineral Occurrence and Development Potential Report

Buffalo Field Office

June 19, 2009

It is the mission of the Bureau of Land Management to sustain the health, diversity, and productivity of the public lands for the use and enjoyment of present and future generations.

FINAL
MINERAL OCCURRENCE AND DEVELOPMENT POTENTIAL REPORT

Buffalo Resource Management Plan Revision

United States Department of the Interior

Bureau of Land Management

Buffalo Field Office, Wyoming

June 19, 2009

Errata Sheet for Buffalo Field Office
Final Mineral Occurrence and Development Potential Report

July 9, 2009

Page No.	Paragraph or Figure No., or Section	Line No.	Errata Information
2-3	Figure 2-1	reference	Reference should read: "Source: Fenneman and Johnson, 1946; as modified by **Science Applications International Corporation for use in Casper Field Office Mineral Occurrence and Potential Development Report, Figure 2-1, p. 2-3 (BLM, 2004)**."
2-7	Figure 2-7	legend/ explanation	**Information that should have been included in this figure:** **Cgl = Conglomerate.** The **Steele Shale** is part of the Cody Shale, and equivalent to the lower portion of the Pierre Shale. The **Paleozoic Era** includes Cambrian Period through Permian Period strata; the **Mesozoic Era** includes Triassic Period through Cretaceous Period strata; and the **Cenozoic Era** includes Paleocene Epoch through Holocene Epoch strata. **The left-hand side of each portion of the stratigraphic column represents strata occurring in the western side of the Powder River Basin, while the right-hand side of each portion represents strata occurring in the eastern side of the basin.**

2-9	Madison Limestone	section heading	Madison Limestone (**Mississippian)**
2-10	Goose Egg Formation	section heading	Goose Egg Formation (Middle Permian **to** Lower Triassic)
3-5	Paragraph 8 (**replace entire text** "The Amsden Creek winter game range (480 acres) have also been withdrawn from mineral location" **with that indicated in far right column**.	all	**The Amsden Creek Big Game Winter Range (aka Tongue River Deer Refuge and Winter Pasture) (551 acres) and the Middle Fork of the Powder River (aka Ed O. Taylor Big Game Winter Range) (10,950 acres) have been formally withdrawn from mineral location.**
6-1 *ff*	Chapter 6.0, References	n/a	**References that should have been included:** **United States Geological Survey [USGS], 1994, Bedrock Geology Map of Wyoming: Denver, Colorado, GIS data. Available on-line (last accessed 7/8/09): http://www.wygisc.uwyo.edu/geolibrary/.** **United States Bureau of Mines, 1990, Potential Exploitable Minerals Map: Denver, Colorado, GIS data. Available on-line (last accessed 7/8/09): http://www.wygisc.uwyo.edu/geolibrary/.**

			Wyoming State Geological Survey [WSGS], 1998, Surficial Geology Map of Wyoming: Laramie, Wyoming, Wyoming Geographic Information Systems [GIS] Center data. Available on-line (last accessed 7/8/09): http://www.wygisc.uwyo.edu/geolibrary/. **WSGS, 2004, Bedrock Geology Map of the Powder River Basin: Laramie, Wyoming, GIS Center data prepared for the Powder River Basin Project.**

Section	Map No.	Information Type	Errata Information
Appendix A	4	Surficial Geology (Map & Legend)	**Source: WSGS, 1998.**
Appendix A	5	Bedrock Geology (Map & Legend)	**Source: USGS, 1994.**
Appendix A	6	Bentonite Development Potential Areas	**Source: United States Bureau of Mines, 1990.**
Appendix A	7	Uranium Development Potential Areas	**Source: United States Bureau of Mines, 1990.**
Appendix A	8	Coal Development Potential Areas	**Source: United States Bureau of Mines, 1990.**
Appendix A	10	Major Sand and Gravel Deposits	**Source: WSGS, 1998.**
Appendix A	11	Gypsum Development Potential Areas	**Source: United States Bureau of Mines, 1990.**
Appendix A	12	Clinker Development Potential Areas	**Source: WSGS, 2004.**

Form 3060-1
(July 1984)
(Formerly 3980-1)

Serial Number

UNITED STATES
DEPARTMENT OF INTERIOR
BUREAU OF LAND MANAGEMENT

SOLID MINERAL OCCURRENCE AND DEVELOPMENT POTENTIAL REPORT

Lands Involved

Buffalo Resource Management Plan Revision
National System of Public Lands within the Buffalo Field Office
Campbell, Johnson, and Sheridan Counties, Wyoming;
782,102 Acres BLM-Administered Federal *Surface Lands*; and
4,803,277 Acres BLM-Administered Federal *Mineral Estate*.

Prepared By:

15 JUNE 2009

Matthew M.G. Shafer, WY PG-361 Date
Geologist – ICF International

Technical Approval by:

Gerald W. Queen 6/30/09

Gerald W Queen, CME66, WY PG-75 Date
BLM Buffalo Field Office Geologist

Management Acknowledgement by:

7/7/09

for Duane Spencer Date
BLM Buffalo Field Office Manager

EXECUTIVE SUMMARY

This Mineral Occurrence and Development Potential Report (Report) was prepared to support the process of revising the Resource Management Plan (RMP) for the Bureau of Land Management (BLM) Buffalo Field Office, Wyoming. The Buffalo planning area encompasses Campbell, Johnson, and Sheridan Counties, Wyoming. This Report provides an assessment of locatable, solid leasable, and salable minerals (mineral materials) within the Buffalo planning area as prescribed in BLM Manual 3031, Energy and Mineral Assessment (BLM, 1985a). Mineral potential classifications were not prepared and field studies were not performed in preparation of this document. Information provided in this Report will be incorporated into the RMP and the Environmental Impact Statement (EIS) for the RMP revision.

Oil, gas, and coalbed natural gas (CBNG) resources in the Buffalo planning area are addressed in the Reasonably Foreseeable Oil and Gas Development (RFD) Potential Report (currently under development) and the Summary of the Analysis of the Management Situation (AMS) (BLM, 2009c). As a result, these energy resources are not addressed in this Report.

This Report provides an understanding of solid mineral resources in the area and the importance of these resources in future land use decisions. This Report identifies solid mineral resource occurrence and development potential. Preparation for this Report involved reviewing published data and selecting internal data for use in this document. This Report is prepared for use in the preparation of the EIS and is required by the National Environmental Policy Act (NEPA) for revising the RMP.

The Buffalo planning area is divided into three regional geological features consisting of the eastern flank of the Big Horn Mountains, the northeastern part of the Casper Arch, and the western and central parts of the Powder River Basin.

The Buffalo Field Office manages approximately 782,102 acres of federal surface land and approximately 4,803,277 acres of federal mineral estate. There are approximately 2,418,761 acres of federal mineral ownership in Campbell County, 1,682,668 acres in Johnson County, and 701,848 acres in Sheridan County. Federal solid minerals within the Buffalo planning area are classified into three major categories: 1) Locatable minerals – bentonite, uranium, and gypsum; 2) Solid leasable minerals – coal; and 3) salable minerals (also referred to as mineral materials) – sand, gravel, clinker, moss rock, and building stone. This Report addresses solid mineral resource occurrences and reasonably foreseeable development potential of these minerals in the Buffalo planning area.

Future mineral development in the Buffalo planning area is influenced by a number of factors, including the price of commodities, management conflicts, laws, and regulations. With all commodities, whether they are locatable, solid leasable, or salable minerals, the level of potential for development can be difficult to predict, even with extensive geological studies.

In general, it is anticipated that as a result of the current global economic downturn, Powder River Basin coal production will decrease slightly for at least the remainder of 2009. Growth in coal production is predicted to resume during 2010 or 2011, and continue through 2020 (L. Jensen, oral commun., 2009). Current high and low coal production estimates for 2020 are 591 million tons and 508 million tons, respectively, most of which is within the Buffalo planning area (L. Jensen, oral commun., 2009).

While uranium production is not currently occurring in Campbell and Johnson Counties, the Wyoming 2007 Mineral and Energy Yearbook (Hoffman and others, 2007, p. 92-94) estimates that uranium production would reach 200,000 pounds for Campbell County and 100,000 pounds for Johnson County in 2009, and more than double for each of these counties by 2011. Although some production of uranium is probable, this forecasted production is not likely due to the lack of necessary plans, permits, and approvals from the BLM, Nuclear Regulatory Commission, and the Wyoming Department of Environmental Quality Land Quality Division, as well as current economic circumstances that are likely to result in a decreased demand for energy sources, including uranium.

Bentonite and uranium production is expected to increase during the next several years. There is only one gypsum claim in the planning area; production of gypsum from the planning area during the next several years is not anticipated.

Clinker, sand, and gravel demand is likely to remain stable, but is largely dependent on the growth of Wyoming's economy, particularly the local coal, and oil and gas industries. Growth in these industries would result in increased demand for sand, gravel, and clinker. To a lesser degree, the demand for sand, gravel, and clinker resources is dependent on state, municipal, and local population growth, which is expected to at least remain steady during coming years. No recommendations or stipulations for minerals management have been developed at this time. Appropriate recommendations relating to management of future mineral resource development within the Buffalo planning area will be developed during the RMP revision process.

EXECUTIVE SUMMARY **ES-1**

1.0 INTRODUCTION **1-1**
1.1 Purpose of Report 1-1
1.1.1 Terminology 1-1
1.1.2 Organization 1-2
1.2 Lands Involved and Record Data 1-2

2.0 GEOLOGY **2-1**
2.1 Physiography 2-2
2.2 Stratigraphy 2-5
2.3 Structural Geology and Tectonics 2-21
2.4 Geologic Hazards 2-21

3.0 DESCRIPTION OF MINERAL RESOURCES **3-1**
3.1 Locatable Minerals 3-2
3.1.1 Bentonite 3-6
3.1.2 Uranium 3-9
3.1.3 Gypsum 3-12
3.2 Solid Leasable Minerals 3-13
3.2.1 Coal 3-13
3.3 Salable Minerals 3-25
3.3.1 Aggregates (Sand and Gravel) 3-30
3.3.2 Clinker 3-31
3.3.3 Moss Rock and Building Stone 3-31
3.4 Abandoned Mines 3-32

4.0 MINERAL DEVELOPMENT POTENTIAL **4-1**
4.1 Locatable Minerals 4-1
4.1.1 Bentonite 4-1
4.1.2 Uranium 4-2
4.1.3 Gypsum 4-4
4.2 Solid Leasable Minerals 4-4
4.2.1 Coal 4-4
4.3 Salable Minerals 4-9
4.3.1 Sand and Gravel 4-10
4.3.2 Clinker 4-11
4.3.3 Moss Rock and Building Stone 4-11
4.4 Mineral Potential Summary 4-12

5.0 RECOMMENDATIONS **5-1**

6.0 REFERENCES **6-1**

APPENDIX A — MAPS

LIST OF FIGURES

Figure 2-1 Wyoming Physiographic Provinces 2-3

Figure 2-2 Stratigraphic Chart for the Powder River Basin 2-7

Figure 3-1 Wyoming Powder River Basin Coal Lease Status Map, as of August 2008 3-15

Figure 3-2 Primary Coal-Bearing Formations in Wyoming 3-21

LIST OF TABLES

Table 1-1 Federal Surface Lands and Federal Mineral Estate within the Buffalo Planning Area 1-3

Table 3-1 Annual Bentonite Production in the Buffalo Planning Area 3-8

Table 3-2 Current Authorized Bentonite Plans of Operations Within the Buffalo Planning Area 3-8

Table 3-3 Annual Uranium Production in the Buffalo Planning Area 3-11

Table 3-4 Current Authorized and Pending Uranium Plans of Operations Within the Buffalo Planning Area 3-12

Table 3-5 Wyoming Powder River Basin Coal Production in 2007 3-23

Table 3-6 Leased Federal Coal (acres) in the Buffalo Planning Area 3-23

Table 3-7 Powder River Basin Coal Production (in Millions of Tons) 3-24

Table 3-8 Powder River Basin Permitted Production Capacities During 2007 3-25

Table 3-9 Common Varieties of Mineral Materials 3-26

Table 3-10 Current Authorized Mineral Material Disposals Within the Buffalo Planning Area 3-26

Table 3-11 Mineral Material Disposals for the Buffalo Planning Area 3-29

Table 4-1 Buffalo Planning Area Bentonite Production 4-2

Table 4-2 Uranium Production Estimates for the Buffalo Planning Area 4-4

Table 4-3 Future Coal Leasing Requirements, Powder River Basin 4-6

Table 4-4 Coal Production Estimates for Campbell, Sheridan, and Converse Counties 4-8

Table 4-5 Drainages with Known Deposits of Sand and Gravel in the Buffalo Planning Area 4-11

ACRONYMS AND ABBREVIATIONS

>	Greater than
AML	Abandoned Mine Land
AMS	Analysis of the Management Situation
AMSCM	Abandoned Mine/Site Cleanup Module
ASTM	American Society for Testing and Materials
BLM	Bureau of Land Management
Btu	British Thermal Unit
CBNG	Coalbed natural gas
CFR	Code of Federal Regulations
CL	Clinker pit
CO_2	Carbon dioxide
CT	Contract
DEQ	Department of Environmental Quality
EIA	Energy Information Administration
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FCLAA	Federal Coal Leasing Amendments Act of 1976
FLPMA	Federal Land Policy and Management Act
FUP	Free Use Permit
GIS	Geographic information system
ISR	In-situ recovery
LBA	Lease by application
LLC	Limited Liability Company
MER	Maximum economic recovery
MMBtu	One thousand thousand British Thermal Units
MMS	Minerals Management Service
MOU	Memorandum of Understanding
NAAQS	National Ambient Air Quality Standards
NEPA	National Environmental Policy Act
NO_x	Nitrogen oxides
OSMRE	Office of Surface Mining Reclamation and Enforcement
PRRCT	Powder River Regional Coal Team
RFD	Reasonably Foreseeable Development
RMP	Resource Management Plan
S&G	Sand and gravel pit
SRHA	Stock Raising Homestead Act of 1916
SMCRA	Surface Mining Control and Reclamation Act of 1977
SO_2	Sulfur dioxide
U_3O_8	Triuranium octoxide
$\mu g/m^3$	micrograms per cubic meter
U.S.C.	United States Code
USGS	United States Geological Survey
WSGS	Wyoming State Geological Survey
WSA	Wilderness Study Area

1.0 INTRODUCTION

1.1 Purpose of Report

This Mineral Occurrence and Development Potential Report (Report) was prepared to support the process of revising the Resource Management Plan (RMP) for the Bureau of Land Management (BLM) Buffalo Field Office, Wyoming. This Report provides an assessment of locatable, solid leasable, and salable minerals (also known as mineral materials) within the Buffalo planning area as prescribed in BLM Manual 3031, Energy and Mineral Resource Assessment (BLM, 1985a). Information provided in this Report will be incorporated into the RMP and the Environmental Impact Statement (EIS) for the RMP revision.

Oil, gas, and coalbed natural gas (CBNG) resources in the Buffalo planning area are addressed in the Reasonably Foreseeable Development (RFD) Potential Report (currently under development) and the Summary of the Analysis of the Management Situation (AMS) (BLM, 2009c). Because mineral occurrence and development potential of these energy resources is addressed in other documents, these resources are not addressed in this Report.

The intent of this Report is to provide an understanding of the occurrence and development potential of locatable, solid leasable, and salable mineral resources that are present within the planning area (except for oil, gas, and CBNG as described above). Occurrence and the RFD potential of these resources are particularly useful as they apply to future land use decisions. Published data were reviewed and selected for use in this Report. This Report is for use in the preparation of the EIS and required by the National Environmental Policy Act (NEPA) for revising the RMP.

1.1.1 Terminology

This Report presents known and potential mineral occurrences and mineral deposits. According to the United States Geological Survey (USGS) (Cox and Singer, 1986) and BLM Manual 3031 (BLM, 1985a), occurrences, deposits, the potential for mineral resources, and mineral resource development potential are defined as follows:

- A "mineral occurrence" is a concentration of a mineral (usually, but not necessarily, considered in terms of some commodity, such as copper, barite, or gold) that is considered valuable by someone somewhere, or that is of scientific or technical interest (Cox and Singer, 1986). In rare instances (such as titanium in a rutile-bearing black sand), the commodity might not even be concentrated above its average crustal abundance.
- A "mineral deposit" is a mineral occurrence of sufficient size and grade that it might, under the most favorable of circumstances, be considered to have economic potential (Cox and Singer, 1986).
- An "ore deposit" is a mineral deposit that has been tested and is known to be of sufficient size, grade, and accessibility to be producible to yield a profit (Cox and Singer, 1986). In these days of controlled economies and integrated industries, the "profit"

decision may be based on considerations that extend far beyond the mine itself, in some instances relating to the overall health of the national economy.

- According to BLM Manual 3031, the potential for mineral resources is a prediction of the likelihood of the occurrence of these resources (BLM, 1985a). The occurrence of a mineral resource does not necessarily imply that the mineral can be economically exploited or is likely to be developed. The mineral occurrence potential includes undiscovered, minable or potentially minable occurrences. The potential for the occurrence of a mineral resource does not imply that the quality or quantity of the resource is known.
- Mineral resource development potential is a prediction of future mineral development. Future development potential is influenced by the price of commodities, management, laws, and regulations. With all commodities whether they are locatable, solid leasable, or salable, the level of resource potential can be difficult to predict, even with extensive geological studies.

1.1.2 Organization

This Report is organized into six chapters and an appendix. Chapter 2.0 summarizes the geology of the Buffalo planning area and, in particular, the Powder River Basin. This chapter is subdivided into separate discussions of physiography, stratigraphy, structural geology and tectonics, and geologic hazards. Chapter 3.0 addresses the occurrence of locatable, solid leasable, and salable mineral resources within the planning area, as well as abandoned mines. Chapter 4.0 discusses mineral development potential for locatable, solid leasable, and salable mineral resources within the planning area. Chapter 5.0 discusses the formation of recommendations regarding future development of locatable, solid leasable, and salable mineral resources for the planning area. Chapter 6.0 lists references used in development of the Report. Appendix A provides maps referenced in this Report.

1.2 Lands Involved and Record Data

Located within north-central Wyoming, the Buffalo planning area (**Map 1**) covers approximately 782,000 acres of public surface land and 4.8 million acres of federal mineral estate in three counties (**Table 1-1**). BLM-administered surface land in the planning area is in scattered tracts intermingled with state and private lands. The majority of the Buffalo planning area is located in the Powder River Basin, which is an asymmetrical synclinal basin covering northeastern Wyoming and extending into southeastern Montana. It is bordered by the Big Horn Mountains on the western boundary, by the Casper Arch, Laramie Range, and the Hartville Uplift on the southern boundary, and the Black Hills on the eastern boundary. The BLM-administered land in the area is managed by the BLM Buffalo Field Office.

Table 1-1. Federal Surface Lands and Federal Mineral Estate within the Buffalo Planning Area

County	Federal Surface Land (acres)	Federal Mineral Estate (acres)
Campbell	223,994	2,418,761
Johnson	504,325	1,682,668
Sheridan	53,724	701,848
Total	782,102	4,803,277

The Buffalo planning area consists of three dominant, regional geological features: the eastern flank of the Big Horn Mountains, the northeastern part of the Casper Arch, and the western and central portions of the Powder River Basin.

The majority of the surface land in the Buffalo planning area is privately owned. However, the majority of the mineral estate in the planning area is federally administered. Federal mineral estate can include all minerals in some locations and only specific minerals in other locations. This is partially due to the history of legislation governing federal surface and subsurface management in the region. While under the Enlarged Homestead Act of 1909, only coal resources were reserved by the federal government. The Stock Raising Homestead Act of 1916 reserved all minerals to the federal government, while still conveying the surface to private ownership. The Bankhead-Jones Farm Tenant Act of 1937 then brought some homesteaded surface land back to federal administration when many homesteads in the region failed during the Great Depression. As a result, split-estates (where the surface ownership is different than the mineral ownership) exist in a large portion of the Powder River Basin. Likewise, the administrative jurisdictions for land use planning and surface management of mineral resources are also varied and overlapping. Surface ownership within the Buffalo planning area is presented in **Map 2** and mineral ownership within the Buffalo planning area is presented on **Map 3**.

Information for this Report was obtained from the BLM, the Wyoming State Geological Survey (WSGS), the USGS, industry reports, Internet reports, and a variety of other sources identified in Chapter 6.

2.0 GEOLOGY

The majority of the Buffalo planning area falls within the Wyoming portion of the Powder River Basin. The Powder River Basin is an asymmetrical syncline that extends from northeastern Wyoming northward into southeastern Montana. In the Powder River Basin, thick sedimentary deposits overlie Precambrian crystalline basement rock. The deepest sediments in the Powder River Basin are found along its northwest-trending basin axis at a depth of approximately 18,000 feet below the surface (Geo/Resource Consultants, Inc., 1987, p. C-2).

The Powder River Basin formed at the same time the Big Horn Mountains and Black Hills were uplifted, from about 70 to 50 million years ago during the Laramide Orogeny. Regional compressive forces folded and deformed the rock layers into mountains and basins. Erosion shed sediments from the rising mountain areas into the low area in between; these sediments formed the Paleocene Fort Union Formation and Eocene Wasatch Formation (Whipkey and others, 1991, p. 15). The present elevation of the Powder River Basin in Wyoming is between approximately 4,000 and 6,000 feet above sea level (E. Heffern, written commun[s]., 2009). When originally deposited by ancient rivers that drained north and east into the Cannonball Sea in present-day North Dakota, the source of sediments that formed the Fort Union and Wasatch Formations were only slightly above sea level. During this time, the regional climate was tropical with high levels of rainfall causing large quantities of organic matter to grow and accumulate in extensive swamps (Flores and Bader, 1999, p. 9-13). The climate slowly cooled and became drier, and erosion of nearby mountains produced the sediments that buried this organic matter. Buried organic matter eventually transformed into coal, creating the large deposits found within the basin today. During late Eocene and Oligocene time, volcanic ash-rich sediments from the west, such as from the Absaroka volcanic complex in northwest Wyoming, further buried the basin, forming the Oligocene White River Formation, remnants of which cap the Pumpkin Buttes in southwest Campbell County. Over the past 10 million years, the thick sediments which buried the coal deposits slowly eroded, exposing coal near the surface.

Over the past few million years, exposed and near surface coal in many areas gradually burned. Heat from the burning coal baked, welded, and melted overlying sediments, which created reddish colored layers of clinker rock; the term “clinker” pertains to rocks that have been altered by heating from a coal bed fire. Clinker rocks cap many hills and plateaus in the Powder River Basin (Heffern and Coates, 2004, p. 25). The term “scoria” has become established in popular usage in the northern Great Plains. The term apparently was misapplied when the dark, bubbly, paralava was mistaken for volcanic rock, which clinker strongly resembles. For the purposes of this Report, the term clinker will be used.

The dominant exposed surface formations in the Powder River Basin are terrestrial sedimentary deposits from the Tertiary Paleocene Fort Union and Eocene Wasatch Formations. These two formations are as much as 4,000 feet thick along the basin axis. The underlying Cretaceous Lance, Fox Hills, Mesaverde, Cody Shale, and other formations are exposed along the upturned edges of the Powder River Basin. Older Mesozoic and Paleozoic sediments are buried beneath

these younger sediments. The Powder River Basin contains Quaternary-aged through Cambrian-aged sedimentary rocks, which include conglomerates, sandstones, siltstones, shales, coals, claystones, limestones, and dolomites. However, rocks of Devonian and Silurian age are absent.

The following sections describe physiography, stratigraphy, and structural geology and tectonics. Except where noted, information in the physiography and stratigraphy sections was obtained from the Geologic Atlas: Geologic Resource Inventory, Powder River Basin, Wyoming 1987 (Geo/Resource Consultants, Inc., 1987).

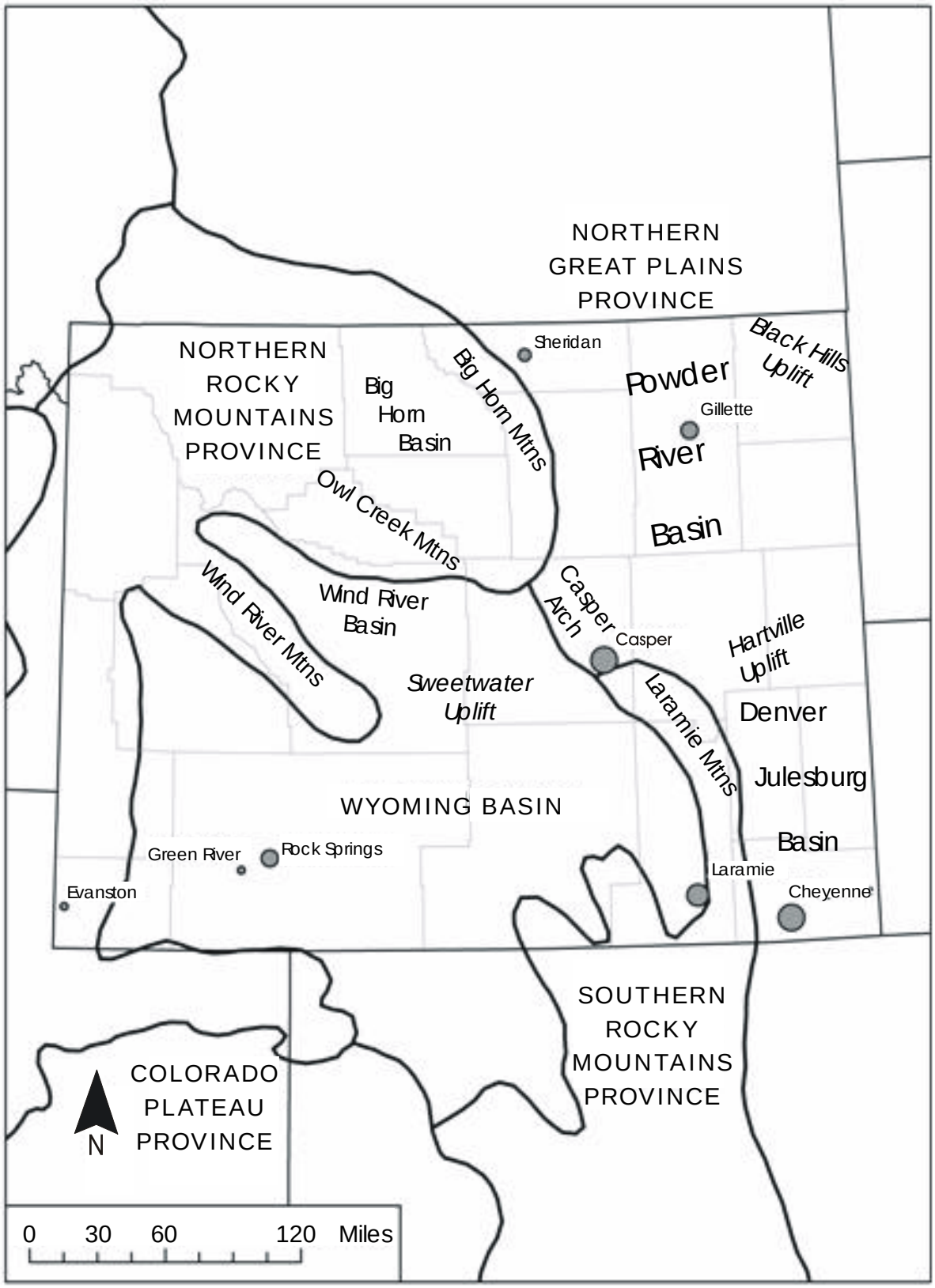
2.1 Physiography

The Buffalo planning area lies within the Northern Great Plains Province, east of the Northern Rocky Mountains Province. It is bordered by the Big Horn Mountains on the western boundary, by the Casper Arch, Laramie Range, and the Hartville Uplift on the southern boundary, and the Black Hills on the eastern boundary (**Figure 2-1**). These features were formed during the late Cretaceous and the early Tertiary Laramide Orogeny.

