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1.0 INTRODUCTION

1.1 Purpose of Report

The Bureau of Land Management (BLM) – Rawlins Field Office is currently managing BLM-administered land within the Rawlins Field Office area according to the management prescriptions provided in the existing Great Divide Resource Area Record of Decision and Approved Resource Management Plan (RMP), which was published in November 1990. The BLM Rawlins Field Office is preparing an amended RMP since the management prescriptions described in the existing RMP are outdated. The increase in resource development within the Rawlins Field Office area in the last 12 years has lead to associated environmental impacts beyond those analyzed or anticipated in the existing RMP. As part of the RMP process, the BLM is required to prepare a Mineral Occurrence and Development Potential Report, which provides specific information regarding mineral occurrences and development potential within the Resource Management Plan Planning Area (RMPPA) (i.e., Rawlins Field Office Area). This report provides an intermediate level of detail for mineral assessment as prescribed in BLM Manual 3031. Information provided in this report would be incorporated into the Management Situation Analysis as part of the RMP and Environmental Impact Statement (EIS), which would be completed for the RMPPA.

Since the completion of the existing RMP and EIS, oil and gas development has substantially increased within the RMPPA, which has affected the management of natural, human, and other physical resources. Oil and gas development is likely to continue to increase in the RMPPA throughout the 20-year planning period (2001 to 2020), based on information provided in the Reasonably Foreseeable Development (RFD) Report for oil and gas written by the Wyoming State Office Reservoir Management Group (RMG) in Casper, Wyoming. The RFD and discussion of hydrocarbon resource development potential in Chapter 4.0 (Sections 4.1.1 through 4.1.4) were provided by the RMG. All maps, graphs, and discussion are the product of the RMG and it is solely responsible for the content and the conclusions contained therein. In addition, portions of text and graphs in Chapter 3.0 (description of hydrocarbon resources) and the entire text of Section A6.0 (New Technologies) of Appendix A were also provided by the RMG. Demand for other minerals also will likely increase as a result of oil and gas development and population growth within the RMPPA.

A summary of the following chapters in this report is provided below:

- Chapter 2.0, Description of Geology, provides a description of the geologic resources as they relate to historical and future development or use of leasable, locatable, and salable minerals within the RMPPA. Information provided in this chapter includes physiography, stratigraphy, structural geology and tectonics, and historical geology.

- Chapter 3.0, Description of Mineral Resources, describes the leasable, locatable, and salable minerals that have historically occurred and/or currently occur within the RMPPA.

- Chapter 4.0, Mineral Resource Potential, describes the potential development of the leasable, locatable, and salable minerals within the 20-year planning period.

- Chapter 5.0, Recommendations, provides a description of recommendations and prescriptions developed by BLM staff based on the future development of leasable, locatable, and salable minerals for the proper management of natural, human, and other physical resources for the 20-year planning period.

- Chapter 6.0, References, lists the references that were utilized to develop this report.

- Appendix A, Oil and Gas Operations, provides a detailed report regarding future oil and gas development within the RMPPA.

1.2 Lands Involved and Record Data

The RMPPA is located in southeastern Wyoming and includes approximately 3.5 million acres of public surface and 4.7 million acres of federal mineral estate **(Figure 1-1)**. The RMPPA boundary includes all or nearly all of Laramie, Albany, and Carbon Counties and a substantial portion of Sweetwater County. Other land categories present within the general RMPPA boundary include land managed by the U.S. Forest Service (USFS), Bureau of Reclamation (BOR), State of Wyoming, and private land. In addition, USFS lands are present at various locations adjacent to and/or within the delineated RMPPA boundaries. Since BLM does not manage USFS lands, this report does not include an assessment of mineral occurrence or development potential for those minerals present on or beneath USFS lands.

Information provided in this report was obtained from published geologic reports and maps, various technical files and maps, the RFD provided by the Wyoming State Office RMG, computer databases, field review of current mineral development operations within the RMPPA, and personal communications with technical experts.