The landforms found in the Powder River Basin are primarily the result of geologic and climatic influences. The characteristic topographic features include steep-sided drainages, ridges, buttes, and local badlands. Topographic features generally are the result of:

- Differences in the erosional characteristics of Tertiary bedrock deposits, clinker, and alluvium;
- Downward and lateral (meandering) stream-cutting; and
- Minor subsidence of overlying rocks and sediment due to natural burning of underlying coal seams. Lake DeSmet, the only location in the Powder River Basin where this phenomenon has had a major impact on topography, occupies a basin formed by the natural burning of the 200-foot thick Healy coal zone (Mapel, 1959, p. 89).

The interior of the Powder River Basin is characterized by undulating to hilly topography that is the result of stream erosion. Tributaries of the Powder River have formed an intricate northwest-trending trellis drainage pattern. Hills and interstream divides with rounded to sharp slopes occur in much of the planning area. Less resistant rocks (for example, soft shale, claystone, and sandstone) were rapidly eroded resulting in dissected “badlands.” Flat terraces of old floodplain deposits are interspersed with more rounded, hilly areas and stream valleys, especially along the western margins of the Powder River Basin at the base of the Big Horn Mountains. Areas near the Big Horn Mountains along the western margin of the Powder River Basin are characterized by flat terraces of paleo-floodplain deposits and stream valleys interspersed with hilly areas. Terraces in these areas are formed by rock benches that have been covered with alluvial (stream deposited) material. These terraces parallel major drainages such as the Tongue River, Clear Creek, and Powder River. At present, minimal rainfall occurs in the Powder River Basin, due to the rain shadow effect from the Big Horn Mountains, resulting in a semiarid climate.



Source: Fenneman and Johnson, 1946; as modified by SAIC, 2004

Figure 2-1. Wyoming Physiographic Provinces

Geologic deposits found at the surface within the Powder River Basin can be divided into seven categories:

- **Alluvial** – These floodplain and terrace alluvial deposits generally consist of sand, silt, and clay containing pebbles of baked and fused rock, such as clinker. These deposits are generally found in large drainages, such as the Powder River, Little Powder River, Belle Fourche River, and Crazy Woman Creek. Floodplain material was deposited adjacent to stream channels during periods of flooding and is preserved as isolated terraces up to 15 feet above the stream bed.
- **Lacustrine (Lake)** – Gray clay and silt deposited in ephemeral lakes by wind and sheetwash are characteristic of lake deposits that accumulate in small, natural, closed depressions scattered throughout the planning area.
- **Eolian** – Eolian (windblown) deposits consist of sand and silt in dunes or irregular sheets that were eroded from poorly cemented sandstone outcrops and deposited downwind.
- **Mass Wasting** – Mass wasting deposits consist of loose and incoherent deposits of colluvium and landslide debris that commonly include sand and silt mixed with fragments of clinker. Colluvial deposits are composed of rocks and sediments that fell or slid down steep slopes flanking hills or plateaus and are often capped by more resistant clinker. This process may be on-going, as indicated by the lack of vegetation on cliffs and slopes.
- **Residual** – Weathered formations consist of sand and silt material containing variable amounts of clay forming flat to moderately steep, dissected terrain that covers a large portion of the planning area.
- **Clinker** – About 500 square miles of the Wyoming portion of the Powder River Basin are covered by clinker – baked, fused, and melted rock formed by natural burning of underlying coal beds and baking of overburden (Heffern and Coates, 2004, p. 31). The reddish clinker is more resistant than the surrounding sediments and commonly caps hills, plateaus, and ridges.
- **Bedrock Outcrops** – The bedrock deposits in the Powder River Basin are primarily sediments of the Eocene Wasatch Formation and Paleocene Fort Union Formation. These are largely layers of sandstone, siltstone, shale, and coal, with thin horizons of limestone, siderite nodules, and silcrete (E. Heffern, written commun[s]., 2009).

Much of the central portion of the Powder River Basin is a highly dissected plateau. In the eastern half of Johnson County, for example, uplands typically have several hundred feet of relief and are characterized by extensive badlands with numerous butte-like hills, capped by clinker, and steep valleys and gulches. The Rochelle Hills, located east of the coal mines near Gillette and Wright, is an extensive eastward-facing escarpment several hundred feet in height. The Rochelle Hills are capped by a layer of clinker as much as 200 feet thick that was formed by the natural burning of the Wyodak-Anderson coal zone during the last several hundred thousand years (Heffern and others, 2007). Steep, nearly barren badland terrain, deeply dissected by intermittent drainages is primarily found on the eastern side of the Powder River

south of Sussex, along the South Fork of the Powder River, and south and west of United States Highways 14 and 16 in northeastern Johnson County and western Campbell County.

The Pumpkin Buttes are prominent landmarks in the Powder River Basin, standing over 1,000 feet above the surrounding plains on a divide separating the Belle Fourche and Powder Rivers. The Buttes consist of five major flat-topped mesas and several smaller buttes (Sharp and others, 1964, p. 5). Slopes surrounding the buttes are covered by landslides and slumps, and alluvium and colluvium deeply dissected by gullies cover the base of these slopes.

2.2 Stratigraphy

Stratigraphy is the science of studying rock strata, particularly as it pertains to lithology, composition, mode of origin, and geologic history. Stratigraphy of the Powder River Basin is closely associated with contemporaneous structural and geologically historical events. Therefore, the following stratigraphic summary (presented from oldest to youngest) includes major structural and historical events that affected and/or resulted in current basin stratigraphy. A stratigraphic section for the Powder River Basin is provided in **Figure 2-2**. The major geologic formations occurring in the Powder River Basin, along with their sequences and ages of deposition, are shown in this figure and described in text.

Beginning with the Paleozoic Era, summary lithologic and stratigraphic information for the significant formations and associated members (as applicable) are provided below. Lithologic descriptions may include rock type, grain size, and rock color. Stratigraphic information may include information pertaining to depositional environments, extent, and average thickness.

<u>PRECAMBRIAN Era (>570 Million Years Ago)</u>

Precambrian rocks of the Big Horn Mountains and Black Hills are chiefly composed of Archean granitic and other plutonic, gneissic, and metamorphic rocks that were intruded by pyroxenite and diabase irregularily-shaped dikes and pegmatite masses having irregular shapes (Bureau of Land Management [BLM], 1992, p. 2). Radiometric ages of Precambrian rocks in the Laramie Range and Big Horn Mountains indicate silica and alumina rich granitic magma existed in the region about three billion years ago; at that time Wyoming was probably an extension of the Superior Province of Canada. The Precambrian history of the region is complex, but can generally be characterized as containing a series of northeast trending volcanic arc complexes followed by development of northeast trending faults. The entire area now covered by the Buffalo planning area was emergent at the end of the Precambrian, subjecting it to a period of extensive erosion and resulting in a major unconformity which separates the Precambrian rocks from overlying Paleozoic rocks.

<u>PALEOZOIC Era (570 – 240 Million Years Ago)</u>

Creation of the Cordilleran geosyncline is the result of a subduction zone that developed during the early Ordovician period along the western margin of the continent. Through the remainder of the Paleozoic, the Buffalo planning area was located on the craton near the edge of the Cordilleran miogeosyncline. This region was a part of the Pangaea Supercontinent, which was generally in an equatorial position, and experienced a period of relative quiet for the remainder

of the Paleozoic. Paleozoic units are typically sandstones, limestones, dolomites, and shales that were deposited during the numerous transgressions of the epicontinental seas. Interbedding and interfingering of rock types is common in these rock units as a result of numerous sea-level fluctuations during major transgressions and regressions. From oldest to youngest, the significant formations of the Paleozoic Era include:

Flathead Sandstone (Middle Cambrian)

The Flathead Sandstone is a pink, red to white, or gray fine sandstone. It is locally indurated to quartzite; iron oxide cementation and/or conglomeratic zones may also be present. In the Big Horn Mountains, the Flathead Sandstone is composed of three units: a lower sandstone, a middle shale, and an upper sandstone. The Flathead Sandstone is not exposed in the planning area, but crops out to the west, on the east flank of the Big Horn Mountains. The Flathead Formation generally thins to the south over the length of the Powder River Basin, from a thickness of 500 to 90 feet. The thickness varies due to an irregular Precambrian depositional surface. The Flathead is not found in the eastern part of the Powder River Basin. The contact between the Flathead Sandstone and the underlying Precambrian granitic and metamorphic rocks is unconformable.

Gallatin Formation (Upper Cambrian to Lower Ordovician)

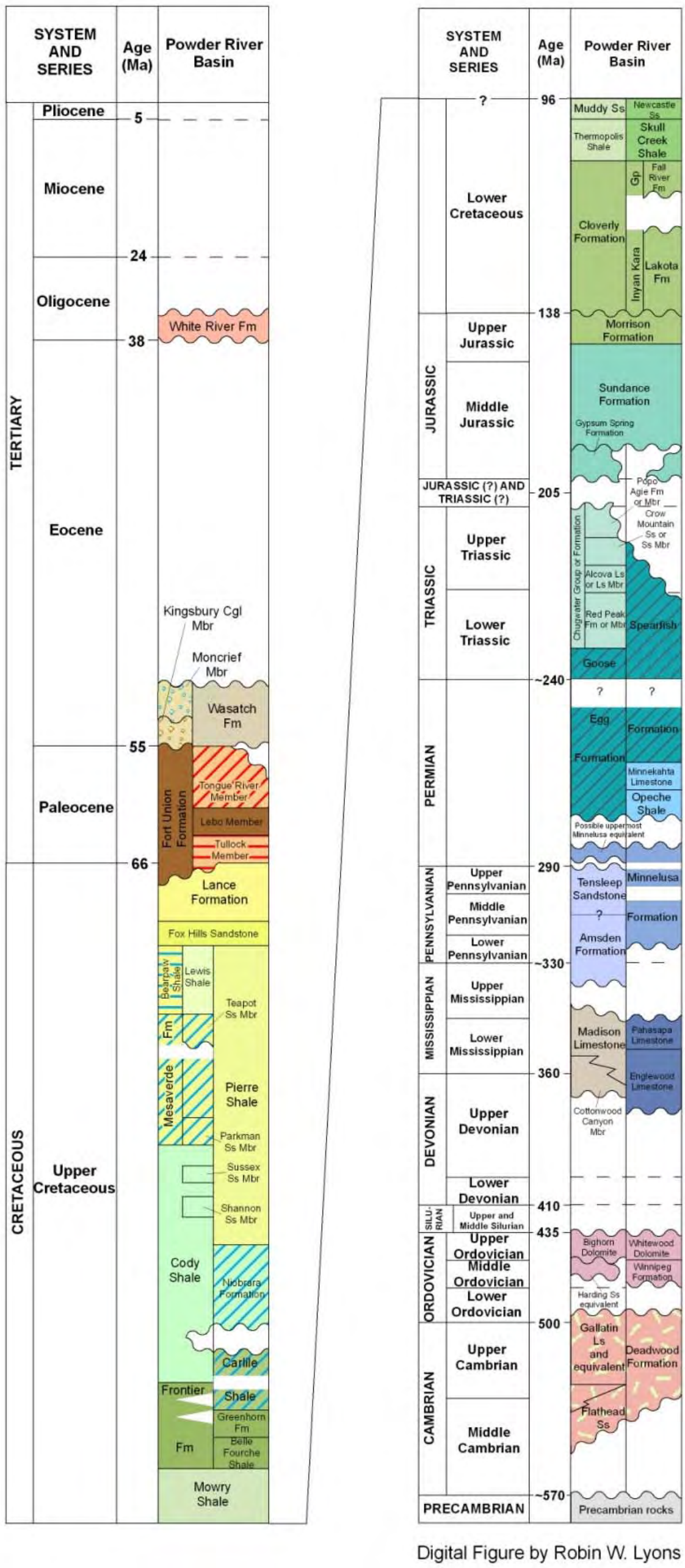
The Gallatin Formation is composed of three lithic units. At the base is a light gray fossiliferous limestone that has thin-to-flaggy bedding, which forms ridges where exposed. A limey-green shale unit overlies the basal limestone. The upper unit consists of gray-green shales and intraformational flat-pebble limestone conglomerates. Exposures of the Gallatin Formation are found in the Big Horn Mountains. The Gallatin is not present in the eastern portion of the Powder River Basin. Along the northwestern part of the Powder River Basin, the Gallatin Formation is 240 to 320 feet thick. The thickness of the lower unit is 160 to 200 feet, the middle unit is 20 to 60 feet thick, and the upper unit is 60 feet thick.

Deadwood Formation (Upper Cambrian)

The Deadwood Formation overlies eroded Precambrian schists or quartzites and is composed of a massive red-brown quartzite and sandstone unit at the top. A unit of sandstone and conglomerate is found at the base of the formation; this lower unit often contains gold. The Deadwood Formation is 350 to 400 feet thick in the Black Hills. The Deadwood Formation is found only in the northeastern portion of the Powder River Basin. As with the western units, the Deadwood Formation also thins to the south and pinches out.

Harding Sandstone Equivalent (Middle Ordovician)

The Harding Sandstone equivalent combined with the Lander Sandstone Member of the Bighorn Dolomite. The base of the Harding equivalent is an erosional unconformity and contains rock fragments of the underlying Cambrian in its lower portion. Above the base, the Harding Sandstone Equivalent is more argillaceous; a clean, yellowish sandstone containing fish fragments caps the unit. The Gallatin-Harding contact is a sharply defined unconformity; the Harding-Lander contact is also an unconformity. Red and white mottling indicates the top of the Harding equivalent below the unconformity with the Lander Sandstone Equivalent (Macke, 1993, p. 49).



Source: Love and others, 1993

Fm= Formation; Mbr=Member; Gp=Group; Ls=Limestone; Ss=Sandstone

Figure 2-2. Stratigraphic Chart for the Powder River Basin

Winnipeg Formation (Middle Ordovician)

The Winnipeg Formation represents the initial clastic deposits of the Middle Ordovician-Silurian sedimentary sequence. In the Big Horn Mountains, the Winnipeg Formation is primarily a sandstone, generally less than 50 feet thick. The Winnipeg Formation consists of three members: the Black Island, Icebox, and Roughlock. The sands that formed the Winnipeg Formation were derived primarily from a western source area (Macke, 1993, p. 49).

Bighorn Dolomite (Middle-Upper Ordovician)

For the Bighorn Dolomite, the basal sandstone unit is composed of yellow or pink fine-grained sandstones of the Lander Formation overlying gray medium- to coarse-grained sandstones of the Harding Sandstone. The Bighorn Dolomite is a massive gray to yellowish dolomite containing bands of chert nodules. Some beds are vuggy, with others being more coarsely crystalline or somewhat sandy. The upper portion of the Leigh Member is thin-bedded and locally cherty or brecciated. Overall, it is resistant and tends to form cliffs. On average, the Bighorn Dolomite is 250 to 300 feet thick. The Bighorn Dolomite pinches out near the Middle Fork of the Powder River.

Whitewood Dolomite (Middle-Upper Ordovician)

The Whitewood Dolomite is a fossiliferous, marine, buff to tawny dolomite with massive bedding. The upper contact of the Whitewood Dolomite is an unconformity with the Englewood Formation. The base of the Whitewood becomes increasingly silty and has a gradational contact with the underlying Roughlock Siltstone. On average, the Whitewood is approximately 50 feet thick and is only found in the eastern portion of the Powder River Basin.

Madison Limestone (Upper Ordovician to Upper Mississippian)

The Madison Limestone consists of white to grayish-brown limestone and dolomite. This unit is massive to thin-bedded and is cherty in places. Where exposed, its resistance to weathering results in prominent cliffs. The Madison is found in continuous outcrop along the east flank of the Big Horn Mountains. Its thickness ranges from 1,150 feet, near Sheridan, to 342 feet to the south and east and at the south end of the Big Horn Mountains. The Madison Limestone unconformably overlies the Bighorn Formation. At the southern end it is found disconformably overlying the Gallatin Formation. It also has an unconformable contact with the overlying Amsden Formation.

The Cottonwood Canyon Member of the Madison Limestone is an uppermost Devonian through Lower Mississippian limestone rock (Macke, 1993, p. 82).

Englewood Limestone (Devonian-Lower Mississippian)

The Englewood Limestone is composed of distinctive pink to red-purple calcareous shales and limestones. This unit unconformably overlies the Whitewood Dolomite. The Englewood has a gradational upper contact with the overlying Pahasapa Limestone Formation. The unit underlies the entire western Basin and ranges in thickness from 25 to 60 feet.

Pahapsa Limestone Formation (Lower Mississippian)

The Pahapsa Limestone was formed by normal marine carbonate deposition as a carbonate platform. This formation onlapped the sea shelf from the east and, most likely, from the north and west (Macke, 1993, p. 70).

Amsden Formation(Upper Mississippian to Middle Pennsylvanian))

The Lower-Pennsylvanian Amsden Formation is composed of red shales, red sandstone, or sandstone-limestone breccia and interbedded white, gray, or tan limestones. The limestones contain chert and dolomite, and the basal sandstone unit is light brown and cross-bedded. In the Sheridan area, this unit has been described primarily as dolomite with shale and sandstone interbeds. A thickness of 275 feet has been noted in the Sheridan area.

Tensleep Sandstone (Middle to Upper Pennsylvanian)

The Tensleep Sandstone is composed primarily of a series of cross-bedded sandstones. The tan to gray, fine- to medium-grained, massive to thick-bedded sandstone is interbedded with cherty dolomite, shale, anhydrite, and limestone. The Tensleep Sandstone covers a large part of the state, but crosses timelines and becomes progressively younger to the east. It is approximately 280 feet thick in the Buffalo area, and forms flatirons along the flanks of the Big Horn Mountains. It is unconformably overlain by the Goose Egg Formation.

Minnelusa Formation (Pennsylvanian-Lower Permian)

White to buff, very fine- to fine-grained, friable, hard subsaccharoidal sandstone, anhydrite, shale, and limestone make up the Minnelusa Formation. The sandstone is coarsely granular when weathered and shows local iron staining. Cryptocrystalline dolomite containing chert has been described in this unit. Underlying the eastern part of the Powder River Basin, the Minnelusa is an oil producer with no surficial exposures. This formation has been informally divided into the lower, middle, and upper units.

Goose Egg Formation (Middle Permian and Lower Triassic)

The Goose Egg Formation is found underlying the entire Powder River Basin and is composed of interbeds of red to ochre colored shales and siltstones; thin, pale-green, purple and gray limestones that are somewhat anhydritic or dolomitic; and light gray to white gypsum and limestone breccia. The average thickness of this formation throughout the basin is approximately 300 feet. In the western portion of the Powder River Basin the Goose Egg Formation unconformably overlies the Tensleep Sandstone, while in the eastern portion of the Powder River Basin the Goose Egg Formation has an unconformable contact with the underlying Minnelusa Formation. An uncomformity exists within the formation at the Permian-Triassic boundary. As discussed below, several members of the Goose Egg Formation cover only limited portions of the basin.

The Opeche Shale member of the Goose Egg Formation is composed of maroon, ochre, to deep purple shales, siltstones, and sandy shales. Red soft sandstone beds are found in the basal portion of the Opeche Shale. Locally thin interbeds of brown and white gypsum, anhydrite, and dolomite are present. The thickness of the Opeche Shale is approximately 130 feet near the

Black Hills and pinches out in the northwestern part of the Powder River Basin. The lower contact with the Tensleep is uncomformable.

The Minnekahta Limestone Member of the Goose Egg Formation varies from a dense, hard, thin-bedded gray limestone to a finely crystalline soft dolomite. Throughout the Powder River Basin, this member is anhydritic and locally dolomitic. The Minnekahta Limestone Member is the most extensive limestone member of the Goose Egg Formation, and some oil has been noted. The Minnekahta Limestone Member varies from 10 to 50 feet in thickness, thickening to the east and south.

Spearfish Formation (Permian to Triassic)

The Spearfish Formation is composed of red, sandy claystone, shale, siltstone, and sandstone, with gray gypsum and dolomite interbeds. The average thickness in the eastern part of the Powder River Basin is 450 feet, thickening to the west. The upper contact with the Gypsum Spring Formation is unconformable. Locally, where the Gypsum Spring Formation is absent, the Sundance Formation uncomformably overlies the Spearfish Formation.

MESOZOIC Era (240 – 66 Million Years Ago)

A period of relative tectonic inactivity that began in the Paleozoic lasted into the Mesozoic, at which time Pangaea began to breakup. The North American continent began to migrate north, and by the end of the Mesozoic Era it was located near its present latitude. During the Mesozoic, several orogenic disturbances occurred in the region, including thrusting that occurred in association with the Sevier Orogeny and resulted in development of the western Wyoming, Utah, and Idaho Thrust Belt. Clastic material was rapidly deposited during the Sevier Orogeny.

Geologic formations of the Mesozoic Era often have different names, but very similar lithologies as a result of deposition in a marine environment during numerous sea level fluctuations that occurred prior to the Laramide Orogeny. Sea level fluctuations continued throughout the Mesozoic with a widespread submergence occurring during the Cretaceous period. Therefore, Cretaceous-aged rocks primarily consist of marine shales with some interbedded sandstone units. Sedimentary formations such as the Lower Cretaceous Muddy Sandstone, and other Cretaceous units accumulated in shallow marine seas covering the present-day midcontinent region of North America. Marine organisms buried in the sediment during this time resulted in formation of oil and gas. Ash deposited from volcanoes to the west of the region fell into the marine seas and formed widespread layers of bentonite clay.

Toward the end of the Late Cretaceous, the Laramide Orogeny began. This orogeny occurred east of the Sevier Orogeny and was a time when compressional forces created mountains and basins, such as the Big Horn Mountains, Black Hills, and Powder River Basin. Several phases of deformation occurred, starting in the late Cretaceous period and continuing until the beginning of the Oligocene epoch and deposition of the White River Formation. With the onset of the Laramide Orogeny, a major change in the depositional environment occurred within the area now occupied by the Powder River Basin. Uplifts associated with this orogeny resulted in withdrawal of the shallow Cretaceous seas toward the east. Sediments shed from the rising Big

Horn Mountains, Black Hills, and Laramie Range filled the developing Powder River Basin at a time when the climate was much wetter than today (Whipkey and others, 1991, p. 1), creating an extensive flood plain and coal swamp environment. Uplifts of the Laramide Orogeny also exposed Precambrian rocks at high elevations as overlying sedimentary rocks were eroded away. For example, Precambrian igneous and metamorphic rocks are today exposed in the core of the Big Horn Mountains at 7,000 feet above sea level and higher. Uplifting and associated erosion resulted in some of the major unconformities in the rock record during the early to mid Cambrian, early Ordovician, Silurian, Devonian, late Mississippian, Triassic, and early to mid Jurassic periods. From oldest to youngest, the significant formations of the Mesozoic Era include:

Chugwater Formation (Triassic)

The undivided Chugwater Formation is composed primarily of a red siltstone with shale, sandstone, limestone, and gypsum interbeds. The sandstone is typically fine- to medium-grained, poorly sorted and cross-bedded. The Chugwater Formation is found in the western and southern parts of the Powder River Basin. A major unconformity exists between the youngest member of the Chugwater Formation, the Popo Agie, and the overlying Gypsum Spring or Sundance Formations. The lower part of the Chugwater or Red Peak Member is approximately equivalent to the Spearfish Formation in the eastern portion of the Powder River Basin. The maximum thickness is approximately 800 feet in the western part of the Powder River Basin.

The Red Peak Member of the Chugwater Formation is divisible into two units, with the lower unit consisting of siltstone interbedded with brown shale. The siltstone of the upper unit is orange to red, medium hard. The siltstone is calcareous and contains some white gypsum, anhydrite, and very fine-grained sandstone lenses. The maximum thickness of the Red Peak Member is 575 feet. Thickest in the west and southwest, this unit thins to the east. The upper contact with the Alcova Member may be an unconformity.

Composed of purplish-gray to cream-colored hard, dense, crenulated limestone, the Alcova Member of the Chugwater Fomation forms conspicuous ledges where exposed. Locally, it may be slightly sandy and soft. The maximum thickness of the Alcova Member is 20 feet, but it thins then pinches out to the northeast.

The Crow Mountain Sandstone Member of the Chugwater Formation is composed primarily of gray to orange and reddish-brown, very-fine to fine-grained, friable, calcareous sandstone that is poorly sorted with coarse-grained interbeds. Locally, the middle part of the Crow Mountain Sandstone is shaley or silty, and is often oil-stained or oil-saturated. The Crow Mountain Sandstone is difficult to distinguish from sandstone beds of the Red Peak Member when the Alcova Member is missing. In the Crazy Woman Creek area, the thickness of the Crow Mountain Member varies from 45 to over 100 feet. It thins to the north and east, and near Sheridan it is less than 25 feet thick. The Red Peak Member is found unconformably underlying this unit. A sharp unconformity is found at the upper contact of the Crow Mountain Sandstone with the Gypsum Spring Formation. Locally, the Popo Agie Member overlies the Crow Mountain Sandstone with probable unconformity.

The Popo Agie Member of the Chugwater Formation is composed of red to ochre-yellow oolitic and dolomitic claystone, interbedded with limestone pellet conglomerate and red to purple siltstone and shale. With a maximum thickness of 100 feet, this unit is found only in the extreme western portion of the basin. To the east, its absence is due to erosion or nondeposition. A sharp lithologic break exists between the Popo Agie Member and the Gypsum Spring Formation, described as both unconformable and conformable.

Gypsum Spring Formation (Middle Jurassic)

The Gypsum Spring Formation is primarily composed of massive gypsum and dolomite interbedded with soft red shale and siltstone. Locally, the gypsum beds grade laterally into dolomite and limestone. The Gypsum Spring Formation is generally disconformable with both the underlying Chugwater and Spearfish formations and the overlying Sundance Formation. Because the erosion surface at the top of the Spearfish Formation is somewhat irregular, the thickness of the Gypsum Spring Formation varies. Its maximum thickness is approximately 175 feet in the Sheridan area. This formation is found only in the northern portion of the basin and pinches out along an east-west line across the northern half of the Powder River Basin.

Sundance Formation (Middle Jurassic to Upper Jurassic)

The Lower Sundance Formation is typically composed of pink or gray sandstone with interbeds of gray to green shale and some oolitic limestone. Glauconitic green shale and shaley sandstone make up the majority of the Upper Sundance. A yellow to bluish-gray limey siltstone and sandstone is found within this unit. A sharp lithologic break has been noted between the Upper and Lower Sundance. The base of the Sundance Formation is generally unconformable with the underlying Gypsum Spring Formation. The thickness of the Sundance Formation ranges from 200 to 350 feet. In the Sheridan area, the Sundance Formation generally forms valleys below the Lakota (Cloverly) hogback, which has minor ridges of limestone and sandstone.

Morrison Formation (Upper Jurassic)

The Morrison Formation is typically composed of waxy-appearing variegated shales that are interbedded with sandstones and siltstones. In the lower portion of this formation, lenticular beds of limestone are present. The thickness of the Morrison Formation ranges from 21 to 200 feet.

Cloverly Formation (Lower Cretaceous)

The Cloverly Formation is composed of very light gray, thick-bedded to massive, crossbedded, lenticular sandstone. A gray shale has been described in the upper section of this formation, and thin coal beds are found locally. Thicknesses of the Cloverly Formation range from 100 to 165 feet in the northwestern portion of the basin. The Cloverly Formation is resistant to weathering, often forming hogbacks.

Inyan Kara Group (Lower Cretaceous)

Undivided, the Inyan Kara Group consists of discontinuous beds of sandstone, siltstone, claystone, sandy shale, and conglomerate with beds of lignite. A transgressive disconformity separates the two formations of the Inyan Kara Group. The contact with the underlying Morrison Formation is unconformable, although in places it may be gradational. The Skull Creek contact at the top of the Inyan Kara Group is conformable and gradational, varying from a relatively distinct contact to a zone of approximately 20 feet. No exposures of the Inyan Kara Group are found within the Buffalo planning area.

Lakota Formation (Lower Cretaceous)

The Lakota Formation is composed of massive, coarse-grained sandstone that is often cross-bedded. Generally, this unit becomes increasingly finer-grained upward and clay-shales have been observed near the top. Locally, this unit is conglomeratic or interbedded with shale and coal beds. The Lakota Formation locally fills depressions in the underlying eroded surface. The relationship between the Lakota and the Morrison formations is not clearly established. The the sandy beds of the lower part of the Lakota Formation transition to the shaley beds at the top. These shaley beds at the top of the Lakota Formation were at one time divided out into another member named the Fuson. A transgressive disconformity exists between the Lakota and the overlying Fall River Formation.

Fall River Formation (Lower Cretaceous)

The Fall River Formation is composed of fine-grained, quartz sandstone containing numerous interbeds of dark gray shale. This formation grades from marine to littoral to continental deposits from the west to the east. Ironstone concretions, ripple marks, trails, and burrows or castings are common in this formation. Some thin, low-grade coal beds are also found in this formation. The Fall River Formation ranges from 110 to 160 feet thick and is only found in the subsurface.

Thermopolis Shale (Lower Cretaceous)

The Thermopolis Shale unit is composed of dark gray and black shale that contains some lenticular sandstone beds. Occasional ironstone beds or concretions and bentonite beds occur. The Thermopolis Shale ranges in thickness from 135 to 700 feet.

Skull Creek Shale (Lower Cretaceous)

Dark gray to black shale makes up the Skull Creek Shale unit. A few thin interbeds of soft shale are present, as well as occasional rounded concretions. The lower portion consists of thin interbeds of siltstone and sandstone often referred to as the "Dakota Silt."

Muddy Sandstone (Lower Cretaceous)

The Muddy Sandstone consists of sandstone and some siltstone. It is white in outcrop and is occasionally glauconitic. Thicknesses range from 30 to 50 feet with local thicknesses up to 100 feet, varying due to the nature of the eroded surface of the underlying formation.

Mowry Shale (Upper Cretaceous)

The upper portion of the Mowry Shale is a hard, dark gray to black, fissile, siliceous shale that contains occasional sandstone and siltstone beds and numerous fossil fish scales. This shale weathers to a silvery gray color. The lower part is composed of black nonresistant shale, with numerous white to yellow bentonite beds. The upper portion of the Mowry Shale has a very conspicuous bentonite bed at the top of the unit, which has been called the Clay Spur Bentonite. Thickness varies from 200 to 500 feet.

Frontier Formation (Upper Cretaceous)

The lower part of the Frontier Formation is a sequence of interstratified shale, siltstone, sandstone, and bentonite thought to be of marine origin. A thickness of 835 feet occurs near Kaycee. The sandstones and shales of the Frontier Formation are laterally gradational. There is an unconformity within the Frontier Formation. The contact between the main part of the Frontier Formation and the Wall Creek Member is gradational.

Belle Fourche Shale (Upper Cretaceous)

The Belle Fourche Shale is composed of a gray to black shale with many bentonite beds and occasional ironstone concretions. It has a thickness of 565 feet in the northern Black Hills. The overlying Greenhorn Limestone interfingers with the Belle Fourche Shale.

Greenhorn Limestone (Upper Cretaceous)

The Greenhorn Limestone is composed of thin-bedded limestones, which are interbedded with thicker beds of light gray sandy shale and contain numerous calcareous concretions. Where exposed, this unit forms a prominent scarp. The overall composition of the Greenhorn Limestone varies over its extent from limestone to calcareous clay. This unit interfingers with the underlying Belle Fourche Shale. The limestone beds range from 3 to 12 inches thick; total thickness ranges from 136 to 360 feet.

Cody Shale (Upper Cretaceous)

The Cody Shale is composed of soft gray and brown shale. At the base is dark gray, silty shale that is approximately 185 feet thick. Overall, the Cody Shale is slightly calcareous, and contains calcareous concretions. Hydrocarbons are found in discontinuous laminations, and its maximum thickness is approximately 3,500 feet.

Carlile Shale (Upper Cretaceous)

The Carlile Shale is composed primarily of a noncalcareous, medium to dark gray shale that contains some calcareous concretions. A purple limestone and yellow sandstone occur at the top, and thin chalk beds have been noted in the area around Douglas, Wyoming. This formation is approximately 475 to 550 feet. In the west, it interfingers with overlying Niobrara Formation chalk. No exposures of the Carlile Shale or its members are found within the Powder River Basin.

Niobrara Formation (Upper Cretaceous)

Within the Powder River Basin, the Niobrara is composed primarily of gray shale containing thin, tan to white, calcareous lenses, which give it a speckled appearance. Thin bentonite beds are abundant. At the base, a zone of dark gray noncalcareous shale is present. The Niobrara Formation is found basinwide. In the northern Black Hills, the contact between the Sage Breaks (the uppermost member of the Carlile Shale) and the Niobrara Formation is disconformable. In the western part of the Powder River Basin, the Niobrara Formation has been described as indistinct and is included in the Cody Shale. In the Buffalo area it is 985 feet thick.

Steele Shale (Upper Cretaceous)

The Steele Shale is made up of dark shale with thin sandstone beds and numerous concretions. The Shannon Member has been identified to the eastern portion of the basin, while the Sussex Member appears only along the western and southern portions.

The Shannon Sandstone Member of the Steele Shale Formation is composed of a clean to argillaceous, thin-bedded, fine-grained silty sandstone interbedded with thin, dark gray shale partings. The sandstone is often glauconitic or cross-bedded and may contain claystone pebbles. The Shannon Sandstone Member thickens to the south and forms a north-south trending band approximately 20 miles wide. In the eastern part of the Powder River Basin, thin, silty shale is found, and surface exposures occur on the Salt Creek anticline. It has a thickness of 215 feet near Elgin Creek.

The Sussex Sandstone is composed of light greenish-gray, fine-grained glauconitic sandstone of marine origin, and this unit contains oil. Surface outcrops of the Sussex Sandstone are found about 10 miles south of the Sussex Oil Field on the east flank of the Salt Creek Anticline. In the subsurface, this unit can be traced along the western and southern margins of the Powder River Basin, while south of the Sussex Oil Field, it grades into siltstone and shale. The unit's thickness varies from less than a foot in the southwestern part of the Powder River Basin to more than 80 feet in the northeast.

Pierre Shale (Upper Cretaceous)

The Pierre Shale is found in the eastern part of the Powder River Basin, and both the Teapot and Parkman sandstones of the Mesaverde Formation interfinger with the Pierre to the west. Its thickness varies from 2,050 to 2,700 feet.

Mesaverde Formation (Upper Cretaceous)

The undivided Mesaverde Formation is composed of rocks of both marine and continental origin. Sandstones of the Mesaverde are massive to thin-bedded and soft, and are locally interbedded with shales or contain ironstone concretions. The shales are dark gray and contain calcareous concretions. Occasional, thin coal beds are found in these units. The oldest member, the Parkman Sandstone Member, has a transitional contact with the underlying Steele Shale. To the east, the members of the Mesaverde Formation, grade into the upper portion of the Pierre Shale. Total thickness of the formation ranges from approximately 500 to 1,500 feet.

Massive to thick-bedded, soft, buff-colored, medium-grained, cross-bedded sandstone of both marine and continental origin comprise the majority of the Parkman Sandstone Member of the Mesaverde Formation. Thin-bedded coal and carbonaceous gray shale and hard, dark limonitic concretions are found within this sandstone. To the east, the shale content of the Parkman Member increases. To the east, the Parkman Sandstone grades into siltstones and shales of the Pierre Shale. The thickness in the southwestern part of the Powder River Basin is approximately 500 feet, thickening to the north and west. It is found throughout the Powder River Basin.

Soft, gray, medium-grained, massive to thick-bedded, cross-bedded sandstone and carbonaceous shale make up the Teapot Sandstone Member of the Mesaverde Formation. Some coal beds are present. Over half of the Teapot Sandstone Member is nonmarine. The Teapot Sandstone Member gradually thickens from the northwest to the southwest in the Powder River Basin and grades laterally into the Pierre Shale in the eastern portion of the Powder River Basin, with the thickness averaging 50 feet.

The Bearpaw Shale Member is composed of dark green and gray shale with laminae of light green siltstone; calcareous concretions are numerous. The Bearpaw Shale Member is found along the western side of the Powder River Basin. The upper contact with the Fox Hills Sandstone is transitional. Near Sheridan, the Bearpaw Shale Member forms slopes and valleys between the more resistant Teapot Sandstone and the Lance Formation.

Lewis Formation (Upper Cretaceous)

The Lewis Formation consists of dark gray marine shale that has many thin beds of olive-green sandstone. Some calcareous concretions have been noted. Both the upper contact with the Fox Hills Sandstone and the lower contact with the Mesaverde Formation are transitional. It has a thickness of 1,150 feet in the southwestern portion of the Powder River Basin. The Teckla Sand Member is 112 feet thick and occurs in the middle portion of the Lewis Formation. The Kara Bentonitic Member of the Pierre Shale to the east forms the middle bed of the Teckla Sand Member.

Fox Hills Sandstone (Upper Cretaceous)

The Fox Hills Sandstone is generally composed of gray to rusty or yellow, fine-to medium-grained sandstone and sandy claystone. Typically, this marine unit is slightly calcareous to noncalcareous. Outcrops of the Fox Hills Sandstone are found along the margins of the Powder River Basin and are independently mapped only in the extreme northeast corner of the Powder River Basin and in the southern portion near Glenrock. The thickness of the Fox Hills Sandstone in the northern portion of the Powder River Basin is approximately 100 feet, thickening to approximately 300 feet in the southern portion of the Powder River Basin.

Lance Formation (Upper Cretaceous)

Continental deposits of buff to white, fine- to medium-grained, friable, calcareous sandstone, gray to black carbonaceous shale, and coal form the Lance Formation. Numerous large, hard, sandy concretions are found in the lower part of the formation, and bentonite beds are common. The Lance Formation ranges in thickness from 650 feet thick around the margins of

the basin to more than 3,000 feet thick in the central portion. The upper contact with the Fort Union is reported to be both unconformable and conformable, depending on location.

CENOZOIC Era (66 Million Years Ago – Present)

During the Tertiary period, the mountain ranges surrounding the Powder River Basin were the source of sedimentary deposits that formed the thick sequences found in the central portions of the Powder River Basin syncline. These ranges include the Big Horn Mountains, the Laramie Mountains and Hartville Uplift, and the Black Hills. The subsiding Powder River Basin gradually filled with fluvial, paludal, and lacustrine sediments. Extensive coal deposits, accumulated as peat swamps in many of these areas, were slowly buried (BLM, 2009c, p. 2-10).

Geologic formations of the Tertiary period include the Fort Union Formation and its members (the Tullock, the Lebo Shale, and the Tongue River for example) and the overlying, younger, Wasatch Formation (Lillegraven, 1993). Rock members of the Fort Union Formation were deposited in a swampy flood-plain environment during the Laramide Orogeny. Interbedding and interfingering of lithologic sequences is common in these rock units as a result of changing depocenters of swamps and lakes as the course of major rivers shifted over time (Flores and others, 1999, p. 5-6; Flores and Bader, 1999, p. 14; Jones, 2008, p. 49). Regional folding and faulting continued during the early Eocene epoch which caused erosion of adjacent uplifted bedrock. Development of the Laramide Orogeny continued into the early Eocene epoch and was largely responsible for ancestral development of present-day Powder River Basin geologic structures. The major uplifts in the region occurred during the late Cretaceous and resulted in development of the Big Horn Mountains, the Black Hills, and the Laramie Mountains. Development of these structures continued into the Eocene epoch. Conglomerates were deposited in alluvial fans along the east flank of the Big Horn Mountains which today form the Kingsbury Conglomerate and the Moncrief Members of the Wasatch Formation.

Volcanic activity during late Eocene and Oligocene time within the Yellowstone-Absaroka area and other areas west of the Powder River Basin resulted in the complete burial of the Laramide uplifts with sediments rich in volcanic ash by the mid Pliocene epoch. During this time, the extensive uranium deposits found in Wasatch Formation sandstones were formed along roll-fronts where uranium dissolved in groundwater precipitated due to reduction by carbon-rich sediment (Sharp and others, 1964, p. 6). The source of the uranium may have been in the volcanic ash or Precambrian rocks in surrounding uplifts such as the Laramie Range. Regional uplift occurred during the Miocene and Pliocene. Corresponding erosion of most of the post-Eocene rocks throughout the region exhumed structures of the Laramide Orogeny and contributed substantially to the area's present-day topography (Mears, 1993; Flanagan and Montagne, 1993). The warm-humid to arid-subtropical climate that existed during the early Cenozoic Era gradually gave way to extreme cold during the Pleistocene ice-age. Glaciation during the Pleistocene resulted in the development of U-shaped valleys, horns, cirques, and moraines in high elevations of the Big Horn Mountains.

Bedrock exposed at the surface of the Powder River Basin primarily consists of the early to mid Tertiary Fort Union and Wasatch Formations. Rocks of the Oligocene White River Formation cap the Pumpkin Buttes. These remnants were left after an extensive cycle of erosion. The

White River is the youngest bedrock formation within the Powder River Basin, not including the clinker and the unconsolidated alluvial surface deposits of the Quaternary that are found along drainages and that overlie Tertiary formations. The 1,600 square miles of clinker outcrops in the Powder River Basin (500 square miles in the Wyoming portion) formed during the past few million years as the downcutting Tongue and Powder Rivers and other tributaries of the Missouri River began exposing and burning the coal beds in the Wasatch and Fort Union formations (Heffern and Coates, 2004, p. 39). Due to the synclinal structure of the Powder River Basin, rock units deposited prior to the Tertiary are only exposed on the margins of the Powder River Basin. Geologic information including the distribution, lithology, and age relationships of surficial units within the Buffalo planning area is provided on **Map 4** and bedrock geology is shown on **Map 5**. From oldest to youngest, the significant formations of the Cenozoic Era include:

Fort Union Formation (Paleocene)

Overall the Fort Union Formation is composed of buff to gray sandstone interbedded with dark gray siltstone, claystone, shale, and coal. Because of the interbedded nature of the Fort Union Formation, it is often banded in appearance, and zones containing ironstone concretions are common. Outcrops of the Fort Union Formation are found in locations throughout the entire Powder River Basin, except between Buffalo and Banner, where it is buried or offset by faulting. The Tullock Member of the Fort Union Formation is only found in the northern portion of the Powder River Basin. The Lebo and Tongue River Members form the remainder of the outcrops. Total thickness of the Fort Union Formation ranges from 1,900 to 3,200 feet (Flores and Bader, 1999, p. 9).

Yellow, fine-grained, massive sandstone and shale make up the Tullock Member of the Fort Union Formation. These rocks are often calcareous and contain many thin lenticular coal seams. A thin sandstone bed marks the top of the Tullock Member at its contact with the overlying Lebo Shale. The Tullock Member has a thickness of as much as 740feet (Flores and Bader, 1999, p. 9).

The Lebo Shale Member of the Fort Union Formation is composed of gray shale with interbeds of yellow to gray, fine-grained, arkosic, lenticular, cross-bedded sandstone. Numerous ironstone concretions are present in some of the beds. Typically, this member is soft and easily erodible. Thin beds of coal are present, most less than 18 inches thick. The Lebo Shale Member varies in thickness from as much as 2,600 feet (Flores and Bader, 1999, p. 9). Typically, a resistant ledge formed by the lower unit of the Tongue River Member is found overlying the softer, more easily erodible Lebo Member.

The Tongue River Member is composed primarily of yellow or light-colored silty or carbonaceous shales interbedded with claystone. Some massive, fine-grained, cross-bedded sandstone and siltstone beds, which contain black to red-brown ironstone concretions, are present. Numerous coal and clinker beds are found in this member. In the Gillette area, fine-grained sandstone predominates over the siltstone, claystone, and shale; these sandstones are thin-bedded and have cross stratification or are ripple-laminated. Many mineable coal beds occur in the Tongue River Member, with thicknesses of 10 to 100 feet along strike. The net

thickness of this member is as much as 1,860 feet (Flores and Bader, 1999, p. 9). In the Gillette area, the thickness ranges from 500 to 800 feet. The maximum thickness of the Tongue River Member in the Powder River Basin is approximately 800 feet in the Sheridan-Buffalo area. The top of the Tongue River Member has been placed at the top of the Roland coal bed in the Sheridan coal field. However, since the Roland coal bed does not underlie the entire Powder River Basin, there is some difficulty in establishing the contact of the Tongue River Member with the overlying Wasatch Formation. The Fort Union-Wasatch contact may be an unconformity of regional extent that truncates the coal beds of the Fort Union Formation. The lower contact with the Lebo Shale is distinct. When exposed at the surface, the underlying Lebo Shale forms badlands that are capped by a resistant coal or clinker escarpment.

Wasatch Formation (Lower Eocene)

Overall, the Wasatch Formation is composed of variegated siltstone, shale, and claystone with interbeds of gray to light-brown lenticular, cross-bedded sandstone of continental origin. This sandstone is locally conglomeratic. Numerous subbituminous and lignitic coal beds and carbonaceous shale beds are present. Locally resistant baked and fused beds are present. As a whole, the Wasatch Formation is noncalcareous. The Wasatch Formation covers almost the entire Powder River Basin. The maximum thickness is approximately 3,500 feet, but in places it is substantially thinner. The upper contact of the Wasatch Formation with the White River Formation is unconformable with a gap in time spanning the Upper Eocene.

Pebbles and boulders derived from the Paleozoic-aged rocks in the Big Horn Mountains make up the Kingsbury Conglomerate member of the Wasatch Formation. Occasional interbeds of green to yellow clays may be present. To the east, this unit grades into a sequence of sandstone, shale, and coal.

The Moncrief Gravel Member of the Wasatch Formation is composed of boulders with arkosic sandstone beds and gravels derived from Precambrian granitics. Locally, this member lies unconformably over the Kingsbury Conglomerate and grades eastward into finer sediments.

White River Formation (Oligocene)

The White River Formation is divided into two facies. The lower portion is composed of tan to gray, coarse-grained, hard, siliceous sandstone and lenticular, arkosic conglomerate that tends to form a caprock. White or pink to gray, blocky, bentonitic claystone that is somewhat tuffaceous makes up the upper portion. This is the uppermost Tertiary unit found in the Powder River Basin. The majority of the Powder River Basin may have been covered at one time with the White River Formation, but most has been removed by erosion. It is found in only a few places within the Powder River Basin, such as the central portion of the basin where it caps the Pumpkin Buttes, and in the south. Where exposed at the Pumpkin Buttes, this formation is 50 feet thick. The contact between the White River Formation and the underlying Wasatch Formation is unconformable.

2.3 Structural Geology and Tectonics

The three major structural features found in the Buffalo planning area include the Casper Arch, the eastern slope of the Big Horn Mountains, and the Powder River Basin (BLM, 1992, p. 1). The Powder River Basin is asymmetrical, with the axis near the western edge, just east of Sheridan and Buffalo, parallel to the front of the Big Horn Mountains. The western limb dips steeply to the east, while the eastern limb dips gently to the west. Mountain building and basin development was caused by Laramide compressional forces in the western United States during late Cretaceous and early Tertiary time.

During Tertiary deposition, the surficial axis of the Powder River Basin was offset eastward relative to the position of the structural axis on the Precambrian basement. The present surficial axis currently lies several miles east of the basement axis and is the result of regional tilting of the basin during the early Tertiary, resulting in increasing basin asymmetry at depth. Also in the Tertiary, east-northeast trending echelon faults with vertical displacements up to a few hundred feet developed along the east-west trending, left-lateral Nye-Bowler shear zone near the Montana-Wyoming state line. These faults offset Fort Union Formation and Wasatch Formation coal beds north and east of Sheridan. The Casper Arch is a northwest trending uplift bordering the southwestern boundary of the Powder River Basin and the southeastern boundary of the Big Horn Mountains and consists of mostly Mesozoic and Paleozoic deposits. This arch separates the Powder River Basin from the Wind River Basin. As the relatively undisturbed and gently dipping sediments from the Powder River Basin approach the arch, they develop into a large drape fold (BLM, 1992, p. 1).

Structurally, the Big Horn Mountains have been classified as a large box fold which forms a north-south trending uplift. The fold is characterized by relatively flat lying Paleozoic rocks, capping sections of the Big Horn Mountains and flanked on the eastern margin by moderately to steeply dipping or overturned beds (Geo/Resource Consultants, Inc., 1987, p. E.2.2-1). Block faulting of Precambrian basement rock during the early Tertiary resulted in the Big Horn Mountains that create the western border of the Powder River Basin. At approximately the same time, Paleozoic and Mesozoic sedimentary rocks were drapefolded over Precambrian blocks. Drapefolding is produced in layered rocks by movement of an underlying brittle block at high angles to the layering.

2.4 Geologic Hazards

Geologic hazards, or geohazards, include coal fires, landslides, and active fault or seismic zones that are generally identified and forecast through the earthquake and landslide hazard programs of the United States Geological Survey (USGS).

Coal bed fires pose a hazard to the public in the Buffalo planning area. Coal fires can be either natural or manmade. Natural fires in the Powder River Basin commonly occur after range and forest fires, as well as from lightning strikes and spontaneous combustion. Range fires north of Gillette in 2002 caused sixty coal fires, which naturally diminished or were extinguished by the BLM and the Campbell County Fire Department during the next winter and spring (Heffern and Coates, 2004, p. 43). Juniper and pine trees rooted in coal beds burned, and the smoldering

roots set fire to the coal beds. Human-caused coal fires are most common in the Tongue River Valley north of Sheridan, where massive subsidence from abandoned coal mines has caused air to circulate in the old mine workings and oxidation to provide conditions suitable for spontaneous combustion of the remaining coal. Underground room-and-pillar mining during the first half of the twentieth century near the old mining town of Acme has caused subsidence of the mined out areas between the pillars and led to ignition of the remaining pillars on a sporadic basis (Dunrud and Osterwald, 1980, p. 14). The Wyoming Department of Environmental Quality Abandoned Mine Land Division has had several projects over the past twenty years to extinguish or control these fires. Active coal fires on and encroaching on the Welch Ranch recreational property along the Tongue River north of Sheridan, Wyoming that the BLM acquired in 2004 pose a safety hazard; these hazards require mitigation and the development of a management plan (E. Heffern, written commun[s]., 2009).

Within the planning area, both naturally occurring and human-induced earthquakes have been recorded. Nearly all naturally occurring earthquakes in the Powder River Basin have been recorded in the western half of the basin, where sedimentary rocks are thickest and geologic structures are the most prominent (Geo/Resource Consultants, Inc., 1987). Many seismic disturbances have occurred in the vicinity of the Big Horn Mountains to the west and in the Laramie Mountains to the south. Human-induced earthquakes have occurred as a result of coal mine subsidence and mining activities, such as blasting (Geo/Resource Consultants, Inc., 1987, p.N.2.1-1).