Figure **1-1** General Location Map of the RMPPA

2.0 DESCRIPTION OF GEOLOGY

2.1 Physiography

The Rawlins RMPPA is located in three major physiographic provinces: the Wyoming Basin, the Southern Rocky Mountains, and the Great Plains (Howard and Williams, 1972). **Figure 2-1** depicts the RMPPA in relation to the physiographic elements. The western and northwestern portions of the RMPPA are located in the Wyoming Basin, a 40,000-square-mile area that includes much of southwestern Wyoming and part of northwestern Colorado. The Wyoming Basin Province is typified by topographic and structural basins that are either bounded by mountains in the adjacent provinces or bounded by ranges within the province itself. There are several west-east trending mountain ranges in the north-central part of the RMPPA. The ranges are, from west to east, the Ferris Mountains, the Seminoe Mountains, and the Shirley Mountains. The Ferris Mountains are up to 10,000 feet national geodetic vertical datum (NGVD) while the Seminoe and Shirley Mountains peak about 9,500 NGVD.

Sub-basins of the Wyoming Basin within the RMPPA boundaries include the Washakie and Great Divide Basins of the eastern Greater Green River Basin, the Hanna Basin, Carbon Basin, Kindt Basin, Shirley Basin, and the Laramie Basin. In the basin areas the topography is typified by rolling plains dissected by badlands.

Elevations in the sub-basins of the Wyoming Basin portion of the RMPPA generally range from 6,500 to 7,500 feet (NGVD). The Great Divide Basin is bounded by branches of the Continental Divide and has no external drainage outlet. Major river drainages in the Wyoming Basin portion of the RMPPA are the North Platte River, Laramie River, and the Little Snake River. All of these rivers head in the Southern Rocky Mountains.

A small part of the Southern Rocky Mountains Province is in the south and south-central portions of the RMPPA. The Southern Rocky Mountains extends through northern New Mexico, Colorado, and southern Wyoming. Mountain ranges in the southern part of the RMPPA consist of the northernmost portions of the Southern Rocky Mountains. Those ranges are the Laramie Mountains, Medicine Bow Mountains, and the Sierra Madre (the northern extension of Colorado's Park Range). The portions of the planning area on the flanks of the mountains generally range from 7,500 to 8,000 feet NGVD with the highest point in the Rawlins RMPPA being Elk Mountain at 11,156 feet NGVD. In many places, hogback ridges mark the flanks of the mountain ranges.

The southeastern portion of the planning area is located in the Great Plains province in a sub-province called the High Plains (U.S. Geological Survey [USGS], 1970). The High Plains are characterized by nearly flat-lying Tertiary deposits with mesas and badland topography. A prominent physiographic feature in southeastern Wyoming is called the "Gangplank," so-called

Figure **2-1** Physiographic Provinces in Relation to the Wyoming Basin because the Tertiary rocks form a long sloping surface up to the 7,000-foot level of the Laramie Range (Howard and Williams, 1972). Elevations in the High Plains portion of the RMPPA range from 7,000 feet at the east flank of the Laramie Range to less than 5,000 feet NGVD in northeastern Laramie County.

In this portion of the RMPPA, drainages head in the Laramie Range and flow from west to east. The important drainages from south to north include Crow Creek, Lodgepole Creek, Horse Creek, and Little Bear Creek. Crow Creek eventually empties into the South Platte River in Colorado and the others are in the North Platte River basin.

2.2 Stratigraphy

The rocks in the planning area range in age from Precambrian to recent deposits (**Figure 2-2**). In the eastern Green River Basin, at the western edge of the RMPPA, the total thickness of sedimentary rock above the Precambrian is about 30,000 in the Washakie Basin (Kent, 1972). The Hanna Basin contains a thick sequence of post Precambrian rocks which is estimated to be greater than 42,000 feet (Law, 1995). Precambrian rocks are generally exposed in the cores of the mountain ranges and smaller uplifts such as the Rawlins uplift. In southeastern Wyoming in the northwest portion of the Denver-Cheyenne Basin, the sedimentary rock section is slightly more than 10,000 feet thick (Kent, 1972). Paleozoic, Mesozoic, and Cenozoic rocks are exposed throughout the RMPPA.