The region that includes eastern Wyoming and the western portions of South Dakota and Nebraska is generally considered to have minor earthquake potential due to widespread and erratic distribution of seismic events, the lack of data associating earthquake activity to geologic structures, and incomplete intensity data. Based on historical seismicity data in this region it is classified as having an intensity value of VII (based on the Modified Mercalli Intensity Scale) (Geo/Resource Consultants, Inc., 1987, p.N.2.1-1). Damage resulting from an earthquake of intensity VII is expected to be negligible to buildings of good design and construction, but could result in considerable impacts to poorly built or designed structures.

The strongest earthquake in the region during modern times occurred near Casper, Wyoming on November 14, 1897. At its epicenter, the earthquake was rated with a maximum intensity of VI-VII on the Modified Mercalli Intensity Scale. The body-wave magnitude (Richter Scale) was estimated between 5.5 and 6.0. Another strong earthquake of similar intensity occurred on March 28, 1964, near Merriman, Nebraska, and was felt over an area of 90,000 square miles (Geo/Resource Consultants, Inc., 1987, p.N.2.1-1). Instrument data collected since 1954 has identified numerous earthquakes; several of which have produced ground shaking felt in various populated areas of eastern Wyoming and neighboring areas of Montana, South Dakota, Nebraska, and Colorado.

3.0 DESCRIPTION OF MINERAL RESOURCES

Minerals within the Buffalo planning area are classified into three major categories: locatable minerals (such as bentonite, uranium and other metals, and gems); leasable minerals (such as oil, gas, and coal); and salable minerals (such as common varieties of sand, stone, gravel, clinker, and common clay), also referred to as mineral materials. This classification system is based on several laws, beginning with the General Mining Law of 1872, which allowed the location of placer and lode mining claims as well as patents. This law declared, "all valuable mineral deposits in lands belonging to the United States … to be free and open to exploration and purchase." Federal regulations further defined a "locatable mineral" or a "valuable mineral" as being whatever is recognized as a mineral by the standard authorities, and being found on public lands in quantity and quality sufficient to render the lands valuable. The law encourages mining companies to initiate exploration and development, stating that "all valuable mineral deposits in lands belonging to the United States, both surveyed and unsurveyed, [are] to be free and open to exploration and purchase" (30 United States Code [U.S.C.] 22). The disposal of salable minerals and the location of mining claims and subsequent development on federal land are authorized by various Congressional Acts and regulated by the Code of Federal Regulations (CFR).

The principal regulations governing mineral activity in the Buffalo planning area include:

- *General Mining Law of 1872*. This law allowed the location of placer and lode mining claims as well as patents, declaring "all valuable mineral deposits in lands belonging to the United States … to be free and open to exploration and purchase."
- *Mineral Leasing Act of 1920* (as amended). Under this act, the Bureau of Land Management (BLM) issues leases for development of oil and gas, deposits of coal, phosphate, potash, sodium, sulfur and other leasable minerals on public domain lands and on lands having federal reserved minerals.
- *Materials Act of 1947* (as amended by the Surface Resources Act of 1955). Under this act, certain mineral and vegetative materials may be disposed of either through a contract of sale or a free-use permit (FUP). These mineral materials include common varieties of sand, stone, gravel, pumice, pumicite, clinker, and clay. The act also provides for free use of material by government agencies, municipalities, or non-profit organizations if not used for commercial purposes.
- *Surface Resources Act of July 23, 1955*. This act removed sand, gravel, cinders, pumice, pumicite, and clay from locatable mineral classification unless they have some type of uncommon characteristic.
- *Petrified Wood Act of 1962.* This act provides for free collection of limited amounts of petrified wood by the public and for sale of larger quantities for commercial purposes.
- *Mineral Leasing Act for Acquired Lands of 1947* (as amended). This act authorizes and governs mineral leasing on acquired lands. It provides that minerals on acquired federal lands are subject to the federal mineral leasing system, even though the commodity may be locatable or salable on lands retained by the federal government.

- *Mining and Minerals Policy Act of 1970.* This act identifies the continuing federal policy to foster and encourage private enterprise in the development of a stable domestic minerals industry and the orderly and economic development of domestic mineral resources.
- *Federal Coal Leasing Amendments Act of 1976 (FCLAA).* This act amended Section 2 of the Mineral Leasing Act of 1920 to require that all public lands available for coal leasing be offered competitively. Competitive leasing provides an opportunity for any qualified interested party to competitively bid for a federal coal lease.
- *Surface Mining Control and Reclamation Act of 1977 (SMCRA)*. This act requires reclamation of surface coal mining operations, imposes bonding requirements, and sets up the United States Office of Surface Mining to oversee reclamation.

Most of the Buffalo planning area is located in the Wyoming portion of the Powder River Basin, which is an energy development area. The Powder River Basin is the largest coal-producing region in the United States and also produces large quantities of oil and natural gas used to generate electricity both within and outside the region. Petroleum and natural gas are addressed in two other reports: the Reasonably Foreseeable Development (RFD) Potential for Oil and Gas and the Summary of the Analysis of the Management Situation (AMS) (BLM, 2009c). Coal is the only leasable mineral occurring in the Buffalo planning area addressed in this Report.

Locatable mineral deposits within the Buffalo planning area consist of bentonite, gypsum, and uranium. Mineral materials in the Buffalo planning area include sand, gravel, clinker, moss rock (a type of decorative stone), and flagstone.

The following sections provide a description of the solid leasable, locatable, and salable minerals in the Buffalo planning area. Each mineral resource is addressed individually in accordance with BLM Manual 3031, Energy and Mineral Resource Assessment (BLM, 1985a).

3.1 Locatable Minerals

Locatable minerals (both metallic and nonmetallic) are those that are open to mining claim location under the General Mining Law of 1872, as amended (30 United States Code [USC] 22-54 and 611-615). This law governs locatable minerals and other mineral activity in the Buffalo planning area. It provides authorization for the exclusive right of possession and use of the surface for locatable mineral development as defined by the type of deposit, including lodes, ledges, veins, or placers with the valid ownership of the mining claim. Claim holders must pay an annual maintenance fee of $125 to the BLM (43 CFR 3430-3436). Small miners (those holding no more than a total of ten mining claims and sites nationwide) are eligible for a waiver of this fee, provided a minimum of $100 worth of assessment work is completed on each claim. Claimants in active military service, those reclaiming their mining claims or sites, and those who have been denied access to their claim or site by a federal agency can also receive maintenance fee waivers subject to the requirements in 43 CFR 3835. If these conditions are not met, the claim or mine will be declared null and void and open to relocation. The law also has provisions for the mining claimant to obtain a patent on each claim where a valuable mineral deposit has

been discovered and $500 has been expended for labor or improvements. The patent provision of the General Mining Law of 1872 has been under a moratorium by Congress since 1993.

Exploration, mining, and reclamation activities on public lands administered by the BLM are authorized by the General Mining Law of 1872, as amended, as well as by sections 302(b) and 603[c] of Federal Land Policy and Management Act (FLPMA) (43 USC 1732[b]); surface management of such activities is regulated by the BLM under 43 CFR 3802 and 43 CFR 3809. With regard to land where the BLM manages the surface, all locatable mineral exploration activities that disturb five acres or less of the surface of mining claims occurring outside Wilderness Study Areas (WSA) require notice, according to 43 CFR 3809.21. Exploration covering more than five acres, exploration of five acres or less in a WSA and other special status areas, and all mining operations regardless of acreage require BLM approval of a Plan Of Operations (43 CFR 3809.10 and 11), National Environmental Policy Act (NEPA) analysis (43 CFR 3809.411), and a financial guarantee (43 CFR 3809.551) before those activities may proceed.

Much of the Buffalo planning area, especially in the Powder River Basin, is split-estate where the federal government retained the right to all minerals (including locatable minerals) under the Stock Raising Homestead Act of 1916 (SRHA). On these split-estate lands, the claimant does not have to file a Plan of Operations if they obtain written consent to mine from the surface owner (43 CFR 3809.31(d) and 3814). On SRHA lands, the claimant is required to file a Notice of Intent to Locate with the BLM and serve a copy on the surface owner (43 CFR 3838). The necessary authorizations and approvals are obtained through the administratively responsible BLM field office and the BLM Wyoming State Office.

The locatable minerals program and associated mining claims are regulated by 43 CFR 3800. Guidance and requirements described in these regulations include:

- Mining claims under the General Mining Law of 1872;
- Lands and minerals subject to location;
- Areas subject to special mining laws;
- Location of mining claims;
- Nature and class of mining claims;
- Assessment work;
- Mineral patent applications; and
- Adverse claims, protest, and conflicts.

Development is subject to the regulations contained in 43 CFR 3809 and 43 CFR 3802. In addition, BLM Manuals 3802, 3809, 3810, 3820, 3830, 3840, 3850, 3860, 3870, and 3890 provide guidance on BLM policy in accordance with 43 CFR 3800.

Mineral prospecting and claim location can take place only on lands open to mineral entry. Claims may not be staked in areas closed to mineral entry by a special act of Congress, Executive Order, regulation, or public land order. These areas are withdrawn from the operation of the mining laws. A mining claim is a parcel of federal land valuable for a specific mineral deposit or deposits. It is a parcel for which an individual has asserted a right of

possession. This right is restricted to the extraction and development of a mineral deposit as regulated by the BLM or the United States Forest Service. The rights granted by a mining claim are valid against a challenge by the United States and other claimants only after the discovery of a valuable mineral deposit. A mining claim is referred to as a lode claim if mineralization occurs as a vein of ore in place or as a placer claim if minerals are dispersed among particles of sand or gravel and transported from the point of origin. A mill site claim is used to process locatable minerals on lands that are generally non-mineral in character.

All necessary permits and approvals must be obtained before mining can begin. The BLM has developed regulations to protect the surface resources of the federal lands during exploration and mining activities. A Notice or a Plan of Operations must be submitted before conducting any surface-disturbing activities, except for casual use activities as defined in 43 CFR 3809. Once exploration or mining has commenced, compliance is required to assure no unnecessary, or undue degradation occurs on BLM-administered land, and that the project is in compliance with any other terms of the Plan of Operations, when applicable. The BLM in Wyoming has a statewide Memorandum of Understanding (MOU), signed in 2003, with the Wyoming Department of Environmental Quality (DEQ) Land Quality Division, for management of surface mining and exploration of locatable minerals on public lands. The MOU sets out procedures for joint inspections and bonding for reclamation, as well as general coordination of responsibilities. Compliance is determined concurrently by the BLM and the Wyoming DEQ Land Quality Division for all locatable minerals. For uranium, the United States Nuclear Regulatory Commission is also involved in licensing and reclamation requirements (for some uranium operations), in addition to the BLM and Wyoming DEQ. These responsibilities are established through various regulations and MOUs.

There are three levels of use defined in 43 CFR 3809 for locatable minerals: casual use, notice level, and plan of operations level. These are described below.

1. Casual Use (as defined in 43 CFR 3809.5) – Activities ordinarily resulting in no or negligible disturbance of the public lands or resources. Casual use generally includes the collection of geochemical, rock, soil, or mineral specimens using hand tools; hand panning; or non-motorized sluicing. It may include use of small portable suction dredges. It also generally includes use of metal detectors, gold spears and other battery-operated devices for sensing the presence of minerals, and hand and battery-operated dry washers. Operators may use motorized vehicles for casual use activities provided the use is consistent with the regulations governing such use as defined in 43 CFR 8340, off-road vehicle use designations contained in BLM land-use plans, and the terms of temporary closures ordered by the BLM. Casual use does not include use of mechanized earth-moving equipment, truck-mounted drilling equipment, motorized vehicles in areas when designated as closed to off-road vehicles as defined in 43 CFR 8340.0–5, chemicals, or explosives. It also does not include “occupancy” as defined in 43 CFR 3715.0–5 or operations in areas where the cumulative effects of the activities result in more than negligible disturbance.

2. Notice Level Activity – A Notice must be submitted 15 calendar days before commencing exploration activities that would cause up to five acres of surface disturbance on the public lands, or remove up to 1,000 tons of presumed ore for testing, on which reclamation has not been completed. A project area cannot be segmented by filing a series of notices for the purpose of avoiding filing a Plan of Operations. While the BLM does not approve a Notice, it may notify the operator of certain additional requirements.
3. Plan of Operations Level Activity – A Plan of Operations must be submitted for approval by the BLM before beginning operations greater than a casual use, or Notice-level activity. A Plan of Operations is required to be submitted and approved prior to actual mining operations on a mining claim intended to produce minerals for commercial use, even if the disturbance is anticipated to be less than five acres. A Plan of Operations must be submitted to conduct any bulk sampling in which 1,000 tons or more of presumed ore would be removed for testing.

Unless formally withdrawn from mineral location, all lands in the Buffalo planning area, including federally-administered surface/minerals and split-estate, are open to exploration, location, and development of locatable minerals. In order to explore and develop locatable minerals (excluding casual use), a Notice or a Plan of Operations is required (depending on the amount of disturbance and type of activity). All locatable mineral actions are reviewed to ensure compliance with the bonding policy for surface-disturbing activities (BLM, 2001a, p. 12).

The following areas within the Buffalo planning area are not open to location and mineral development:

- Fortification Creek WSA – This 12,419 acre WSA is located in northeastern Johnson County and northwestern Campbell County. Clinker may be present in the eastern portions of the WSA. However, adequate quantities of these minerals are available outside the WSA.
- Gardner Mountain WSA – This 6,423 acre WSA is located in southwestern Johnson County in the southern Big Horn Mountains. Moss rock/building stone are the only known minerals within this WSA.
- North Fork WSA – The 10,089 acre North Fork WSA is also located in southwestern Johnson County in the southern Big Horn Mountains. Moss rock/building stone are the only known minerals within this WSA.

The Amsden Creek winter game range (480 acres) has also been withdrawn from mineral location.

Notices or Plans of Operations have been filed in accordance with 43 CFR 3809 within the Buffalo planning area. Management of the locatable minerals programs in the Buffalo Field Office is performed in compliance with the Buffalo Resource Management Plan (RMP), which was approved and signed on October 4, 1985 (BLM, 1985b).

The only locatable minerals that currently occur in commercial quantities within the Buffalo planning area are bentonite, uranium, and gypsum; bentonite is the only locatable mineral

currently being mined. Uranium deposits are found in southeastern Johnson and southwestern Campbell Counties. Bentonite and gypsum are found along the western Powder River Basin margins near the base of the Big Horn Mountains in southern Johnson County.

Though exploration in the planning area has been minimal, the position of the Buffalo planning area within the thermally stable Archean Wyoming craton suggests the potential for the occurrence of diamonds and their kimberlitic host rocks. However, there are no known diamond deposits on BLM-administered land in the planning area, though microdiamonds were reported by the United States Geological Survey (USGS) from a coal seam near Gillette (Hausel, 1998). The base and precious lode metals such as gold, silver, platinum, and copper are not currently known to occur in commercial quantities in the Buffalo planning area.

Limestone has many industrial and construction uses. Some varieties of limestone, such as metallurgical grade limestone, may be classified as a locatable mineral. Metallurgical grade limestone is a relatively high grade of limestone used as blast-furnace flux in the conversion of iron ore into pig iron, furnace lining in the manufacture of steel, lime burning, and chemical manufacture. There are no known metallurgical limestone deposits in the Powder River Basin. Because metallurgical limestone deposits are not present on BLM-administered land, this type of limestone is not addressed further in this Report. Aggregate consisting of limestone is generally the most suitable for construction purposes; such limestone is generally considered to be “common variety” and therefore a salable mineral. Limestone outcrops appropriate for quarries are present either on the margins of the Powder River Basin on land that is not administered by the BLM, or in areas that are not accessible to commercial operators (Harris and others, 1992, p. N2).

Bentonite, uranium, and gypsum occurrences within the Buffalo planning area are addressed in the following sections.

3.1.1 Bentonite

Bentonite deposits in Wyoming make up approximately 70 percent of the world's known supply, and Wyoming is the primary producer of high-swelling sodium-type bentonite in the world. Wyoming bentonite production has risen from 1,141 tons in 1927 to nearly 5.9 million tons in 2007 (Wyoming State Inspector of Mines, 2008, p. 58). Bentonite is a type of light-colored clay that is soft and plastic, and which is formed by chemical alteration of volcanic ash deposited in Cretaceous seas that covered much of Wyoming. Bentonite consists of hydrous silicate of alumina, more commonly known as montmorillinite or beidellite, which is an alteration product of volcanic ash or tuff. Bentonite’s property of absorption is largely due to its ion-exchange characteristics. Because sodium is a readily available exchangeable cation, the sodium within Wyoming bentonite allows it to swell by absorbing water. Bentonite can swell up to 16 times its original size, and can absorb up to 10 times its weight in water. Bentonite beds generally range in thickness from less than one inch up to approximately 20 feet; however, beds more than 10 feet thick are unusual. For example, of about 100 bentonite beds in the Mowry and Frontier Formations, only four exceed 10 feet in thickness, and only one is greater than 15 feet. Bentonite beds two to five feet thick are common, but the average is about one

to 1.5 feet. These thicknesses do not include thickening that is the result of postdepositional deformation (Slaughter and Earley, 1965, p. 12).

The important physical properties utilized to classify and determine the various commercial applications of bentonite including yield/viscosity; water loss; water holding capacity; thixotropy; plastic viscosity; yield point; surface area, activity and adsorptive properties; and bonding properties. Bentonite contains minor mineral components, such as crystals of apatite, feldspar, biotite, augite, hornblende, muscovite and zircon. Bentonite differs in color from bed to bed, and is most commonly cream, white, yellow, light to olive green, brown, or blue green in color. Bentonite is used for absorbents, animal feed, drilling fluids, foundry, iron ore pelletizing, and sealants. It is increasingly being used for cat litter. Bentonite is used in drilling mud to lubricate oilfield drilling equipment, hold back formation pressure, and help prevent caving of the drill hole. Used in the foundry industry, it acts as a molding sand binder when added to taconite and for binding iron pellets that are later fed into a blast furnace for processing. Bentonite is also used to seal reservoirs and landfills. Other uses include crayons, medicine, food thickeners, and cosmetics.

3.1.1.1. Geologic Summary

Cretaceous bentonite deposits of Wyoming and the Buffalo planning area are the result of the in-situ chemical alteration or devitrification of airborne, glassy volcanic ash deposited in shallow marine and estuarine environments. The Mowry Sea inundated much of Wyoming by the end of the Early Cretaceous and remained until the Late Cretaceous, creating an environment conducive to the development of bentonite. Bentonite originating from the Cretaceous often contains mineral inclusions including quartz, cristobalite, chlorite, biotite, and feldspar. Less common mineral inclusions include gypsum, calcite, mica, and zeolites. Five to ten percent of bentonite often consists of these mineral inclusions.

Three prominent bentonite beds are exposed in the Buffalo planning area. The Upper Mowry Clay Spur, ranging in thickness from approximately three to five feet, is the lowermost bentonite bed exposed in the Buffalo planning area. Two bentonite beds averaging approximately two feet in thickness are exposed above the Clay Spur in the Frontier Formation. The bentonite beds exhibit a characteristic popcorn appearance on dry weathered surfaces. Outcrops range in color from yellow to blue to brown, and lack vegetation, while unweathered surfaces appear waxy in texture. Hard bentonite (chip material) is present in scattered areas of the Clay Spur bed and Frontier Formation.

3.1.1.2. Previous Mining Activity

It is likely that western Native Americans and early settlers first used bentonite. It was first sold to eastern plants for use in manufacturing cosmetics, with the first commercial shipment conducted in 1888 (Hoffman and others, 2007, p. 18). The name bentonite was derived due to its occurrence in the Fort Benton shale member of the Mowry formation.

Substantial deposits were discovered during the 1920s, around the same time that bentonite's usefulness as a binding agent in foundry sand and as an additive to oil well drilling mud was first discovered. Wyoming bentonite production increased substantially during the 15 year period

from 1927, when 1,141 tons were produced, to 1942, when over 200,000 tons were produced (Hoffman and others, 2007, p. 21). Today, Wyoming is the leading producer of bentonite in the United States, mining nearly 5.9 million tons of bentonite in 2007 (Wyoming State Inspector of Mines, 2008, p. 58).

3.1.1.3. Mineral Occurrence / Recent Mining Activity

Currently, all active bentonite production in the Buffalo planning area is occurring in Johnson County. The Buffalo planning area bentonite production was 548,066 tons in 2007. Bentonite production varies with market demand as well as available stockpiles. **Table 3-1** provides annual bentonite production in the Buffalo planning area for the years 2000 through 2007.

Table 3-1. Annual Bentonite Production in the Buffalo Planning Area

Year	Tons
2000	312,482
2001	400,309
2002	338,507
2003	431,718
2004	458,770
2005	492,368
2006	491,188
2007	548,066

Source: Wyoming State Inspector of Mines, 2001-2008

Currently there are two, active open pit bentonite mines in the Buffalo planning area (**Table 3-2**) and 47 active bentonite mining claims located on federal lands in Campbell, Johnson, and Sheridan Counties (both federal surface/federal minerals and private surface/federal minerals). One company is mining bentonite from Cretaceous-age rocks in the Buffalo planning area using strip mining and cast-back techniques. Most bentonite mining is concentrated in an area west and southwest of Kaycee, Wyoming.

Table 3-2. Current Authorized Bentonite Plans of Operations Within the Buffalo Planning Area

Operator(Mine)	Location
Black Hills Bentonite (Mayoworth Mine)	T. 45 N., R. 83 W., Sections 24, 25, & 35
Black Hills Bentonite (Willow Creek Mine)	T. 41 N., R. 81 W., Sections 3, 4, & 14 T. 41 N., R. 82 W., Section 19 T. 42 N., R. 81 W., Section 33 T. 42 N., R. 83 W., Sections 2, 3, 10, 11 14, & 15 T. 43 N., R. 82 W., Sections 6, 8, 18, 23, 28, & 31

Source: BLM, 2008a

The bentonite development potential and existing bentonite permit areas within the Buffalo planning area are shown on **Map 6**. Bentonite development potential is discussed in Chapter 4.

3.1.2 Uranium

Uranium in Wyoming has been increasingly mined using in-situ recovery (ISR) techniques in recent years. The uranium concentrate, or yellowcake, derived from mined ore is shipped to an enrichment facility to improve the concentration of fissionable uranium to a useful level for the application. The domestic uranium industry is facing competition from foreign sources.

Uranium is a radioactive metallic element used primarily as a fuel for nuclear power generation, in various capacities in military arms and armor production, and in certain fields of medicine and biology. According to the Energy Information Administration (EIA), there are 443 operating commercial nuclear reactors in the world (EIA, 2009b). Of this, 104 nuclear power reactors are in the United States (Nuclear Regulatory Commission, 2009). In the United States, the total uranium mine production in 2007 was 4,541,000 pounds (EIA, 2008a), almost half of which came from the southernmost Powder River Basin.

3.1.2.1. Geologic Summary

Three types of uranium roll-front deposits are identified in the Powder River Basin (BLM, 1992, p. 13):

- Oxidized uranium minerals disseminated in porous sandstone and concentrated around calcite-enriched sandstone;
- Oxidized uranium minerals enclosed in or closely associated with manganese oxide nodular concretions; and
- Nodular concretions of uraninite with pyrite in the reddish sandstones. However, not all reddish sandstones in the region contain uranium.

In the Buffalo planning area, uranium occurrences have been documented in (from oldest to youngest) Precambrian crystalline rocks, the Pennsylvanian Tensleep Formation, the Jurassic Sundance Formation, the Tertiary Paleocene Fort Union Formation, and the Tertiary Eocene Wasatch Formation (BLM, 1992, p. 13). The Fort Union Formation and the Wasatch Formation are the most important uranium-bearing formations in the Powder River Basin. Most uranium ore deposits are found in host arkosic fluvial sediments. The fluvial sediments originated as channel and point bar deposits in meandering braided streams which were part of a larger stream system originating in the south/southwest part of the Powder River Basin. Finer grained sediments grade laterally into floodplains and back swamp environments.

Uranium deposits in the Pumpkin Buttes District are primarily roll-front type deposits in Eocene-age Wasatch Formation sandstones (Sharp and others, 1964, p. 6). Roll-front ore bodies are crescent-shaped in cross section and typically form in relatively thick, tabular, or elongate sandstone bodies. Multiple roll-fronts are likely to occur within a single area.

Because oxidized uranium is highly soluble in water, it is easily transported with oxygenated rain water that percolates into the subsurface, through uranium-bearing sediments, such as rock inter-bedded with volcanic ash (White River Formation), or downgradient from basin margins through aquifers. As oxidized (soluble) uranium migrates through an aquifer, it may enter a reducing environment created by the presence of sulfides, such as pyrite or hydrogen

sulfide, and organic material, such as coal, fossilized plant material, and oil or gas. This reducing environment causes the uranium to precipitate out of solution. Commercial grade ore deposits accumulate over millions of years, as huge amounts of weakly oxidized groundwater containing the soluble uranium pass a reducing interface in the sandstone; uranium is deposited in sharply curving roll-front deposits. Roll-front deposits are seldom more than about 15 feet wide and 10 feet thick but may extend for several hundred feet.

Typical uranium minerals for these types of deposits include uraninite and coffinite, and occur as sub-microscopic grains intergrown with pyrite, as coatings on individual sand grains, and as interstitial pore fillings. Ore-grade mineralization generally averages a few tenths of one percent uranium. Ore grades in small areas near the center of an ore body may contain up to two percent uranium.

3.1.2.2. Previous Mining Activity

Uranium exploration and production in Wyoming dates back to about 1918. Uranium was first mined in Niobrara County, Wyoming in 1920 for its radium content. The first uranium occurrence in the Buffalo planning area was discovered in 1951 on the south flank of the North Pumpkin Butte (BLM, 2001a, p. 160).

Continued exploration for uranium resulted in discovery of additional sedimentary uranium deposits in the major basins of central and southern Wyoming. Most uranium production in the planning area occurred during the years 1955 to 1959. Uranium production declined in the mid-1960s, but picked up again in the late 1960s and 1970s with the discovery of major uranium deposits in the Powder River Basin, including Christensen Ranch, Smith Ranch, Morton Ranch, and the Highland Mine (Paydirt, 1999). Conventional mine production peaked in 1980, then decreased in the early 1980s through the early 1990s when many in-situ mines were developed (Paydirt, 1999).

During the 1980s ISR replaced conventional mine production as the preferred means for extracting uranium ores in the United States. Currently, only in-situ plants are producing uranium in Wyoming. The only remaining conventional uranium mining/milling operation in Wyoming, the Sweetwater Mine in Sweetwater County, remains on standby (Wyoming Mining Association, 2009).

3.1.2.3. Mineral Occurrence / Recent Mining Activity

The Smith Ranch-Highland operation is currently the only active uranium producer in Wyoming. Originally separate mining operations, the Smith Ranch and Highland Mine were combined into one operation several years ago to form the Smith Ranch-Highland operation in Converse County, located just outside the planning area but still within the Powder River Basin. During 2006, Wyoming ranked second to New Mexico in estimated uranium reserves in the United States and produced just over 2 million pounds (Hoffman and others, 2007, p. 40). According to the Wyoming Mining Association (2008), Wyoming produced almost 2 million pounds of uranium in 2007, representing around 40 percent of the total national uranium production of 4.5 million pounds for that year (EIA, 2008c).

According to the 2000-2007 Annual Reports of the State Inspector of Mines of Wyoming (Wyoming State Inspector of Mines, 2001-2008), approximately 169,626 pounds of uranium were produced in the Buffalo planning area from 2000 through 2005. No Uranium production occurred in the Buffalo planning area during 2006 or 2007. Uranium production figures for the Buffalo planning area for the years 2000 to 2007 are provided in **Table 3-3**.

Table 3-3. Annual Uranium Production in the Buffalo Planning Area

Year	Pounds
2000	63,381
2001	37,990
2002	33,284
2003	23,693
2004	8,174
2005	3,104
2006	0
2007	0

Source: Wyoming State Inspector of Mines , 2001-2008

Two uranium districts occur within the Buffalo planning area, the Pumpkin Buttes and Kaycee Uranium Districts. The Pumpkin Buttes District is the larger of the two, at approximately 940 square miles; it is located in southwest Campbell and southeast Johnson Counties. There is a proposal to mine the Hank/Nichols Ranch in the Pumpkin Buttes area, but the Nuclear Regulatory Commission has not yet issued a license, the Wyoming DEQ Land Quality Division has not approved a mining plan, and the BLM has not approved a Plan of Operations. These would need to occur before mining could begin. The Kaycee Uranium District is approximately 40 square miles. Located in south-central Johnson County, active mining has not occurred in the Kaycee Uranium District since the early 1980s (BLM, 2001a, p. 160).

Two uranium mining Plans of Operation, for the Christensen Ranch and Ruth mines, are active within the Buffalo planning area; no mining activity has yet occurred at the Ruth Mine. Another mine, the Nichols Ranch Mine, is currently in the permitting process (**Table 3-4**). None of these mines is currently actively mining uranium ore. It is assumed, however, that uranium processing continued at the Christensen Ranch Mine following the end of active mining by processing existing materials and materials collected during ground water restoration. With an increase in uranium market prices, a new application has been received from the mine's operator with plans to resume active in-situ uranium mining operations at the Christensen Ranch Mine.

With the increased interest in uranium due to market price increases, mining claim numbers are increasing in southern Campbell and Johnson Counties. The majority of the uranium claims are located on split-estate lands. There are 3,604 active uranium mining claims in the Buffalo planning area on federal lands (both federal surface/federal minerals and private surface/federal minerals) (BLM, 2009c, p. 2-30).

Table 3-4. Current Authorized and Pending Uranium Plans of Operations Within the Buffalo Planning Area

Operator	Mine	Status	Location
Power Resources	Ruth	Active; no active mining	T. 42 N., R. 77 W., Section 23
Cogema	Irigaray/ Christensen Ranch	Renewal Process; no active mining	T. 44 N., R. 76 W., Sections 3, 4, 5, 6, 7, 8, & 9 T. 44 N., R. 77 W., Sections 1, 2, 3, 10, & 11 T. 45 N., R. 76 W., Sections 19, 30,31 & 33 T. 45 N., R. 77 W., Sections 8, 24, 34, & 35
Uranerz	Nichols Ranch	Pending	T. 43 N., R. 75 W., Sections 5, 6, 7, & 8 T. 44 N., R. 75 W., Sections 30 & 31

Source: BLM, 2008a

Uranium development potential and uranium permit areas within the Buffalo planning area are indicated on **Map 7**. Uranium development potential is discussed in Chapter 4 of this document.

3.1.3 Gypsum

Gypsum is a water soluble mineral used primarily in the construction industry in products such as plaster, drywall, and as a cement additive. As described below, the origin of gypsum is not entirely understood.

3.1.3.1. Geologic Summary

Gypsum is an evaporative mineral formed primarily by water loss in salt flat environments. The evaporation is probably caused primarily by climatic change from tropical to arid conditions. As seawater evaporates, the water becomes saturated with the various salts and precipitation begins. The first evaporative salt to precipitate out of solution is believed to be calcium carbonate followed by calcium sulfate. Gypsum is a naturally occurring sulfate mineral that is composed of 79 percent calcium sulfate and 21 percent water. Other common salts found in association with gypsum include sodium chloride, sodium bromide, magnesium sulfate, potassium sulfate, magnesium chloride, and trace amounts of borates and nitrates. The presence of these other salts is dependent on the depositional environment.

If the entrance into the inland sea is deep enough, the seawater may be stratified with the upper section of the water column entering the sea with normal salinity and density. As evaporation and super saturation of the calcium salts progresses inward into the sea, precipitation begins. Density of the other salts may increase with continued evaporation while precipitating gypsum and anhydrite. Following the precipitation of the calcium salts, the seawater may flow back out across the entrance to the basin and beneath in the lower section of the seawater column entering the basin. As the saturated sodium chloride and bittern waters enter the open sea, it becomes diluted and may re-enter the inland sea again with recharged calcium salts.

The Absaroka Sea, which is the likely source of Buffalo planning area gypsum deposits, inundated northeastern Wyoming during much of the Permian Period and early Triassic Period. The complete withdrawal and evaporation of this sea occurred during the late Triassic (BLM, 1992, p. 10).

3.1.3.2. Previous Mining Activity

No known gypsum mining has occurred in the Buffalo planning area.

3.1.3.3. Mineral Occurrence / Recent Mining Activity

The majority of the gypsum outcrops in the Buffalo planning area are found within the redbeds of the Permian Goose Egg and Triassic Chugwater Formations as well as within the Gypsum Spring Formation. The contact between the Permian and Triassic is difficult to determine. The interbedded gypsum and siltstone is probably characteristic of the majority of the deposits found in the Buffalo planning area. The gypsum beds exposed along the eastern flank of the Big Horn Mountains in western Sheridan and northwestern Johnson counties have a relatively steep dip, while beds in southwestern Johnson County tend to have a more gentle dip (BLM, 1992, p. 10). The thickness of the gypsum beds probably vary throughout the formations.

Some gypsum has been mined in Wyoming since the 1890's, but current production comes from mines in Bighorn, Crook, Albany, and Park Counties. All of Wyoming's gypsum output from the Bighorn Basin is utilized in the manufacture of wallboard, while the Albany County mine's production is used in the manufacturing of cement. Wyoming gypsum production in 2006 was over 2.6 million tons (Hoffman and others, 2007, p. 45). Although gypsum is currently mined at three locations in Wyoming, none are located in the Buffalo planning area. There is only one mining claim of record for gypsum in the planning area.

3.2 Solid Leasable Minerals

Under the Mineral Leasing Act of 1920 (as amended), the BLM issues leases for the development of leasable minerals. Depending on geographic location, in addition to coal, oil, and gas, leasable minerals may include chlorides, sulfates, carbonates, borates, silicates or nitrates of potassium or sodium, sulfur in Louisiana and New Mexico, phosphates, asphalt, and gilsonite (43 CFR 3501.5). This act specifies, among other things, royalty rates, rental rates, lease size, and terms required for each kind of leasable mineral. With the exceptions of oil, gas, and coal, the act also provides for the issuance of prospecting permits prior to lease issuance and competitive bidding for certain deposits.

Leasable minerals in the Buffalo planning area in commercial quantities are oil, gas, and coal. As stated previously, oil and gas are not addressed in this Report.

The following section provides a detailed description of coal in the Buffalo planning area.

3.2.1 Coal

Wyoming has the largest federal coal program in the United States and is the nation’s largest producer of coal, producing nearly 40 percent of the nation’s coal in 2007 (BLM, 2009e). Most Wyoming coal is used for steam generation in the electrical utility industry and shipped by rail

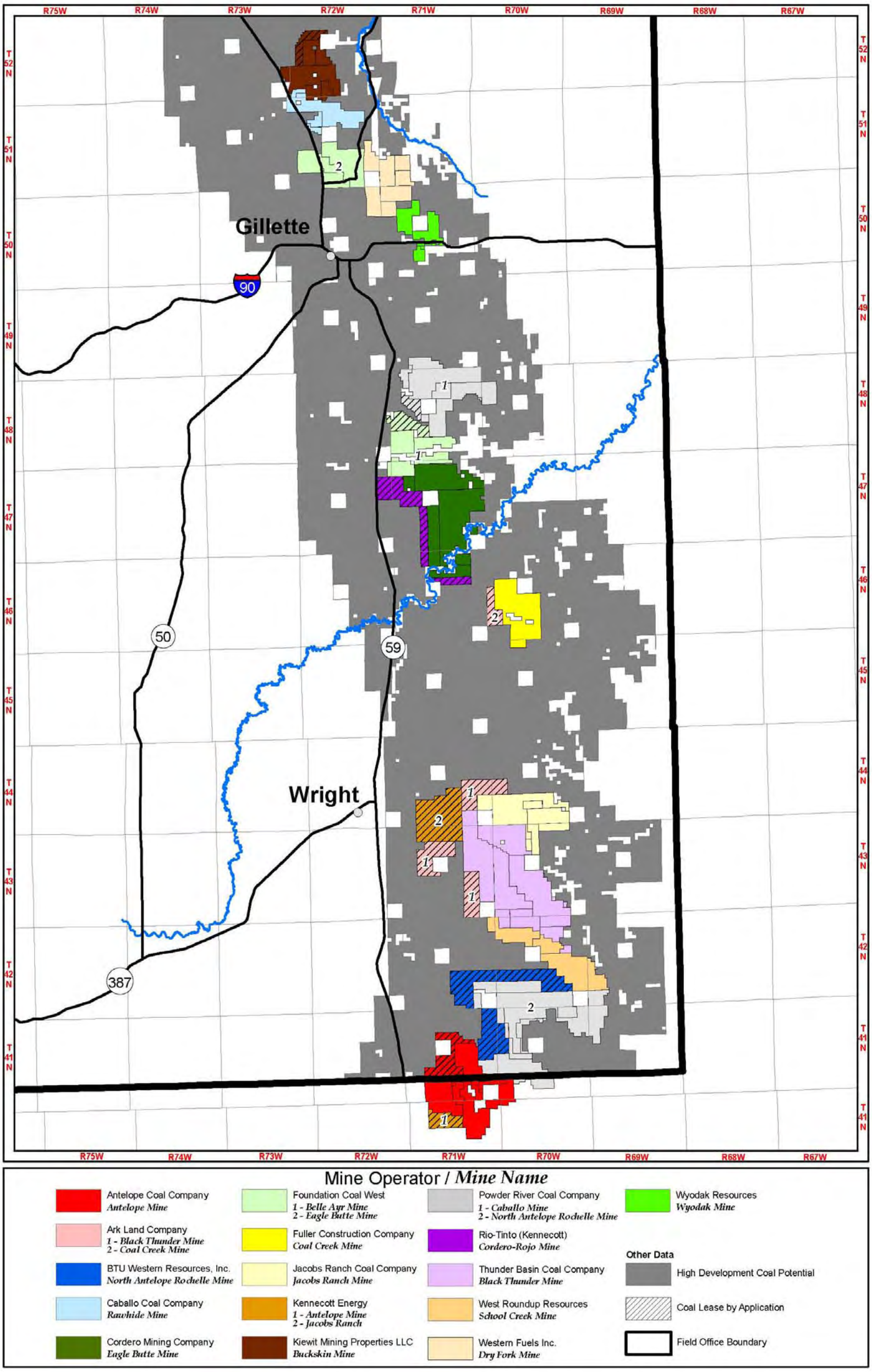
to power plants throughout the United States. Coal production in Wyoming occurs in four areas, including the Powder River Basin (BLM, 2008a, p. 2-33). The Powder River Basin is by far the most productive coal region in Wyoming and the United States. Based on production figures for the first three quarters of 2008, Wyoming produced over 462.4 million tons of coal in 2008, with approximately 97 percent, or 446.5 million tons, of that production coming from the Powder River Basin (Casper Star-Tribune, 2009). Campbell County alone produced 402 million tons of coal in 2007, 35 percent of the total national production of 1,147 million tons (EIA, 2008b).

Figure 3-1 depicts coal leases and coal mining areas in the eastern part of the Powder River Basin near Gillette and Wright, Wyoming.

Coal underlies most of the Buffalo planning area. Some of the world's thickest coal deposits occur in Johnson, Campbell, Sheridan, and Converse Counties; Converse County is outside of the Buffalo planning area but contains part of the Antelope Mine (see Figure 3-1). A recent estimate identified 1.1 trillion tons of coal in these counties (Jones, 2008). Four of the 26 coal beds identified (Ucross/Lake DeSmet, Smith/Big George, Anderson, and Canyon) exceed a thickness of 200 feet in at least one location. The USGS recently estimated a total of 201 billion tons in eleven coal beds, of which 77 billion tons was recoverable with a stripping ratio of 10:1 or less, in the 2,000 square mile Gillette Coal Field alone (Luppens and others, 2008, p. 2). While coal deposits are present underneath most of the surface of the Powder River Basin, they are not thick everywhere. In some areas thick coal deposits split into several thinner seams, each too thin to mine.

The general trend of coal rank along the eastern part of the Powder River Basin increases from north to south, and ranges from subbituminous C to B. Coal is classified by rank according to the Standards of the American Society for Testing Materials (ASTM), Standard D 388 (ASTM, 1998). Within the Wyoming part of the Powder River Basin, the Wasatch Formation contains coal beds that are subbituminous C in apparent rank. The Fort Union Formation coals generally range from subbituminous C to subbituminous A in apparent rank. The low rank coal (subbituminous C) is located primarily in the shallower part of the basin (from the surface to 1,000 feet of depth), the middle coal rank (subbituminous B) is at an intermediate depth in the basin (from 1,000 to 1,400 feet of depth), and the high rank coal (subbituminous A) is in the deeper part of the basin (greater than 1,400 feet of depth) (Luppens and others, 2008, p. 5).

Geochemical surveys associated with coal exploration are typically performed in order to evaluate the quality or rank of coal zones, assist in correlating coalbed strata across local and regional areas, and to determine economic potential. The quality of coal is determined by performing proximate (determination of moisture, volatile matter, ash and fixed carbon), and ultimate (determination of carbon, hydrogen, sulfur, nitrogen, ash, and oxygen) analyses.



Source: BLM Casper Field Office, 2008

Figure 3-1. Wyoming Powder River Basin Coal Lease Status Map, as of August 2008

Management of Coal

The BLM manages coal leasing and other administrative duties relating to coal production on federal coal lands throughout the United States. The primary responsibilities include management of:

- On-Lease Coal Exploration and Off-Lease Exploration Under Existing Coal Exploration Licenses;
- Environmental Analysis Prior to Issuance of New Coal Leases;
- Mining activity on Existing Coal Leases; and
- Inspection and Production Verification on Existing Leases.

Exploration

Federal coal lands (the federal mineral estate for coal retained by the federal government) are available for exploration upon application and approval by the BLM. Under the federal coal leasing program, federal coal lands are screened for coal development potential, unsuitability criteria, multiple use constraints, and surface owner consultation, according to the procedures in 43 CFR 3420.1-4. Some areas may be deemed unsuitable or unacceptable for leasing because of environmental or land use constraints such as alluvial valley floors important to farming, wildlife concerns, urban buffer zones, or rights-of-way. Federal coal lands that pass through these screens are considered acceptable for further consideration for leasing. These lands are subject to continued field investigations and studies to evaluate potential environmental impacts, where companies have nominated tracts for leasing.

Under the 1985 Buffalo RMP, the entire Buffalo planning area is open to coal exploration with a coal exploration license (BLM, 1985b). An exploration license is required by anyone conducting exploration to gather data concerning federal coal. An exploration license is filed with the BLM, and includes a $250 filing fee and an exploration plan and map of the proposed project. The BLM conducts an environmental assessment (similar to an abbreviated version of an Environmental Impact Statement [EIS]) of proposed exploration activities to verify the area's suitability for exploration. The BLM ensures that exploration activities are in compliance with the pertinent environmental laws and regulations that protect the existing natural resources. Certain stipulations are commonly attached to exploration licenses to protect resources. Reclamation of exploratory drilling is enforced by the BLM.

Coal Leasing

In the planning area, 494,000 acres in Campbell County and 73,000 acres in Sheridan County are available for further consideration for coal leasing. These lands have been reviewed against the four coal planning screens (43 CFR 3420.1-4[e]), one being unsuitability for coal mining (43 CFR 3461). Under the 1985 Buffalo RMP, federal coal lands in central Campbell County and north central Sheridan County are the priority areas available for further consideration for coal leasing (BLM, 1985b). All competitive leasing is limited to the priority areas.

The coal screening process, which was most recently applied in 1997 for the 2001 Buffalo RMP update (BLM, 2001a), identified buffer areas around existing communities. The Gillette buffer

zone (about 78,000 acres) is closed to lease by application (LBA), emergency leasing, exchanges, and lease modifications. About 31,000 acres within the Buffalo buffer zone, 33,000 acres within the Sheridan buffer zone, and 4,000 acres within the Wright buffer zone are closed to further consideration for coal leasing and development (BLM, 2001a, p. 11).

Federal coal lands available for consideration for competitive coal leasing are open for LBA, lease modifications, emergency leases, and exchanges. This includes uncommitted coal land determined to be acceptable for coal development and leasing consideration within the priority areas for competitive leasing. Coal lands outside the priority leasing areas which are applied for, must pass the coal screening process before they will be considered for leasing.

Coal development potential and federal coal leases and lease applications within the Buffalo planning area are indicated on **Map 8**. Coal development potential is discussed in Chapter 4 of this document.

FCLAA amended Section 2 of the Mineral Leasing Act of 1920 to require that all public lands available for coal leasing be offered competitively. Competitive leasing provides an opportunity for any interested party to competitively bid for a federal coal lease. There are several specific requirements that are part of every competitively issued lease. These requirements include a royalty rate of 12.5 percent for coal mined by surface mining methods, and eight percent for coal mined by underground mining methods. There is a diligent development requirement that requires commercial quantities of coal to be produced from the lease within 10 years of lease issuance. Failure to meet this requirement results in termination of the lease. A federal coal lease is issued to the bidder offering the highest bonus payment or bid at each sale if a federal sale panel determines that the bonus bid meets or exceeds the fair market value of the coal as determined by the BLM. A bonus bid is a payment made to acquire a federal coal lease. An average of 3.5 years is required from the time an application is submitted to the actual lease decision.

Leasing conducted under competitive LBA is governed by the procedures in 43 CFR 3425. There is no longer any authority to perform coal leasing under the prior noncompetitive leasing procedures. Decertification, which allowed for leasing through the LBA process by interested parties in order to replenish reserves that had been previously mined and allow for increased production from existing mines, remains in effect in the Powder River Basin and governs the process by which coal leasing is accomplished. The BLM annually monitors the activities in the Powder River Basin and makes recommendations on whether an area should become certified again, or remain decertified.

The BLM prepares an environmental review (typically an EIS) of all new lease applications in the Powder River Basin. As part of its environmental process, the BLM reviews the four coal screens against any new, pertinent information. Such a review may result in areas being removed from unsuitability or new areas being added as unsuitable. In addition, the agency develops mine plans, geologic models, and mine costs. BLM economists and appraisers develop the fair market value of the lease, which is held confidential (for example, the Little Thunder LBA, March 2005, Serial Number WYW-150318).

Coal leasing may be deferred in producing oil and gas fields where coal development would interfere with oil and gas operations and the economic recovery of the existing oil and gas resource. An exception to this would occur where it can be shown that economic recovery of oil and gas has been/will be completed before coal mining operations begin. On those coal leases where mining and reclamation plans have been approved, oil and gas exploration (drilling) and production may be authorized if these activities will not adversely affect coal mining activities. Conflict administration zones were developed in the Powder River Basin to minimize conflicts between coal mines and coalbed natural gas (CBNG) operators in areas expected to be mined over the next 10 years. These zones will optimize the recovery of both coal and CBNG resources; prevent avoidable waste of the resources; honor the rights of each lessee, subject to the terms of the lease; protect public health and safety; and mitigate environmental impacts (BLM, 2003c).

Management of Existing Coal Leases

Before a new federal coal lease can be mined, the State of Wyoming and the United States Department of the Interior must approve the detailed mining and reclamation plan submitted by the lessee. The Wyoming DEQ Land Quality Division has been delegated the authority by the United States Office of Surface Mining Reclamation and Enforcement to permit and administer mining plans required by the Surface Mining Control and Reclamation Act of 1977. The BLM reviews and comments on these proposed mining plans.

Lease operations of existing leases are the responsibility of the BLM, and include: permitting, lease administration, inspection, and production verification/maximum economic recovery. For existing leaseholders, a 12.5 percent royalty is paid to the Minerals Management Service (MMS), which is a bureau in the United States Department of the Interior. In addition, the lessee must pay $3.00 per acre per year to rent the leased land.

The BLM conducts two types of inspections for existing lease holders:

- Production verification, which is an audit that compares what the MMS received in royalties against what the company said it mined; and
- Maximum economic recovery (MER), which is an inspection to ensure that the maximum amount of coal is being extracted that can be mined safely and economically from the area and compares to what the company originally said it would mine.

If there is a discrepancy in production, the loss must be justified or royalties and penalties could be assessed.

3.2.1.1. Geologic Summary

The Powder River Basin is an asymmetrical basin with rocks dipping an average of 20 to 25 degrees along the western margin of the basin and two to five degrees along the eastern margin (Flores and Bader, 1999, p. 8). Coal-forming depositional environments of the early to mid Tertiary Period include fluvial systems consisting of braided, meandering, and anastomosed streams in the basin center, and alluvial fans at the basin margin. Coal-forming peat accumulated in low-lying swamps, domed mires, fluvial floodplains, abandoned fluvial channels,

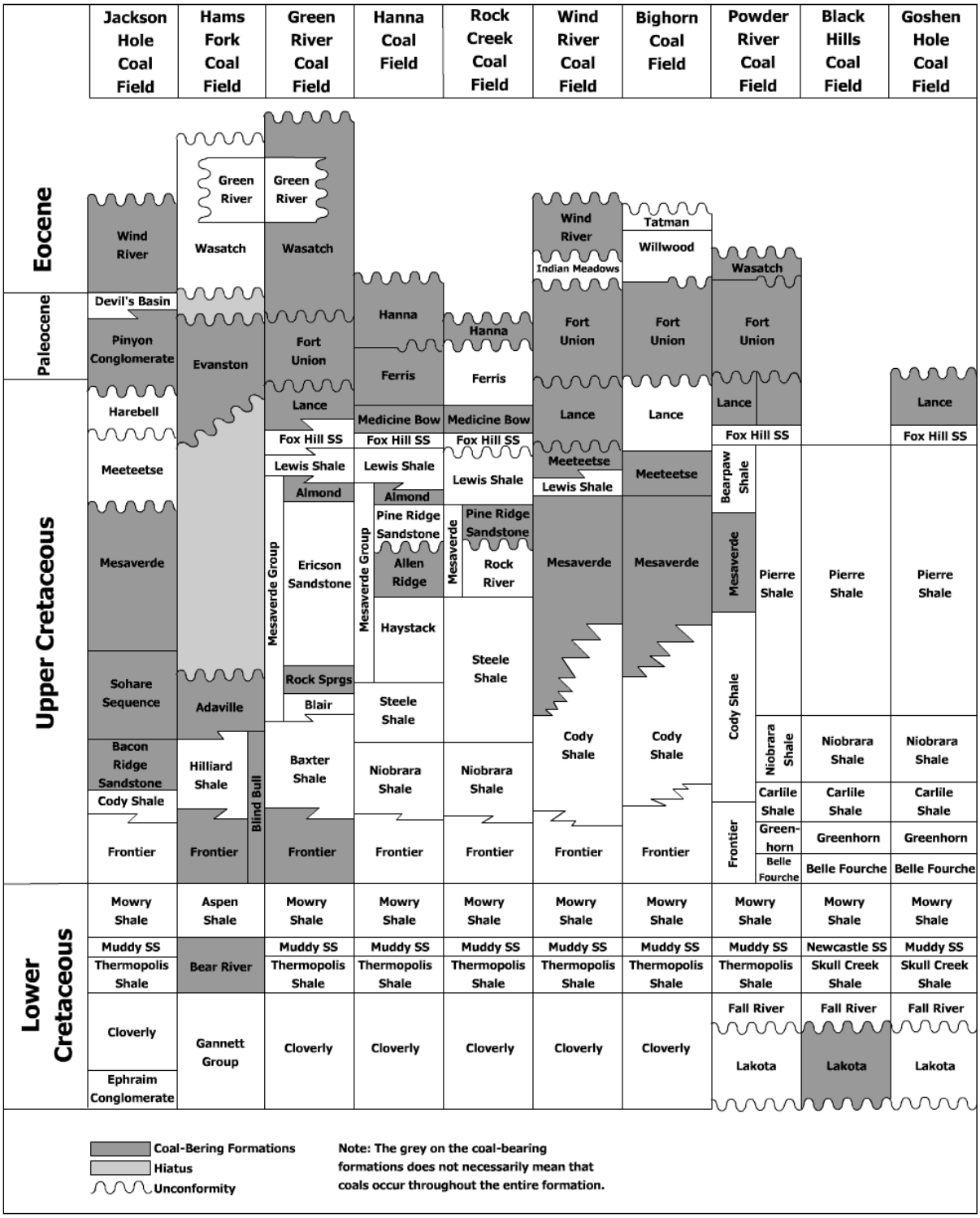
and interchannel environments. The thickest peat deposits accumulated in raised mires well above drainage level and were sustained by rainfall in a tropical-subtropical climate (Flores and others, 1999, p. 2).

Coal within the Powder River Basin occurs in the Paleocene Fort Union Formation and the Eocene Wasatch Formation. The Fort Union Formation consists of seven contiguous coal seams, including (from oldest to youngest): Basal Tongue River, Sawyer, Knobloch, Lower Wyodak, Upper Wyodak, Wyodak Rider, and Roland. The Wasatch Formation consists of three contiguous coal seams including (from oldest to youngest): Lower Wasatch, Felix, and Upper Wasatch (Flores and Bader, 1999, p. 3). Primary coal-bearing formations in Wyoming are indicated on **Figure 3-2**. The following paragraphs provide a description of the principal Powder River Basin coal seams.

The Fort Union Formation contains some of the thickest and most extensive deposits of low-sulfur subbituminous coal in the world (Luppens and others, 2008, p. 6), and is more than 5,200 feet thick along the syncline axis in the western portion of the Powder River Basin. The Fort Union Formation consists of (from oldest to youngest) the Tullock, Lebo, and Tongue River Members. The Tullock Member is up to 740 feet thick, the Lebo Member is up to 2,600 feet thick, and the Tongue River Member is up to 1,860 feet thick (Flores and Bader, 1999, p. 9). The members of the Fort Union Formation are generally differentiated based on the color, dominant lithology, and variation of rock unit thicknesses. The Tullock and Tongue River Members include weathered, drab yellow and light-gray sandstone beds. The Tongue River Member also includes light-gray to tan mudstone. The Lebo Member contains abundant drab-gray mudstone. The coal beds of the Tullock Member are thin to thick compared to the coal beds of the Tongue River Member, which are mainly thick; the Lebo Member includes very thin and sparse coal beds and carbonaceous mudstone (Flores and Bader, 1999, p. 9).

The Lower Wyodak, Upper Wyodak, and Wyodak Rider of the Fort Union Formation are the most economically important coal zones in the Powder River Basin. The major coal deposits of each of these zones (from oldest to youngest) include: The Canyon Rider and Canyon coal deposits within the Lower Wyodak coal zone; the Anderson Rider, Anderson, and Lower Anderson in the Upper Wyodak coal zone; and the Smith Rider, Smith/Big George, and Lower Smith in the Wyodak Rider coal zone. The Smith/Big George coal deposit is up to 216 feet thick, averaging more than 100 feet thick. It occurs in the subsurface of the west central portion of the Powder River Basin at depths between 1,000 and 2,000 feet and is not currently mined. This coal is not exposed at the surface (Luppens and others, 2008).

The Eocene Wasatch Formation covers about one-third of the Powder River Basin, with the underlying Paleocene Fort Union Formation exposed along the basin boundaries in Wyoming and throughout most of the basin in Montana. The Wasatch Formation conformably overlies the Paleocene Fort Union Formation in the center of the Powder River Basin and unconformably overlies it along the basin's margins. The boundary between the two formations is generally placed above the Roland coal bed (Luppens and others, 2008, p. 6).



Source: Wyoming State Geological Survey, 2009

Figure 3-2. Primary Coal-Bearing Formations in Wyoming

3.2.1.2. Historical Production

Coal mining activity in the Powder River Basin began near Glenrock during 1883 (Flores and Bader, 1999, p. 4; ENSR Corporation, 2005, p. 1-1), and underground coal mines began operation during 1894 in the area north of Sheridan (BLM, 2003a, p. 3-68). Production began at the Wyodak mine east of Gillette in 1925 (Jones, 2008, p. 49).

The Powder River Basin emerged as a major coal production area during the 1970s and early 1980s. Because 90 percent of the coal in the Powder River Basin is federally owned, federal coal leasing became an important activity. During 1982, the BLM temporarily halted additional coal leasing, although mining was allowed to continue on existing leases. During this period, many mines in the Powder River Basin depleted their reserves, resulting in the need for maintenance leasing in order to enable these existing mines to meet increasing demand. The region was decertified by the Powder River Regional Coal Team (PRRCT) during 1990 which resulted in implementation of the LBA process (ENSR Corporation, 2005, p.3-1).

Twenty Powder River Basin LBA tracts have been sold, and there are currently ten pending LBA tracts which have been recommended for processing by the PRRCT (BLM, 2009d). All these tracts are in various stages of processing and, combined, cover approximately 34,337 acres and contain roughly 4.5 billion tons of coal reserves (BLM, 2008a).

During 1999, there were 13 active mines operating on around 96,100 acres of leased federal coal in the planning area. Annual total production from the mines in Campbell County increased from 116 million tons in 1985 to over 294 million tons in 1999. Since 1995, the annual increase in production has ranged from 1.1 percent to 11.9 percent over the previous year. Since 1990, mining activities have disturbed an average of 2,600 acres per year, and 950 acres per year (on average) have been permanently reseeded (BLM, 2001a, p. 12).

The total reported production of coal in Wyoming from 1865 through 2006 has been approximately 6.7 trillion tons, with actual production to likely have exceeded this amount (Hoffman and others, 2007, p. 26). In 2007, the Powder River Basin was the single most productive coal basin in the United States, producing nearly 40 percent of the nation's coal. Of that 40 percent, approximately 451.3 million tons were produced in the Wyoming portion of the Powder River Basin (BLM, 2008b).

3.2.1.3. Current Production

According to the Wyoming 2007 Mineral and Energy Yearbook, there are 20 active coal mines in Wyoming, including 19 surface and one underground mine (Hoffman and others, 2007, p. 23). These mines are concentrated in only a few areas: the Hams Fork Coal Region in Lincoln County; the Green River Coal Region in Sweetwater County; and the Powder River Coal Region in Converse and Campbell Counties.

The Powder River Basin accounts for approximately 97 percent of Wyoming's production and boasts all of the 10 largest coal mines in the United States by 2007 production (EIA, 2008b). **Table 3-5** identifies these 10 mines and the amount of coal produced in 2007. Wyoming's Powder River Basin coal production is expected to grow at an annual rate of two to three percent per year, in line with electric power demand.

Table 3-5. Wyoming Powder River Basin Coal Production in 2007

Mine	Coal production (million tons)
North Antelope/Rochelle	91.5
Black Thunder	86.2
Cordero	40.5
Jacobs Ranch	38.1
Antelope	34.5
Caballo	31.2
Belle Ayr	26.6
Buckskin	25.3
Eagle Butte	25.0
Rawhide	17.1

Source: EIA, 2008b

There are currently thirteen operating coal mines in the Powder River Basin. An additional mine, School Creek, is currently proposed in Campbell County. **Table 3-6** provides leased federal coal areas (in acres) within the planning area.

Table 3-6. Leased Federal Coal (acres) in the Buffalo Planning Area

Existing Leases	Pending Lease by Applications	Pending Coal Exchanges	Total
127,999	34,337**	Unknown*	162,336

* The only pending exchange is the Buffalo alluvial valley floor exchange. Since it has not been adjudicated, acreages are unknown.
** Includes pending LBA acreage in Campbell County only.
Source: BLM, 2008c, p. 1-4, 1-7

These 13 coal mines produced approximately 437 million tons of coal during 2007. Production from these coal mines for the period from 1998 through 2007 is shown in **Table 3-7**; the 2007 permitted production capacities of companies operating in the Powder River Basin are provided in **Table 3-8**.

Table 3-7. Powder River Basin Coal Production (in Millions of Tons)

Mine	Operator	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998
SUBREGION 1 (North Gillette)											
Buckskin	Kiewit Mining Properties LLC	25.3	22.5	19.6	20.3	17.5	18.3	19.1	15.8	15.6	17.3
Dry Fork	Western Fuels	5.3	5.9	4.1	4.5	4.3	4.9	4.0	2.2	1.2	1.0
Eagle Butte	Foundation Coal West	25.0	25.3	24.1	23.0	24.7	24.9	24.8	18.6	17.4	18.1
Rawhide	Peabody	17.1	16.2	12.4	6.9	3.7	3.4	0.0	0.0	0.8	5.4
Wyodak	Wyodak	5.0	4.7	4.7	4.8	4.8	4.1	3.5	3.0	3.1	3.3
SUBREGION 2 (South Gillette)											
Belle Ayr	Foundation Coal West	26.6	24.6	19.5	18.7	17.9	17.4	11.8	15.0	17.8	22.5
Caballo	Peabody	31.2	32.5	30.5	26.4	22.7	26.0	27.1	25.7	26.5	25.9
Coal Creek	Arch	10.2	4.7	0.0	0.0	0.0	0.0	0.0	4.2	11.2	7.1
Cordero-Rojo	Rio Tinto Energy America	40.5	39.7	37.8	38.8	36.0	38.2	43.5	38.6	45.7	37.0
SUBREGION 3 (Wright)											
Antelope	Rio Tinto Energy America	34.5	33.9	30.0	29.7	29.5	26.8	24.6	23.0	22.7	19.4
North Rochelle*	Arch	dissolved	dissolved	dissolved	12.4	23.9	23.9	23.9	17.8	8.2	0.04
Black Thunder	Arch	86.2	92.2	87.5	75.1	62.6	65.1	67.6	60.1	48.7	42.7
Jacobs Ranch	Rio Tinto** Energy America	38.1	39.9	37.3	38.6	35.7	31.7	29.3	28.3	29.1	29.1
North Antelope/ Rochelle	Peabody	91.5	89.7	82.7	82.5	80.1	74.8	74.8	70.7	68.9	64.6
Powder River Basin Total		436.6	431.3	390.2	381.7	363.4	359.5	354.0	323.0	316.9	293.4
Wyoming Total		451.3	446.1	403.9	395.8	376.3	372.8	368.5	338.8	334.0	314.5

Source: BLM, 2008b
Legend: LLC – Limited Liability Company
* The North Rochelle Mine is now part of the Black Thunder Mine.
** In March 2009 Rio Tinto Energy reached an agreement to sell Jacobs Ranch Mine to Arch Coal, Inc.

Table 3-8. Powder River Basin Permitted Production Capacities During 2007

Company	Mine	Million Tons/Year
Antelope Coal Company	Antelope Mine	42
Arch Western Resources, LLC	Black Thunder Mine*	100
Arch Western Resources, LLC	Coal Creek	25
Foundation Coal West	Belle Ayr Mine	45
Foundation Coal West	Eagle Butte Mine	35
Kennecott Energy Company	Coredero-Rojo Mine	65
Kennecott Energy Company	Jacobs Ranch	55
Peabody Coal Company	Caballo Mine	50
Peabody Coal Company	Rawhide Mine	24
Powder River Coal Company	North Antelope/Rochelle	105
Triton Coal Company	Buckskin Mine	42
Western Fuels Association	Dry Fork Mine	15
Wyodak Resources	Wyodak Mine	12

Source: Wyoming DEQ-Air Quality Division, 2007
Legend: LLC – Limited Liability Company
* The North Rochelle Mine is now part of the Black Thunder Mine

3.3 Salable Minerals

According to the Materials Act of 1947 (as amended) certain mineral materials (salable minerals) and vegetative materials may be disposed of either through a contract of sale or a FUP (43 CFR 3600). Under the mineral materials program, the BLM manages the exploration, development, and disposal of mineral materials from public lands by sale or free use. Disposal of the minerals is made in conformance with BLM land use plans. Use authorization includes NEPA compliance and appraisal of the fair market value of the mineral materials.

The mineral materials program in the Buffalo Field Office consists of the exploration, disposal and development of sand and gravel, clinker, moss rock, and building stone through Contracts for the Sale of Mineral Materials and FUPs. The locations of mineral material permit areas within the Buffalo planning area are indicated on **Map 9**. Contracts for the Sale of Mineral Materials are issued to individuals, contractors (for road construction), coal mines (for haul roads and surfacing), and oil and gas companies (for access roads, well pads, and other projects requiring mineral materials for development). Materials are not sold at less than fair market value. FUPs may be issued to any federal, state, or territorial agency, unit, or subdivision, including municipalities, or any non-profit organization for public purposes. Under the 1985 Buffalo RMP, Campbell, Johnson, and Sheridan Counties are currently available for the disposal of mineral materials unless otherwise withdrawn by an Act of Congress or designated by the BLM for free use by city, county, and state entities (BLM, 1985b).

Exploration and mining activities related to salable minerals on BLM-administered land are subject to the regulations in 43 CFR 3600. In general, the various types of mineral materials available for disposal under a BLM sales contract or FUP are listed in **Table 3-9**.

Table 3-9. Common Varieties of Mineral Materials

Sand
Gravel
Clinker
Building Stone
Moss Rock
Decorative Stone
Fill Dirt on BLM-Administered Surface
Common Clay
Limestone or Dolomite used for common construction purposes
Petrified Wood for Commercial Purposes and in Excess of Private Collecting Standards (25 pounds per day plus one piece not to exceed 250 pounds per year)
Any Other Common Variety Mineral (as demand occurs)

Mineral material disposal sites are scattered across Campbell, Johnson, and Sheridan Counties. Disposals include sand, gravel, and clinker through both sales contracts and FUPs. Sand and gravel deposits are found scattered along major drainage channels and tend to be more abundant near the base of the Big Horn Mountains. Large amounts of clinker occur east of the coal mines between Gillette and Wright, between Buffalo and Sheridan east of Interstate 90, north of Sheridan west of the Tongue River, and in other scattered areas of Campbell, Sheridan, and northern Johnson Counties. The potential exists in the Buffalo planning area for crushed stone grade (salable) limestone along the flank of the Big Horn Mountains (Harris, 2004). However, no known deposits of salable limestone exist in areas accessible to commercial operators on BLM-administered land, and therefore, this mineral is not addressed further in this report.

Current mineral material disposals for the Buffalo Field Office are listed in **Table 3-10**. The BLM conducts inspections and production verification to assure compliance with the terms of the contract or permit, prevention of unnecessary or undue degradation to surface resources, and prevention and abatement of unauthorized use.

Table 3-10. Current Authorized Mineral Material Disposals Within the Buffalo Planning Area

Operator	Legal Description
Basic Energy (s&g, ct)	T. 42 N., R. 76 W., Section 11, NENW
Sierra Construction (cl, ct)	T. 42 N., R. 78 W., Section 12, SENWSE
Hilcorp Energy (s&g, ct)	T. 42 N., R. 81 W., Section 4, NENENE
Dan Hart Patrol (s&g, ct)	T. 43 N., R. 73 W., Section 18, NWNE
Lone Hart, LLC (s&g, ct)	T. 43 N., R. 77 W., Section 3, SWSE
Cole Lumber (s&g, ct)	T. 43 N., R. 77 W., Section 3, S2SWNW
Johnson County (s&g, fup)	T. 43 N., R. 79 W., Section 3, SESENE, NENESE
Chapman Contracting (s&g, ct)	T. 43 N., R. 79 W., Section 3, NESE, SESE

Table 3-10. Current Authorized Mineral Material Disposals Within the Buffalo Planning Area

Operator	Legal Description
Johnson County (s&g, fup)*	T. 43 N., R. 79 W., Section 9, NENE
Johnson County (s&g, fup)	T. 43 N., R. 80 W., Section 14, SESENW
Johnson County (s&g, fup)	T. 43 N., R. 82 W., Section 32, NENW
Bell's Restoration (s&g, ct)	T. 44 N., R. 73 W., Section 5, NWNW
Johnson County (s&g, fup)	T. 44 N., R. 78 W., Section 3, NESWSW, NWSESW
Johnson County (s&g, fup)	T. 44 N., R. 82 W., Section 17, SWNWNE
Campbell County (cl, fup)	T. 45 N., R. 70 W., Section 4, NWSWSE
First Energy (s&g, ct)	T. 45 N., R. 73 W., Section 11, SWSWSE
Campbell County (s&g, fup)	T. 45 N., R. 73 W., Section 11, S2NESE, N2NESE
Anadarko (s&g, ct)	T. 45 N., R. 77 W., Section 23, NWSENE
Johnson County (s&g, fup)*	T. 45 N., R. 84 W., Section 26, NENESE
Johnson County (s&g, fup)*	T. 46 N., R. 85 W., Section 15, SWNE, SENE
First Energy (s&g, ct)	T. 47 N., R. 78 W., Section 1, NENENE
Dull Knife Dirtwork (s&g, ct)*	T. 47 N., R. 85 W., Section 10, SWNW, NWSW
Johnson County (s&g, fup)*	T. 47 N., R. 85 W., Section 23, S2NWNWSE
Washakie County (s&g, fup)*	T. 47 N., R. 85 W., Section 33, N2NESENE
Johnson County (s&g, fup)*	T. 47 N., R. 85 W., Section 33, E2SWNWNW
KG Construction (s&g, ct)	T. 48 N., R. 77 W., Section 7, NESW
Johnson County (s&g, fup)*	T. 48 N., R. 77 W., Section 7, SESW
Johnson County (s&g, fup)	T. 48 N., R. 81 W., Section 23, NESW
Johnson County (s&g, fup)*	T. 48 N., R. 81 W., Section 25, SENWNE
Johnson County (s&g, fup)	T. 48 N., R. 84 W., Section 32, NENE, SENE
Johnson County (s&g, fup)	T. 49 N., R. 81 W., Section 4, W2SENW
City of Buffalo (s&g, fup)	T. 49 N., R. 82 W., Section 3, S2SE
Hettinger Welding (cl, ct)	T. 50 N., R. 73 W., Section 30, E2SESW
Johnson County (s&g, fup)	T. 50 N., R. 77 W., Section 6, SWSWNW
Melgaard Construction (s&g, ct)*	T. 50 N., R. 77 W., Section 7, NWNW
Kennedy Oil (s&g, ct)	T. 50 N., R. 79 W., Section 19, SWNE
Campbell County (s&g, fup)	T. 50 N., R. 81 W., Section 32, S2SESW
Johnson County (s&g, fup)	T. 50 N., R. 82 W., Section 30, SENWNE
Foundation Coal (cl, ct)	T. 51 N., R. 72 W., Section 18, SESW
Johnson County (s&g, fup)	T. 51 N., R. 77 W., Section 17, SENE
Hettinger Welding (s&g, ct)	T. 51 N., R. 80 W., Section 29, Tr 88
First Energy (s&g, ct)	T. 51 N., R. 80 W., Section 32, SW of Tr88
Wyoming Red Rock (cl, ct)	T. 52 N., R. 72 W., Section 2, W2SWNW

Table 3-10. Current Authorized Mineral Material Disposals Within the Buffalo Planning Area

Operator	Legal Description
Campbell County (cl, fup)	T. 52 N., R. 75 W., Section 6, SWNE
Magna Energy (cl, ct)	T. 55 N., R. 73 W., Section 1, S2 Tr 39H
Hettinger Welding (cl, ct)	T. 56 N., R 73 W., Section 8, SENWSW, NWSESW
Baker MO Services (s&g, ct)	T. 57 N., R. 83 W., Section 6, NWSW
Earth Work Solutions (cl, ct)	T. 57 N., R. 74 W., Section 18, SWSW
Baker MO Services (cl, ct)	T. 57 N., R. 75 W., Section 18, SWNESW, NWSESW
PG Ranch (cl, ct)	T. 57 N., R. 76 W., Section 22, NWNW
Pinnacle Gas Resources (cl, ct)	T.58 N., R. 76 W., Section 27, SESW

Source: BLM, 2008a
Legend: s&g – sand and gravel pit; cl – clinker pit; ct – contract; fup – free use permit; LLC – Limited Liability Company
* BLM-administered surface/mineral lands. The remaining pits are located on private surface/federal minerals.

Disposals within Johnson, Campbell, and Sheridan Counties are authorized on a case-by-case basis as contracts and FUPs are received. A site specific categorical exclusion, environmental assessment, or determination of NEPA adequacy is completed for each disposal following consultation with cultural, wildlife, and other designated BLM staff members as needed.

Prior written authorization is required if testing (associated with mineral exploration, for example) is required before a permit or contract is issued. The BLM will provide written notification following the receipt of a cultural clearance. A contract or FUP for mineral materials can be obtained by filing an application with the appropriate BLM Field Office. For sales of less than $2,000 fair market value, a small-sales Form 5450-5 contract can be obtained; larger sales require more detailed submittals under a Form 3600-9 contract.

A FUP application can be submitted by any federal, state, or territorial agency, unit, or subdivision, including municipalities, or any non-profit organization for public purposes. All cultural, wildlife, and NEPA requirements must be met prior to approval.

There are currently no designated community pits in the Buffalo planning area. The Buffalo Field Office maintains one designated common-use area, which consists of seven other small mineral collection areas, all located on BLM-administered surface land in western Johnson County. These sites were established by the BLM to serve the needs of the local communities for small amounts of mineral materials, such as moss rock, clinker, and flagstone, while reducing and concentrating the amount of surface disturbance. Collectors must obtain a sales contract and pay a nominal fee of $11.00 per ton, and may then collect material from these sites using hand tools (mechanized excavation equipment is prohibited).

Coal mines obtain clinker for surfacing haul roads, for use in coal mine and CBNG operations, and for the construction of pads through two methods: 1) if the clinker used remains within the boundaries of the coal lease from which the clinker was necessarily removed to develop the underlying coal, BLM will not charge for the clinker that had to be moved in order to extract the coal, under the provisions in 43 CFR 3602.33; and 2) if the clinker is present on the lease, it cannot be used free of charge unless it has to be removed to mine the underlying coal. If the

clinker is used outside the particular coal lease from which the clinker was extracted or was mined from a separate pit on or outside of a particular coal lease, the coal mine must obtain a sale contract from BLM. Sales of clinker to coal mines comprise over half the volume of all mineral material sales in the Buffalo Field Office.

Most of the sales and FUPs in the Buffalo planning area occur on split-estate patented under the SRHA. The 1984 Watt versus Western Nuclear decision by the United States Supreme Court established that the United States owns all mineral materials under the "all minerals" reservation on a SRHA patent. Any sale or FUP on SRHA lands must follow the procedures in 43 CFR 3814 regarding surface owner agreement and bonding.

Once a mineral material disposal application is received, mineral ownership of the proposed location is determined by checking the Master Title Plat. Mineral materials may be sold by volume or weight at appraised (fair market) value to commercial or individual users; governmental agencies have free use. The majority of lands in the Buffalo planning area, including federally-administered surface/minerals and split-estate lands, are available for mineral material exploration and development under the 1985 Buffalo RMP (BLM, 1985b). In addition, under the 1985 RMP, mineral materials activities are prohibited in the Fortification Creek, Gardner Mountain, and North Fork WSAs (about 28,931 acres).

Annual authorized sales and FUPs showing the approximate cubic yards or tons per calendar year for the period 2000 to 2007 are listed in **Table 3-11**. The cubic yards and tons listed on the table are for the amount authorized, but the actual annual production may be less. The contracts and FUPs were issued from two to five years. Clinker sales for use in coal mines, and sales of sand, gravel, and clinker required for construction associated with well pads and haul roads for CBNG and oil field wells constitute the majority of salable mineral sales. FUPs were primarily issued to county governments and municipalities for road maintenance.

Table 3-11. Mineral Material Disposals for the Buffalo Planning Area

Year	Free Use Permits (cubic yards)	Free Use Permits (tons)	Contracted Sales (cubic yards)	Contracted Sales (tons)
2000	60,000	57,500	745,100	6,450
2001	100,000	222,000	550,450	8,600
2002	60,000	182,000	897,250	18,000
2003	62,800	423,650	1,122,650	14,900
2004	37,000	121,500	881,100	107,200
2005	73,000	290,000	679,935	22,000
2006	30,000	275,000	698,650	158,000
2007	400,000	113,000	1,306,050	87,800

Source: BLM, 2009a

Some mineral materials, such as building stone and limestone, can be classified as either locatable (uncommon variety) or salable (common variety). To distinguish between the varieties of minerals, the United States Department of the Interior defines common varieties as follows:

> "'Common varieties' includes deposits which, although they may have value for use in trade, manufacture, the sciences, or in the mechanical or ornamental arts, do not possess a distinct, special economic value for such use over and above the normal uses of the general run of such deposits. Mineral materials which occur commonly shall not be deemed to be 'common varieties' if a particular deposit has distinct and special properties making it commercially valuable for use in a manufacturing, industrial, or processing operation." 43 CFR 3711.1(b)

3.3.1 Aggregates (Sand and Gravel)

Sand and gravel deposits are among the most commonly used materials authorized under the Materials Act of 1947 (as amended). Such deposits are generally preferred over clinker for road construction. However, the availability and transportation haul distance for sand and gravel is cost prohibitive in some areas. Clinker generally breaks down (decomposes) faster with road traffic than sand and gravel. Decomposition of clinker can result in degradation of air quality through the release of dust.

The majority of sand and gravel deposits in the Buffalo planning area are found near the eastern flank of the Big Horn Mountains and along major drainages of the Powder River Basin. Major sand and gravel deposits in the Buffalo planning area are indicated on **Map 10**. These deposits were probably washed down by ancient streams from the Big Horn Mountains in the geologic past. These deposits primarily consist of piedmont, terrace and unconsolidated pediment deposits of the Kingsbury and Moncrief Conglomerate members of the Tertiary Wasatch Formation with scattered Quaternary deposits. Quaternary terrace and alluvial sand and gravel deposits are also present along the Powder River, Belle Fourche River, and other drainages east of the Kingsbury and Moncrief Conglomerates. The majority of these deposits within the eastern portion of the Buffalo planning area tend to contain excessive quantities of silt, rendering the sand and gravel commercially uneconomical to produce.

The Kingsbury Conglomerate is composed of ancient alluvial fans derived from unroofing of Paleozoic and Mesozoic carbonate and other sedimentary rocks in the Big Horn Mountains during Eocene time. Paleozoic and Mesozoic limestone, dolomite, and quartzite pebble, cobbles, and boulders comprise the majority of the Kingsbury rock fragments with minor amounts of black and gray chert pebbles. Although Precambrian-aged igneous and metamorphic rocks are rare in the Kingsbury, scattered occurrences are found in the uppermost section of the member near the contact with the overlying Moncrief conglomerate.

The Moncrief conglomerate, also of Eocene age, consists of interbedded siltstone, sandstone, grits, thin conglomerate beds, grading upward into boulder beds. The Moncrief is separated from the underlying Kingsbury by an angular unconformity. The types of deposits and depositional mechanisms for the Moncrief are similar to the Kingsbury. Precambrian rocks

derived from the Big Horn Mountains, consisting of gneiss and granite with minor amounts of diabase, hornfels, pegmatite, and schist, are the primary lithologic constituents of the Moncrief. Most of the Paleozoic and Mesozoic rock units in the Big Horn Mountains were removed through erosion and deposited in the Kingsbury prior to the deposition of the Moncrief.

The remainder of Buffalo planning area sand and gravel deposits primarily consist of Quaternary terrace and alluvial deposits found along or near major drainages. These deposits consist primarily of subrounded to rounded chert, quartzite, and some Precambrian rocks ranging in size from silt to cobbles. These deposits are probably the result of the re-working of the older Kingsbury and Moncrief conglomerates as well as some of the existing Precambrian, Paleozoic, and Mesozoic deposits present in the Big Horn Mountains (BLM, 1992, p. 19).

3.3.2 Clinker

Clinker is more resistant than the unaltered sediments overlying the burned coal seam and commonly caps ridges, buttes and plateaus in the Powder River Basin. Clinker is highly fractured due to collapse of the overlying strata into the void left by the burned coal bed. Clinker is used for mine haul roads, county roads, and oil and gas well pads and access roads. Known clinker deposits cover about 500 square miles in the Buffalo planning area. Clinker permit areas within the Buffalo planning area are indicated, along with other Mineral Material permit areas, on **Map 9**.

Prehistoric Native Americans used the porcellanite form of clinker for spear points and arrowheads. Today, the main use of clinker is for road surfacing in coal mines, and for oil and gas access roads and well pads as well as county roads in areas where better quality gravel is not available. Clinker is lightweight and easily excavated but varies in hardness and breaks down easily. Clinker works well as a cement-treated road base and as a chip seal on asphalt roads. Clinker is also used for landscaping, street sanding, and erosion control (Heffern and Coates, 1997, p. 151).

The main areas that have burned to create clinker in the Buffalo planning area include: 1) the Rochelle Hills, formed by burning of the Wyodak-Anderson coal east of the coal mines near Gillette and Wright; 2) the Lake DeSmet area north and east of Buffalo, where the Walters, Healy, Lake DeSmet and Ulm coals have burned; 3) the Felix coal area in central and western Campbell County; 4) the Powder River breaks near the Montana-Wyoming state line, where the Canyon, Anderson, and Smith coals have burned; and 5) the Tongue River breaks north and northwest of Sheridan, where the Monarch, Dietz, Anderson, and Roland coals have burned (Heffern and Coates, 1997, p. 156).

3.3.3 Moss Rock and Building Stone

Moss rock is identified as a rock, regardless of origin, lying on the surface and covered with crustose and other lichens. Moss rock commonly consists of Precambrian granites, Ordovician Bighorn chert and dolomite, Mississippian Madison Limestone, Pennsylvanian Amsden Limestone and Tensleep Sandstone. Most moss rock consists of “float” material (rock fragments displaced down-slope from the outcrop). In general, the most desired moss rock is tabular in form since the flat surfaces enhance use for construction purposes.

Building stone occurs in the Ordovician Bighorn dolomite, Mississippian Madison Limestone, and the Pennsylvanian Tensleep Sandstone and typically exhibits well defined bedding planes. Typically, building stone and float material are often associated in the same area.

3.4 Abandoned Mines

More than a century of mining in the Buffalo planning area has resulted in hazards (mostly related to abandoned coal mines), including some extreme physical hazards due to collapse of underground room and pillar mines, and coal fires. Such hazards are by-products of an era prior to mine-reclamation requirements. For hikers, cave explorers, and other recreationists, the hazards are not always apparent and serious injury or death can occur. Common hazards include: open shafts, unstable rock and decayed support structures, ground fissures, unstable ground over coal fires, deadly gases and lack of oxygen, explosives and toxic chemicals, disorientation, high walls, open pits, and open drill holes. In 1999, 17 people died at abandoned mines sites in the United States (Wyoming DEQ, 2009). In addition to physical hazards, abandoned mines can also cause environmental degradation. Abandoned Mine Lands (AML) often contain un-mined mineral deposits, mine dumps, and tailings that can contaminate the surrounding watershed and ecosystem (USGS, 1999). Streams that flow near or through AML sites can accumulate heavy metals and other contaminants, which can result in a loss of aquatic life (USGS, 1999).

Collapse of old underground mines is an ongoing problem in the historic coal mining area near Acme, along the Tongue River several miles north of Sheridan (Dunrud and Osterwald, 1980, p. 4). This collapse has led to a series of underground mine fires which have sporadically occurred and been extinguished by the State of Wyoming AML Division over the past thirty years. Most of these hazards are on private surface; however, as part of the 2004 Pittsburg and Midway coal exchange, BLM acquired the Welch Ranch property along the Tongue River near the bridge along State Highway 338 leading to Decker and is in the process of developing it as a public recreation area. As documented in Appendix D of the final EIS for the exchange (BLM, 2003b, p. D-2), the Welch Ranch contains an active coal fire covering 13 acres, which is related to collapse of the north end of the old Acme Mine. Two miles to the northeast, another active coal fire on the Ankney ranch is encroaching onto the east end of the Welch Ranch property (E. Heffern, written commun(s)., 2009). A management plan to limit public access to the area of the fires and monitor and extinguish these fires needs to be developed.

The BLM's AML program in Wyoming currently operates pursuant to the September 22, 1999 assistance agreement (KAA990028) between the BLM and the Wyoming DEQ, entitled "Abandoned Mine Land Reclamation Agreement." This agreement provides for the cooperative effort between the two agencies and for a long-term relationship to efficiently and economically plan and share responsibilities to ensure effective AML reclamation on public lands in Wyoming. The 1999 cooperative agreement with the Wyoming DEQ was updated in 2004, and continues to be updated with new task orders on a periodic basis. The Wyoming DEQ AML Division has been delegated the authority granted to the United States Office of Surface Mining Reclamation and Enforcement (OSMRE) under the SMCRA, as amended, to reclaim abandoned mines. Accordingly, they currently receive about $30 million dollars per

year from OSMRE for this purpose, which can be spent on abandoned mines in Wyoming regardless of ownership.

Instruction memoranda have been issued for the management of AMLs as summarized below.

Instruction Memorandum No. WO-2007-096 (March 28, 2007) identified the goals, steps, measures of progress, and reporting requirements for addressing AML related environmental and physical safety hazards in close proximity to populated places and high use areas on BLM-administered lands.

Instruction Memorandum No. WO-2006-145 (May 1, 2006) transmitted a Cooperative Conservation Base Strategic Plan for the Abandoned Mine Lands Program. It established the context whereby the BLM mitigates and remediates hardrock AML sites, and correlates field activities with program goals, objectives and priorities. An AML work plan for the Wyoming BLM State Office was presented for fiscal years 2007 through 2013.

Instruction Memorandum No. WY-2003-011 (December 26, 2002) requires:

1. Dangerous AML sites near recreation areas receive priority consideration for reclamation;
2. The Wyoming BLM State Office to maintain the Abandoned Mine Land Information System (a database that is the basis for the Abandoned Mine/Site Cleanup Module [AMSCM]);
3. Field Managers to identify Project Facilitators for each AML project within their Field Office;
4. Allocation of 1010 or 1640 subactivity work-months (line-item funding sources) to those facilitators;
5. Field Offices to report project work for special watersheds; and
6. The scheduling of periodic AML program coordination conference calls.

The current practice within the Buffalo Field Office is to follow all established national and Wyoming specific guidelines regarding AML site identification and characterization for human-made AML hazards. The Wyoming DEQ AML Division has the lead in this program pursuant to the agreement cited above. In 1986, the state of Wyoming certified that it had initiated or completed work on all hazardous abandoned coal mines, and began to reclaim other types of abandoned mines in the state. However, more recent on-site inventories conducted between 2000 and 2005 have identified new and ongoing coal mine reclamation needs. The 2006 amendments to SMCRA have limited most reclamation funding for the State of Wyoming AML program in the near future to coal mine reclamation. The BLM provides access permission to contractors of the Wyoming DEQ AML Division who conduct detailed site assessments and reclamation of AML sites.

4.0 MINERAL DEVELOPMENT POTENTIAL

The potential for mineral resource development is a prediction of the likelihood of the occurrence of these resources. The occurrence of a mineral resource does not necessarily imply that the mineral can be economically exploited or is likely to be developed; mineral occurrence potential includes both exploitable and potentially exploitable occurrences. The potential for the occurrence of a mineral resource also does not imply that the quality and quantity of the resource are known (Bureau of Land Management [BLM], 1985a, p. 3).

In addition to known mineral occurrence, this Report also provides mineral resource development potential. Future mineral development is influenced by the price of commodities, management, laws, and regulations. With all commodities whether they are locatable, leasable, or salable, the level of resource potential can be difficult to predict, even with extensive geological studies.

4.1 Locatable Minerals

While the BLM recognizes the importance of maintaining the bentonite and uranium industries in the region in order provide employment and minimize other socioeconomic impacts, the BLM also must manage the land for multiple uses according to its legal mandates. The BLM will process new Notices and Plans of Operations for bentonite, uranium, and other locatable mining or exploration activities in a timely fashion. At the same time, the BLM, in cooperation with the Wyoming Department of Environmental Quality (DEQ) Land Quality Division and Nuclear Regulatory Commission (as applicable), must ensure that mining companies comply with their approved plans and permits.

The Buffalo Field Office will continue to work with its locatable minerals industry to ensure viability, while protecting other resources and preventing unnecessary or undue degradation to the environment as well as other cultural and natural resources. Reasonably foreseeable development (RFD) opportunities coupled with proper mitigation and resource protection is at the forefront of the BLM's and the Buffalo Field Office's locatable minerals programs.

Bentonite is the only locatable mineral currently being produced in the Buffalo planning area. With the exception of uranium, the potential for the development of other locatable minerals within the planning area is low at this time.

4.1.1 Bentonite

The demand for bentonite has remained nearly the same since the signing of the BLM Buffalo Resource Management Plan (RMP) Record of Decision on October 4, 1985. Bentonite has many uses that vary from year to year, but the demand remains fairly constant. Bentonite production for the years 2000 through 2007 is listed in **Table 4-1**.

Table 4-1. Buffalo Planning Area Bentonite Production

Year	Bentonite Production (tons)
2000	312,482
2001	400,309
2002	338,507
2003	431,718
2004	458,770
2005	492,368
2006	491,188
2007	548,066

Source: BLM, 2009c, p. 2-31

Bentonite is found in southwestern Johnson County near the contact between the lower Frontier and upper Mowry Formations (BLM, 1992, p. 5). Given the estimated quantities of reserves, a sustainable level of bentonite clay resources appears to be available to meet demand (BLM, 2009c, p. 2-31).

The Kaycee Bentonite Partnership has submitted Plans of Operations that cover both BLM-administered surface land and split-estate land in the Buffalo planning area. Exploration and mining will probably continue on active bentonite mining claims in the Buffalo planning area where the deposits are profitable to mine. Mining claims with marginally profitable deposits due to current prices or quality of the bentonite can be maintained indefinitely unless the claims are relinquished or found invalid (BLM, 1992, p. 8). **Map 6** presents the bentonite development potential and bentonite permit areas within the Buffalo planning area.

4.1.2 Uranium

Uranium occurrences are distributed worldwide. Australia has the world's largest uranium reserves – 40 percent of the planet's known supply – while Canada is currently the largest exporter of uranium oxide (yellowcake). There are also substantial deposits in South Africa, Gabon, and Russia. Deposits in the United States are all relatively low-grade, ranging from 0.5 to 2.0 percent of uranium oxide per ton (BLM, 2009b, p. 4-33). Within the United States, Wyoming ranks second to New Mexico in amount of reserves and produced just over 2 million pounds of uranium in 2006 (Hoffman and others, 2007, p. 40). Most of the current uranium exploration activity in Wyoming is taking place in Campbell, Johnson, and Converse Counties.

Uranium mining has been cyclical in the Powder River Basin since the last RMP was completed in 1985 (BLM, 1985b). Uranium prices reached an all-time low in 2001, at just $7 per pound for triuranium octoxide (U_3O_8, which represents approximately 70 to 90 percent by weight of yellowcake). The price of triuranium octoxide peaked at over $130 per pound during 2007 (BLM, 2009b, p. 4-35), but during the first quarter of 2009 the spot uranium price hit an average of only $44 per pound (Pett, 2009).

Global production of uranium provides approximately 62 percent of nuclear power utility requirements, with the balance coming from secondary sources (BLM, 2009b, p. 4-33).

Secondary sources include inventories held by utility companies and other fuel cycle companies, government held inventories, previously used reactor fuel which has been reprocessed, recycled nuclear materials from military sources, and uranium from depleted uranium stockpiles. In 2005, approximately 80 percent of the estimated world production of 108 million pounds triuranium octoxide was produced by only eight producers (BLM, 2009b, p. 4-33).

The rich Canadian deposits, located around the rim of the Athabasca Basin in Alberta and Saskatchewan, range from 35 to 70 percent uranium oxide. Rich deposits are also being mined in Australia and Gabon, with lesser grade deposits being mined in South Africa and Namibia.

Current down-blending (the conversion of weapons-grade, highly enriched uranium into fuel suitable for use in commercial nuclear power reactors) contracts between the United States and Russia expire after 2013, which may cause the supply gap to become substantially greater. It is estimated that by 2020, there may be an annual 70 million pound shortage (BLM, 2009b, p. 4-35). A complete analysis of the complexity of global supply and demand and primary and secondary sources is outside the scope of this Report. However, it is generally accepted that only a very large addition of uranium mining and enrichment capacities will fill the anticipated supply gap (BLM, 2009b, p. 4-33). Based on the presence of outcrops, historical and current mining activity, and market demand, uranium deposits within southern Johnson and Campbell Counties appear to be favorable for exploitation. These deposits are found within the Pumpkin Buttes and Kaycee Mining Districts. Current production is obtained from subsurface in-situ solution mining from the Wasatch Formation (BLM, 1992, p. 14).

The estimated recoverable quantity of in-situ uranium is not well known for the Buffalo planning area. However, interested operators can further define recoverable quantities using information gathered from uranium exploration activities and knowledge of uranium roll-front ore deposits, and geophysical well log information collected from coalbed natural gas (CBNG) wells and conventional wells. Powder River Basin uranium companies are currently staking lode mining claims at an accelerated pace. Assuming that the uranium market stabilizes sufficiently to allow for suitable profit margins, current lode mining claim activity is expected to provide these companies with sufficient uranium deposits to sustain them through the upcoming land-use planning cycle.

The potential for uranium resources is a prediction of the likelihood of the occurrence of this mineral within the Buffalo planning area; uranium development potential and uranium permit areas are shown on **Map 7**.

Within the Buffalo planning area, most uranium drilling activity within the planning cycle will likely occur in the Pumpkin Buttes District. Additional exploration is required in order to accurately locate and evaluate uranium (roll-front) ore deposits in this area (BLM, 2001a, p. 161). Most exploration drilling activity will be in support of in-situ recovery (ISR) mining activity.

As indicated in Chapter 3, there is one active in-situ uranium mining operation in the Wyoming portion of the Powder River Basin: Power Resources' Highland/Smith Ranch facility located in Converse County. In addition to this mine, there are two permitted uranium Plans of

Operations within the Buffalo planning area: the Ruth and Christensen Ranch mines. The Nichols Ranch mine is currently in the permitting process.

According to the Wyoming 2007 Mineral and Energy Yearbook (Hoffman and others, 2007), uranium production estimates for 2009, 2010, and 2011 for the counties that fall within the Buffalo planning area are provided in **Table 4-2**. Although some uranium production is likely to occur in the Buffalo planning area, the forecasted production is not probable due to the current global economic downturn. This economic downturn is likely to result in a decreased demand for uranium, including associated exploration and production activities, versus what was predicted by authors of the Wyoming 2007 Mineral and Energy Yearbook (L. Jensen, oral commun., 2009). A lack of necessary plans, permits, and approvals from the BLM, Nuclear Regulatory Commission, and Wyoming DEQ Land Quality Division will also likely contribute to decreased production compared to this estimate.

Table 4-2. Uranium Production Estimates for the Buffalo Planning Area

Year	Campbell County (pounds)	Johnson County (pounds)	Sheridan County (pounds)
2009	200,000	100,000	0
2010	400,000	200,000	0
2011	500,000	250,000	0

Source: Hoffman and others, 2007, p. 92-94

4.1.3 Gypsum

Gypsum deposits are found along the eastern flank of the Big Horn Mountains in Johnson and Sheridan Counties (BLM, 1992, p. 10). The primary gypsum deposits are found in the Goose Egg, Gypsum Spring, and Chugwater Formations.

No known gypsum mining has occurred in the Buffalo planning area. However, there is one mining claim of record in the Buffalo planning area. The relatively steep dip of the gypsum beds exposed along the eastern flank of the Big Horn Mountains in western Sheridan and northwestern Johnson Counties is likely to render these beds uneconomical to mine, assuming current surface mining techniques. Due to the lesser dip of gypsum-containing beds, the most favorable area for gypsum mining is in southwestern Johnson County (BLM, 1992, p. 11). The potential for gypsum resources is a prediction of the likelihood of the occurrence of this mineral within the Buffalo planning area. Gypsum development potential in the Buffalo planning area is indicated on **Map 11**. Present and foreseeable market conditions however, are anticipated to be unfavorable for development of gypsum mining in the Buffalo planning area.

4.2 Solid Leasable Minerals

4.2.1 Coal

Wyoming has the largest federal coal program in the United States. Most Wyoming coal is used for steam generation in the electrical utility industry. Wyoming coal production comes from four primary areas: (1) the Powder River Basin, (2) the Hanna Basin, (3) the Rock Springs area, and (4) the Kemmerer area.

After the Powder River Basin Federal Coal Production Region was decertified in early 1990, regional coal leasing as described under 43 Code of Federal Regulations (CFR) 3420 was abandoned in favor of leasing by application under 43 CFR 3425. Coal production in the United States increased 11 percent from 1,029.1 million tons in 1990 to 1,145.6 million tons in 2007 (Freme, 2007, p. 1). Wyoming coal production increased from 184 million tons in 1990 to 453.6 million tons in 2007, an increase of 147 percent (Freme, 2007, p. 6).

The coal program in the Buffalo planning area represents the largest portion of coal activity that occurs in the Powder River Basin. The economies of communities within the Powder River Basin, especially Gillette and Wright, are dependent on area coal mining activity. BLM-administered lands in central and southern Campbell County and north central Sheridan County are the priority areas available for consideration for coal leasing.

Coal in the Buffalo planning area is produced from 13 existing mines in Campbell County. There is one pending new mine in the planning area, the School Creek mine, which is slated for production in 2010. Coal from Wyoming's Powder River Basin is shipped nationwide.

4.2.1.1. Coal Resources

Coal underlies most of the Buffalo planning area. Most of this coal is low in sulfur and ash and subbituminous in rank. Some of the world's thickest coal deposits occur in Johnson and Campbell Counties, Wyoming (Luppens and others, 2008, p. 1; Jones, 2008, p. 60).

4.2.1.2. Coal Development Potential

Currently within the Buffalo planning area, 494,000 acres of federal coal in eastern and southeastern Campbell County (Subregions 1 through 3) and 73,000 acres in north-central Sheridan County (the Wyoming portions of Subregion 4) are acceptable for further consideration for leasing. There are two main current and historic coal mining areas within the Buffalo planning area. The largest area, the Gillette coal field (Luppens and others, 2008, p. 2) is approximately 15 miles wide and extends from approximately 22 miles north of Gillette, Wyoming, to approximately 25 miles south of Wright, Wyoming. The second area is approximately 20 miles wide and extends from Sheridan, Wyoming, north to the Wyoming/Montana state line (BLM, 2001a, p. 186).

As indicated in the Casper Mineral Occurrence and Development Potential Report (BLM, 2004), in 1999, the United States Geological Survey (USGS) assessed coal resources in the Powder River Basin, to determine the quantity, quality, and the economic and technical feasibility of mining coal likely to be used within the next 20 to 30 years. Basin-wide resources of the Wyodak-Anderson coal zone were estimated to be as much as 550 billion tons (BLM, 2004, p. 4-20). The 2007 USGS Inventory of Assessed Federal Coal Resources and Restrictions to Their Development estimated that, "The Powder River Basin contains nearly 58 percent (over 550,000 million [tons]) of the total federal resources currently assessed" (USGS, 2007, p. vi). However, a 2008 USGS report (Luppens and others, 2008) identified 201 billion tons of coal in 11 coal beds across the 2,000-square-mile Gillette Coalfield, near the towns of Gillette and Wright and in the general area of the existing coal mines. Of this amount, the six primary beds

contain 165 billion tons of available resources lacking restrictions and 77 billion tons of recoverable coal with a stripping ratio of 10:1 or less.

Map 8 indicates coal development potential and federal coal leases and lease applications within the Buffalo planning area.

As discussed above, other areas within the Wyoming portion of the Powder River Basin are underlain by coal, but do not currently have development potential for surface mining due to inadequate quality and/or thickness, and/or excessive depth below the surface. As economic conditions change and as technological advances occur, such as the development of the CBNG play in the Powder River Basin since the 1990s that has allowed energy resources to be extracted from previously unminable coal, the development potential for these other areas may improve.

Price Estimates

According to the Energy Information Administration (EIA), the average real minemouth coal prices (in 2007 dollars) nationally are projected to increase from $25.82 per ton in 2007 to about $30.01 per ton in 2009, then bottom out at $27.94 per ton in 2020 (EIA, 2009a, p. 13). Much of the moderation in coal prices after 2009 is attributable to a shift from more expensive coal production from the Central Appalachian supply region to regions with lower production costs, such as Northern Appalachia, the Eastern Interior, and Wyoming's Powder River Basin. Illustrative of the price difference partially resulting from this lower production cost, EIA coal commodity spot prices for the weeks of March 6 and April 10, 2009 were $13.00 per ton and $8.75 per ton respectively for Powder River Basin coal (8,800 British thermal unit [Btu], 0.8 pound SO_2/one thousand thousand British Thermal Units [mmBtu]), while prices for Central Appalachia coal (12,500 Btu, 1.2 pound SO_2/mmBtu) during these same weeks were $68.20 per ton and $68.95 per ton (EIA, 2009c). Following the low during 2020, coal prices are expected to rise to $28.94 per ton in 2030 nationally (EIA, 2009a, p. 13).

Leasing

Coal leasing is expected to continue in the Wyoming portion of the Powder River Basin as existing reserves are depleted (Section 3.2 of this document provides an overview of the BLM's coal leasing process). The amount of coal being mined from existing leases must be replaced with new reserves for a mine to stay operational. **Table 4-3** lists the quantity of leasing that would be required during five-year increments for the Powder River Basin mines to remain stable.

An inventory in 2001 resulted in 494,000 acres in Campbell County and 73,000 acres in Sheridan County available for further consideration for coal leasing (BLM, 2001a). All competitive leasing is limited to the high priority area.

Table 4-3. Future Coal Leasing Requirements, Powder River Basin

Year	2006-2010	2011-2015	2016-2020
Coal (billion tons)	0.93	2.34	2.93

Source: BLM, 2004, p. 4-23

4.2.1.3. Future Coal Activity

Future Activity

Each year the EIA, a United States government information agency under the Department of Energy, produces an annual energy outlook report. Key findings on coal production and demand predictions in the 2009 draft report are summarized as follows (EIA, 2009a):

- As domestic coal demand grows, United States coal production is projected to increase from 1,147 million tons in 2007 to 1,209 million tons by 2020. By 2030, United States coal production is projected to reach 1,336 million tons.
- Coal (and oil and natural gas) are expected to meet 79 percent of the total United States primary energy supply requirements in 2030, down from 85 percent in 2007. Total coal consumption is expected to grow gradually through 2020 as existing plants are used more intensively and new plants that are already under construction are completed and enter service.
- Overall, energy consumption in the United States is expected to increase by 11 percent from 2007 to 2030 while the population in the United States is expected to increase by 24 percent over the same period. The net result is a decrease in energy consumption per capita at an annual rate of 0.5 percent per year from 2007 to 2030.
- Coal is expected to remain the dominant fuel for electricity generation through 2030. However, natural gas is expected to play a larger role in electricity generation as it is less carbon intensive than coal and because new natural gas-fired plants are much cheaper to construct than new renewable or nuclear plants. The key factor in the increase of electricity generated from natural gas is dampened growth in coal-fired generation as concerns about greenhouse gas emissions and the possible impact of future policies reduce the number of new coal plants added.

Table 4-4 provides the projected annual coal production by county under the lower and upper production scenarios from 2008 through 2020. Estimates for 2008 are included here because actual production figures have not been published at the time of this Report. Also, production figures for Converse County are included because the Antelope Mine (located in the southern portion of the basin) is partially within this county. Although annual production quantities presented in this table were developed during 2005, they remain currently valid with the exception of the period from 2009 through 2010, and possibly 2011. During this period, production is expected to flatten (only slight or no growth) as a result of the current downturn in the global economy and the resultant, anticipated “flattening” of demand for sources of energy, including coal (L. Jensen, oral commun., 2009). Anticipated lower and upper production scenarios for 2020 are 508 million tons and 591 million tons, respectively (ENSR Corporation and Sammons/Dutton, Limited Liability Company [LLC], 2005, p. ES-1).

Table 4-4. Coal Production Estimates for Campbell, Sheridan, and Converse Counties

Year	Campbell	Converse*	Sheridan	Total
Lower Production Scenario (million tons)				
2008	381	21	0	402
2009	386	21	0	407
2010	409	2	5	416
2011	419	2	5	426
2012	429	2	6	437
2013	439	2	7	448
2014	449	2	8	459
2015	461	6	9	476
2016	467	6	9	482
2017	473	6	10	489
2018	479	6	11	496
2019	485	6	12	503
2020	489	6	13	508
Upper Production Scenario (million tons)				
2008	433	21	0	454
2009	445	21	0	466
2010	477	2	5	484
2011	489	2	6	497
2012	501	2	7	510
2013	514	2	8	523
2014	527	2	9	537
2015	522	21	10	553
2016	528	21	11	560
2017	534	21	12	567
2018	541	21	13	574
2019	548	21	14	581
2020	555	21	15	591

Source: ENSR Corporation and Sammons/Dutton, LLC , 2005, p. A-2

* Although Converse County is not within the Buffalo planning area, coal production estimates have been included for Converse County since the Antelope mine is partially located within this county.

4.2.1.4. Impacts of Environmental Regulations

Four major environmental factors are expected to impact demand for Powder River Basin coal:

1. <u>The Clean Air Act Amendments of 1990: Sulfur dioxide and Nitrogen dioxide</u>: Congress created the Acid Rain Program in Title IV of the 1990 Clean Air Act Amendments. The overall goal of the program is to achieve important environmental and public health benefits through reductions in emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x), the primary causes of acid rain (Environmental Protection Agency [EPA], 2009). To help reduce acid rain, the United States EPA is implementing a program to reduce releases of SO_2 and other pollutants from coal-fired power plants. The first phase of the Title IV program began in 1995 for SO_2 and targeted the largest and highest

emitting power plants. The second phase (which started in 2000) set tighter restrictions on smaller coal-, gas-, and oil-fired plants. This program is slated to reduce annual SO_2 emissions by 10 million tons (almost half the 1980 level) between 1980 and 2010.

2. National Ambient Air Quality Standards for Particulate Matter: According to the EPA (EPA, 2009) the Clean Air Act requires EPA to set National Ambient Air Quality Standards (NAAQS) for six criteria pollutants; particle pollution (also known as particulate matter) is one of these. EPA works with partners at state, local, and tribal air quality agencies to meet these standards. EPA revised the air quality standards for particle pollution in 2006. The 2006 standards tighten the 24-hour fine particle standard from the current level of 65 micrograms per cubic meter ($\mu g/m^3$) to 35 $\mu g/m^3$, and retain the current annual fine particle standard at 15 $\mu g/m^3$.
3. Section 112 of the Clean Air Act: This section established the current framework under which EPA regulates mercury and other hazardous air emissions. Under this section, as amended in 1990, Congress identified 189 substances, including mercury, as "hazardous air pollutants." New regulations for the control of mercury emissions are proposed for development and implementation in the 2004 to 2010 timeframe and are the most likely regulations to have an adverse impact on Wyoming coal production (BLM, 2004, p. 4-23).
4. Carbon Dioxide Regulation: In April 2007 the United States Supreme Court ruled that carbon dioxide (CO_2) should be considered a pollutant. The Electric Power Research Institute has attempted to identify a scenario describing the full portfolio of technologies for the electrical energy industry if national policy were to require CO_2 be brought down to 1990 levels (Electric Power Research Institute, 2008, p. vi). There is no regulatory structure or CO_2 emission level or limit that has been set by national policy or law. However, this scenario provides some analysis of the possible impact of regulation as well as decreased demand through energy efficiency, at the user end, in transmission and at the producer end. In February 2009, the EPA indicated it would reopen the possibility of regulating CO_2 emissions from coal-fired power plants. This decision could lead to regulations limiting greenhouse gases emitted by coal-fired power plants (Mufson and Eilperin, 2009).

4.3 Salable Minerals

Salable minerals, or mineral materials, include common varieties of sand, gravel, stone (decorative and building stone), clinker, pumice, and clay, as well as petrified wood. Many of these mineral materials are used in everyday construction, agriculture, and decorative applications. Clinker, sand, and gravel are often used for road building and road maintenance associated with extraction of energy producing minerals such as coal, oil, and gas.

Under the BLM mineral materials program (43 CFR 3600) the BLM manages exploration, development, and disposal of mineral materials either by sale or free use. The BLM does not sell mineral materials at less than fair market value.

The primary mineral materials found in commercial quantities within the Buffalo planning area include sand, gravel, and clinker. Sand and gravel deposits are found scattered along major drainages and are more plentiful near the base of the Big Horn Mountains. Clinker is found in areas along the eastern Powder River Basin margins and scattered areas of Campbell, Sheridan, and northern Johnson Counties. During 2007, the Buffalo Field Office authorized a total of approximately 1.9 million cubic yards of salable mineral disposals (including both sales and issuance of free use permits [FUPs]). Clinker disposals accounted for 1.14 million cubic yards, while sand and gravel accounted for 0.77 million cubic yards (BLM, 2009a).

Demand for mineral materials nationwide is on the increase, with an increase in construction and general growth. Similarly, the Buffalo Field Office has seen an increase in the amount of mineral materials sold and in the number of contracts and request for contracts for mineral materials. The Buffalo Field Office processes the largest number of sales and FUPs of any of the 10 BLM field offices in Wyoming.

Exploration and production of commercially-available mineral materials in the Buffalo planning area is increasing. Local demand and the ongoing need for more mineral material from the public lands for various private and public projects have resulted in a large volume of mineral materials-related work for the Buffalo Field Office. The Buffalo Field Office will continue to work with the mineral materials industry and the public to ensure resource viability while protecting other resources on the ground and preventing unnecessary or undue degradation. It is anticipated that demand for mineral materials will continue to remain about the same in the future, but will depend on the need for these resources by the oil, gas, coal, and other industries, and the population growth in the Powder River Basin (BLM, 2009c, p. 2-51).

The Wyoming portion of the Powder River Basin has about 500 square miles of clinker outcrops. Over 160 square miles of clinker occur in the Rochelle Hills, immediately east of the major coal mines near Gillette and Wright (Heffern and Coates, 2004, p. 32). Sand and gravel deposits are numerous in western Johnson and Sheridan Counties, and scattered in the remainder of Campbell, Johnson, and Sheridan Counties. This allows for a sustainable level of salable mineral resource available to meet demand. The majority of the mineral material resources in the Buffalo planning area are located on either split-estate with federal minerals or on private minerals. Sand and gravel, as well as other mineral materials, are generally part of the federal mineral estate in cases where split-estate exists in the Powder River Basin. Under the 1985 RMP (BLM, 1985b), the majority of lands in the Buffalo planning area, including federally administered surface/minerals and split-estate, are available for mineral material exploration and development. Mineral materials activities are prohibited in the approximately 28,931 acres of the Fortification Creek, Gardner Mountain, and North Fork Wilderness Study Areas (WSAs).

4.3.1 Sand and Gravel

The potential for sand and gravel in the Buffalo planning area is a prediction of the likelihood of the occurrence of these resources and is determined based on visible deposits, current and historical mining activity, and local markets. Major sand and gravel deposits in the Buffalo planning area are indicated on **Map 10**.

Sand and gravel deposits found in the Buffalo planning area are found in western Johnson and Sheridan Counties in the Kingsbury and Moncrief Conglomerates along the eastern flank of the Big Horn Mountains and extending into the Powder River Basin. Other major deposits are found within and/or near floodplains associated with drainages in Campbell, Johnson, and Sheridan Counties. These drainages are listed in **Table 4-5** according to county. These various deposits will provide a sustainable level of mineral material resource availability to meet future demand, which is anticipated to remain about the same as current demand. However, future demand is primarily dependent on oil, gas, coal, and other mineral development in the area as well as local population growth.

Table 4-5. Drainages with Known Deposits of Sand and Gravel in the Buffalo Planning Area

Campbell County	Johnson County	Sheridan County
Donkey Creek	Clear Creek	Badger Creek
Little Powder River	Crazy Woman Creek	Clear Creek
Middle Fork Wild Horse Creek	Piney Creek	Crazy Woman Creek
Powder River	Powder River	Goose Creek
–	Rock Creek	Piney Creek
–	Shell Creek	Powder River
–	–	Prairie Dog Creek
–	–	Soldier Creek
–	–	Tongue River

Source: BLM, 1992, p. 19
– No additional drainages with deposits were identified in this county

4.3.2 Clinker

The potential for development of clinker in the Buffalo planning area is based on the location of clinker outcrops, current and historical mining activity, and local markets. Clinker development potential within the Buffalo planning area is indicated on **Map 12**.

Large quantities of these deposits are found in north-central Johnson County, south-central and north-central Sheridan County, and northern, central, and eastern Campbell County. These vast deposits are expected to meet a future demand that, like for sand and gravel, is anticipated to remain about the same as current demand. Clinker is currently used for road surfacing and pad construction by coal mines, oil and gas firms, and local contractors with limited use by Campbell, Johnson, and Sheridan counties' road departments and the Wyoming Highway Department. Minor volumes are used for landscaping purposes.

4.3.3 Moss Rock and Building Stone

Similar to the previously discussed mineral materials, the potential for moss rock/building stone is determined based on visible deposits, current and historical mining activity, and local markets. Current demand for moss rock/building stone includes building facing, fireplace construction, and sidewalk construction by individuals or small contractors.

The majority of moss rock/building stone is found at numerous locations in the Big Horn Mountains located in southwestern Johnson County. It is anticipated that these deposits will provide a sustainable level of mineral material resource availability to meet a future demand that, like demand for sand and gravel, is anticipated to remain about the same as current resource demand. A common use area has been established in the Buffalo planning area for the collection of moss rock/building stone. All current collecting areas are on BLM-administered surface land with public access in southwestern Johnson County (BLM, 1992, p. 29).

4.4 Mineral Potential Summary

Potential occurrence and development of locatable minerals is associated with bentonite, uranium, and gypsum. The potential occurrence and development of solid leasable minerals in this Report only pertains to coal. Potential occurrence and development for mineral materials is associated with sand, gravel, clinker, and moss rock/building stone. A summary of the potential development of each of these mineral resources is provided below.

Locatable Minerals

Bentonite: The demand for bentonite has remained nearly the same since the current RMP was completed on October 4, 1985 (BLM, 1985b). Bentonite production is expected to remain stable in the near future. Bentonite is only produced from Johnson County.

Uranium: While uranium production is not currently occurring in Campbell and Johnson Counties, the Wyoming 2007 Mineral and Energy Yearbook (Hoffman and others, 2007, p. 92-94) estimated that uranium production would reach 200,000 pounds for Campbell County and 100,000 pounds for Johnson County in 2009 and more than double for each of these counties by 2011. Although some production of uranium is probable, the forecasted production is not likely due to the lack of necessary plans, permits, and approval from the BLM, Nuclear Regulatory Commission, and the Wyoming DEQ Land Quality Division, as well as current economic circumstances that are likely to result in a decreased demand for energy sources, including uranium.

Gypsum: No known gypsum mining has occurred in the Buffalo planning area, and although one mining claim is active, production of gypsum from this claim is not anticipated.

Solid leasable Minerals

Coal: The Buffalo planning area coal program manages 80 to 90 percent of coal production in the Powder River Basin. A slight decrease in coal production is anticipated for the remainder of 2009 due to the current global economic downturn, with a return to coal production growth predicted to occur during 2010 or 2011, and continuing through 2020 (L. Jensen, oral commun., 2009). Current upper and lower coal production estimates for 2020 are 591 million tons and 508 million tons, respectively, most of which is within the Buffalo planning area.

Salable Minerals (Mineral Materials)

Sand and Gravel: Sand and gravel deposits are numerous in western Johnson and Sheridan Counties; deposits are scattered in all other areas of Campbell, Johnson, and Sheridan Counties.

A sustainable level of sand and gravel resources is available to meet demand. Demand for these resources is largely dependent on the growth of Wyoming's economy, particularly the local oil, gas, and coal industries. To a lesser degree, the demand for sand and gravel resources is dependent on state, municipal, and local population growth, which is expected to at least remain steady during coming years.

Clinker: Clinker production is likely to see a growth rate similar to the growth of Wyoming's economy, particularly as this growth pertains to local energy industries. Clinker will continue to be used where it is too expensive to transport better quality sand and gravel over long distances (E. Heffern, written commun[s]., 2009). State, municipal, and local population needs are expected to remain steady.

Moss Rock/Building Stone: The demand for moss rock/building stone mainly comes from local construction companies and private home owners; the demand from these sources is expected to remain steady in coming years.

5.0 RECOMMENDATIONS

No recommendations or potential operating constraints related to mineral development have been identified at this time. However, recommendations relating to continued and future management of solid leasable, locatable and salable mineral resources on federal lands within the Buffalo planning area will be developed during the resource management planning process.

6.0 REFERENCES

American Society for Testing and Materials (ASTM), 1998, ASTM D 388-Standard Classification of Coals by Rank: American Society for Testing and Materials.

Bureau of Land Management (BLM), 1985a, Manual 3031 – Energy and Mineral Resource Assessments: Bureau of Land Management.

BLM, 1985b, Buffalo Resource Area Management Plan Record of Decision (revised 2001): Buffalo, Wyo., Bureau of Land Management.

BLM, 1992, Energy and Minerals Assessment Report for Locatable and Mineral Materials: Prepared for the 2nd Round Buffalo Resource Area Management Plan: Buffalo, Wyo., Bureau of Land Management.

BLM, 2001a, Approved Resource Management Plan for Public Lands Administered by the Bureau of Land Management Buffalo Field Office: Buffalo, Wyo., Bureau of Land Management.

BLM, 2003a, Final Environmental Impact Statement and Proposed Plan Amendment for the Powder River Basin Oil and Gas Project: Buffalo, Wyo., Bureau of Land Management, 4 v.

BLM, 2003b, Final Environmental Impact Statement for the Pittsburg and Midway Coal Mining Company Coal Exchange Proposal: Casper, Wyo., Bureau of Land Management.

BLM, 2003c, IM-2003-253 Policy and Guidance on Conflicts between Coalbed Natural Gas and Surface Coal Mine Development in the Powder River Basin. Available online: http://www.blm.gov/wy/st/en/programs/energy/CAZ/im2003-253.html.

BLM, 2004, Mineral Occurrence and Development Potential Report for the Casper Field Office: Casper, Wyo., Bureau of Land Management.

BLM, 2008a, Analysis of the Management Situation Buffalo Field Office Planning Area: Buffalo, Wyo., Bureau of Land Management.

BLM, 2008b, Powder River Basin Coal Production: Casper, Wyo., Bureau of Land Management. Available online: http://www.blm.gov/wy/st/en/programs/energy/Coal_Resources/PRB_Coal/production.html.

BLM, 2008c, West Antelope II Final Environmental Impact Statement: Casper, Wyo., Bureau of Land Management, 2 v. Available online: http://www.blm.gov/wy/st/en/info/NEPA/cfodocs/West_Antelope_II.html.

BLM, 2009a, LR2000 – Land & Mineral Legacy Rehost 2000 System Database: Bureau of Land Management. Available online: http://www.blm.gov/lr2000.

BLM, 2009b, Mineral Occurrence and Development Potential Report for the Lander Field Office: Lander, Wyo., Bureau of Land Management.

BLM, 2009c, Summary of the Analysis of the Management Situation for the Buffalo Field Office Planning Area: Buffalo, Wyo., Bureau of Land Management.

BLM, 2009d, Powder River Basin Coal Leases by Application: Casper, Wyo., Bureau of Land Management. Available online: http://www.blm.gov/wy/st/en/programs/energy/Coal_Resources/PRB_Coal/lba_title.html.

BLM, 2009e, Percent of Total U.S. Coal Production Mined From The Powder River Basin, Wyoming. Bureau of Land Management. Available online: http://www.blm.gov/pgdata/etc/medialib/blm/wy/programs/energy/coal/prb.Par.5321.Image.-1.-1.1.gif.

BLM Casper Field Office, 2008, Coal leasing geographic information systems (GIS) data: Bureau of Land Management.

Casper Star-Tribune, 2009, Wyo Coal Miners Dig Record Volume in 2008: Casper, Wyo., January 28, 2009.

Cox, D.P., and Singer, D.A., 1986, Mineral Deposit Models: United States Geological Survey Bulletin 1693. Available Online at: http://pubs.usgs.gov/bul/b1693/html/titlpage.htm.

Dunrud, C.R., and Osterwald, F.W., 1980, Effects of Coal Mine Subsidence in the Sheridan, Wyoming Area: United States Geological Survey Professional Paper 1164, 49 p.

Electric Power Research Institute, 2008, The Power to Reduce CO2 Emissions: the Full Portfolio: 2008 Economic Sensitivity Studies: Palo Alto, Calif.

Energy Information Agency (EIA), 2008a, U.S. Uranium Mine Production and Number of Mines and Sources: United States Department of Energy. Available online: http://www.eia.doe.gov/cneaf/nuclear/dupr/umine.html.

EIA, 2008b, Annual Coal Report for 2007: United States Department of Energy. Available online: http://www.eia.doe.gov/cneaf/coal/page/acr/acr_sum.html.

EIA, 2008c, Domestic Uranium Production Report: United States Department of Energy, Report date May 13, 2008. Available online: http://www.eia.doe.gov/cneaf/nuclear/dupr/dupr.html.

EIA, 2009a, Annual Energy Outlook 2009 Early Release Overview: United States Department of Energy. Available online: http://www.eia.doe.gov/oiaf/aeo/overview.html.

EIA, 2009b, World Nuclear Reactors: United States Department of Energy. Available online: http://www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/reactsum2.html.

EIA, 2009c, Average Weekly Coal Commodity Spot Prices. U.S. Department of Energy. Available online: http://tonto.eia.doe.gov/FTPROOT/coal/newsmarket/coalmar090410.html.

ENSR Corporation, 2005, Task 2 Report for the Powder River Basin Coal Review Past and Present and Reasonably Foreseeable Development: Casper, Wyo. Prepared for Bureau of Land Management, Casper Field Office.

ENSR Corporation and Sammons/Dutton, LLC, 2005, Task 3C Report for the Powder River Basin Coal Review Cumulative Social and Economic Effects: Casper, Wyo. Prepared for Bureau of Land Management, Casper Field Office.

Environmental Protection Agency, 2009, What are the Six Common Air Pollutants?: EPA. Available online: http://www.epa.gov/air/urbanair/6poll.html.

Fenneman, N.M. and Johnson, D.W., 1946, Physical Divisions of the United States: Washington, DC, United States Geological Survey; modified by SAIC in 2004.

Flanagan, K.M., and Montagne, J., 1993, Neogene Stratigraphy and Tectonics of Wyoming, *in* Snoke, A.W., Steidtmann, J.R., and Roberts, S.M., eds., Geology of Wyoming: Geological Survey of Wyoming Memoir No. 5, p. 573-607.

Flores, R.M., and Bader, L.R., 1999, Fort Union Coal in the Powder River Basin, Wyoming and Montana: A Synthesis, *in* Fort Union Coal Assessment Team, 1999 Resource Assessment of Selected Tertiary Coal Beds and Zones in the Northern Rocky Mountains and Great Plains Region: United States Geological Survey Professional Paper 1625-A, Chapter PF, Disc 1, version 1.0, p. PF-1 to PF-37.

Flores, R.M., Ochs, A.M., Bader, L.R., Johnson, R.C., and Vogler, D., 1999, Framework Geology of the Fort Union Coal in the Powder River Basin, *in* Fort Union Coal Assessment Team, 1999 Resource Assessment of Selected Tertiary Coal Beds and Zones in the Northern Rocky Mountains and Great Plains Region: United States Geological Survey Professional Paper 1625-A, Chapter PF, Disc 1, version 1.0, p. PS-1 to PS-71.

Freme, Fred, 2007, U.S. Coal Supply and Demand 2007 Review: United States Energy Information Administration. Available online: http://www.eia.doe.gov/cneaf/coal/page/special/feature07.pdf.

Geo/Resource Consultants, Inc., 1987, Geologic Atlas: Geologic Resources Inventory, Powder River Basin, Wyoming: Prepared for Bureau of Land Management.

Harris, Ray E., 2004, Industrial Minerals and Construction Materials Map of Wyoming: Wyoming State Geological Survey Map Series 47, scale 1:500,000.

Harris, Ray E., Debruin, R.H., and Jones, R.W., 1992, Resources in Sedimentary Rocks of the Powder River Basin and Adjacent Uplifts, Northeastern Wyoming: United States Geological Survey Bulletin 1917-N, 10 p.

Hausel, W.D., 1998, Diamonds and Mantle Source Rocks in the Wyoming Craton with a Discussion of other U.S. Occurrences: Wyoming State Geological Survey Report of Investigations No. 53, 93 p.

Heffern, E.L., and Coates, D.A., 1997, Clinker – Its Occurrence, Uses, and Effects on Coal Mining in the Powder River Basin, *in* Jones, R.W., and Harris, R.E., eds., Proceedings of the 32nd Annual Forum on the Geology of Industrial Minerals. Wyoming State Geological Survey Public Information Circular No. 38, p. 151-165.

Heffern, E.L., and Coates, D.A., 2004, Geologic History of Natural Coal-bed Fires, Powder River Basin, USA, *in* Stracher, G.B., ed., Coal Fires Burning around the World: A Global Catastrophe: International Journal of Coal Geology, v. 59, p. 25-47.

Heffern, E.L., Reiners, P.W., Naeser, C.W., and Coates, D.A., 2007, Geochronology of Clinker and Implications for Evolution of the Powder River Basin Landscape, Wyoming and Montana, *in* Stracher, G.B., ed., Geology of Coal Fires: Case Studies from around the World: Geological Society of America Reviews in Engineering Geology, v. XVIII, p. 155-175.

Hoffman, Dale S., Hughes, Sherry, and Fuller, Thomas, 2007, Wyoming 2007 Mineral and Energy Yearbook: Energy Section of the Minerals, Energy & Transportation Division.

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. 45-96.

Lillegraven, J.A., 1993, Correlation of Paleogene Strata across Wyoming – a Users' Guide, *in* Snoke, A.W., Steidtmann, J.R., and Roberts, S.M., eds., Geology of Wyoming: Geological Survey of Wyoming Memoir No. 5, p. 415-477.

Love, J.D., Christiansen, A.C., and Ver Ploeg, A.J., 1993, Stratigraphic Chart Showing Phanerozoic Nomenclature for the State of Wyoming *with cartography by* J.M. Huss, P.A. Ranz, and K.T. Oetting: The Geological Survey of Wyoming, Map Series 41.

Luppens, J.A., Scott, D.C., Haacke, J.E., Osmonson, L.M., Rohrbacher, T.J., and Ellis, M.S., 2008, Assessment of Coal Geology, Resources, and Reserves in the Gillette Coalfield, Powder River Basin, Wyoming: United States Geological Survey Open-File Report 2008-1202, 38 p. plus figures and tables.

Macke, David L., 1993, Cambrian through Mississippian Rocks of the Powder River Basin, Wyoming, Montana, and Adjacent Areas: United States Geological Survey Bulletin 1917-M, 174 p.

Mapel, W.J., 1959, Geology and Coal Resources of the Buffalo – Lake DeSmet Area, Johnson and Sheridan Counties, Wyoming: United States Geological Survey Bulletin 1078, 148 p.

Mears, B. Jr., 1993, Geomorphic History of Wyoming and High-level Erosion Surfaces, *in* Snoke, A.W., Steidtmann, J.R., and Roberts, S.M., eds., Geology of Wyoming: Geological Survey of Wyoming Memoir No. 5, p. 609-626.

Mufson, Steven and Eilperin, Juliet, 2009, EPA May Reverse Bush, Limit Carbon Emissions from Coal-Fired Plants: Washington, DC, Washington Post, February 18, p. A02.

Nuclear Regulatory Commission, 2009, Find Operating Nuclear Power Reactors by Location or Name. Available online: http://www.nrc.gov/info-finder/reactor.

Paydirt, 1999, Interesting Facts about Wyoming Uranium. Available online: http://lithium.vcn.com/~wma/uranium/articles/artframe.htm.

Pett, David, 2009, Sluggish Uranium Prices Leave Cameco Vulnerable: Toronto, Ontario, The National Post, April 6. Available online: http://network.nationalpost.com/np/blogs/tradingdesk/archive/2009/04/06/sluggish-uranium-prices-leave-cameco-vulnerable.aspx.

Sharp, W.N., McKay, E.J., McKeown, F.A., and White, A.M, 1964, Geology and Uranium Deposits of the Pumpkin Buttes Area of the Powder River Basin, Wyoming: United States Geological Survey Bulletin 1107-H, p. 541-638.

Slaughter, M. and Earley, J.W., 1965, Mineralogy and Geological Significance of the Mowry Bentonites, Wyoming: New York, The Geological Society of America, Inc, no. 83.

United States Geological Survey (USGS), 1999, The USGS Abandoned Mine Lands Initiative Fact Sheet. Available online: http://www.usgs.gov/themes/factsheet/095-99/aml.pdf.

USGS, 2007, Inventory of Assessed Federal Coal Resources and Restrictions to Their Development. Prepared by the United States Departments of Energy, Interior, and Agriculture.

Whipkey, C.E., Cavaroc, V.V., and Flores, R.M., 1991, Uplift of the Bighorn Mountains: A Sandstone Provenance Study: United States Geological Survey Bulletin 1917-D, 20 p.

Wyoming Department of Environmental Quality (DEQ) – Air Quality Division, 2007, 2007 Permitted Production Capacities. Available online: http://www.blm.gov/wy/st/en/programs/energy/Coal_Resources/PRB_Coal/deq_aqd.html.

Wyoming DEQ, 2009, AML Dangers. Available online: http://deq.state.wy.us/aml/Dangers.htm.

Wyoming Mining Association, 2008, Uranium Mining: Cheyenne, Wyo., Wyoming Mining Association. Available online: http://www.wma-minelife.com/Brochures/Uranium_08.pdf.

Wyoming Mining Association, 2009, Wyoming Uranium. Available online: http://www.wma-minelife.com/uranium/uranium.html.

Wyoming State Geological Survey, 2009, Coal Bearing Formations: Laramie, Wyo., Nature Science Program, University of Wyoming. Available online: http://www.wsgs.uwyo.edu/coalweb/WyomingCoal/formations.aspx.

Wyoming State Inspector of Mines, 2001, Annual Report of the State Inspector of Mines of Wyoming for the year ending December 31, 2000: Rock Springs, Wyo., pp. 41 and 49.

Wyoming State Inspector of Mines, 2002, Annual Report of the State Inspector of Mines of Wyoming for the year ending December 31, 2001: Rock Springs, Wyo., pp. 39 and 48.

Wyoming State Inspector of Mines, 2003, Annual Report of the State Inspector of Mines of Wyoming for the year ending December 31, 2002: Rock Springs, Wyo., pp. 43 and 53.

Wyoming State Inspector of Mines, 2004, Annual Report of the State Inspector of Mines of Wyoming for the year ending December 31, 2003: Rock Springs, Wyo., pp. 42 and 52.

Wyoming State Inspector of Mines, 2005, Annual Report of the State Inspector of Mines of Wyoming for the year ending December 31, 2004: Rock Springs, Wyo., pp. 43 and 54.

Wyoming State Inspector of Mines, 2006, Annual Report of the State Inspector of Mines of Wyoming for the year ending December 31, 2005: Rock Springs, Wyo., pp. 50 and 61.

Wyoming State Inspector of Mines, 2007, Annual Report of the State Inspector of Mines of Wyoming for the year ending December 31, 2006: Rock Springs, Wyo., pp. 65 and 78.

Wyoming State Inspector of Mines, 2008, Annual Report of the State Inspector of Mines of Wyoming for the year ending December 31, 2007: Rock Springs, Wyo., pp. 61 and 73.