2.2.1 Precambrian Era

The Precambrian rocks that are exposed in the mountain ranges are complex assemblages of igneous and metamorphic rocks (Houston, 1993). The Precambrian rocks that form the basement of the various basins within the RMPPA also are presumed to be similar to the rocks exposed in the mountain ranges (Simms and others, 2001).

2.2.2 Paleozoic Era

2.2.2.1 Cambrian System

Cambrian rocks are present in the west and northwest portion of the RMPPA (Boyd, 1993). The rocks consist of coarse-grained sandstone and conglomerate of the middle Cambrian Flathead Sandstone and sandy shale of the upper Cambrian Buck Springs Formation (Watson, 1980). The Cambrian rocks thin from west to east across the RMPPA from about 1,000 feet thick in the Washakie Basin to zero feet along a line trending from the north end of the Sierra Madre to the north end of the Laramie Range (Lachman-Balk, 1972). Cambrian rocks are not present east of this line.

Figure **2-2** Stratigraphic Nomenclature Chart

2.2.2.2 Ordovician, Silurian, and Devonian Systems

There are no widespread rocks representing Ordovician through Devonian; however, the Ordovician Bighorn Dolomite and Devonian Darby Formation are present further west in the Green River Basin (Boyd, 1993). There is evidence that rocks of the Ordovician and Silurian were present, but were eroded at a later time. In diatremes (diamond-bearing intrusive rocks) of the southern Laramie Mountains, blocks (xenoliths) of rocks containing fossils of Ordovician and Silurian age are present. The diatremes may be of Silurian or Devonian age.

2.2.2.3 Mississippian System

The Mississippian System is represented by the Madison Limestone and the Darwin Sandstone in the western portion of the RMPPA, but the Mississippian rocks thin from west to east until they are absent east of line from Centennial, Wyoming to northwest Laramie County (Boyd, 1993). The Madison Limestone and equivalents are extensive in the Rocky Mountain region from northern Arizona to Montana and North Dakota (Craig and others, 1972). In the northwest portion of the RMPPA, the Madison consists of a lower coarse sandstone and an upper limestone unit (Watson, 1980). The Madison ranges from about 600 in the northeast Great Divide Basin to about 60 feet thick near Elk Mountain. It also is present in the Hanna, Shirley, and Laramie Basins but is mainly composed of limestone with thin sandstone at the base (Watson, 1980). The Darwin Sandstone is the basal member of the Amsden Formation and is white cross-bedded sandstone and may only be present in the northwest corner of the RMPPA (Craig and others, 1972; Boyd, 1993).

2.2.2.4 Pennsylvanian System

Pennsylvanian rocks in the RMPPA consist of the Amsden Formation, the Tensleep Sandstone, the Casper Formation, and the Fountain Formation. Aggregate thickness of Pennsylvanian rocks in the planning area is generally about 500 feet with appreciable thinning next to the mountain ranges (Mallory, 1972). In the southeastern portion of the area, Pennsylvanian age rocks may be up to 750 feet thick. The Amsden Formation occurs in the western portion of the planning area and consists primarily of shale but includes limestone, siltstone, dolomite, and anhydrite (Watson, 1980). Where the Darwin Sandstone Member of the Amsden Formation is present, it appears at the base of the shale in the Amsden and is probably upper Mississippian as discussed above. The Tensleep Sandstone is composed of fine-grained sandstone with minor limestone and dolomite beds (Watson, 1980). The Tensleep and Casper Formations are aeolian deposits of an extensive sand sea that covered most of Wyoming. These sandstones generally display massive bedding and relatively good porosity and permeability. These formations are good aquifers but are also productive of hydrocarbons in structural traps. In the eastern Washakie Basin, the Tensleep Sandstone is very well cemented and is considered a quartzite in places. In the Hanna, Shirley, and Laramie Basins the Casper Formation, equivalent to the Tensleep Sandstone, consists of massive interbedded sandstone and dolomite (Watson, 1980). The sandstone is generally fine-grained and quartzitic. The Fountain Formation occurs in the Denver-Cheyenne Basin and portions of the southern Laramie Basin and is composed of coarse-grained to conglomeratic sandstone with interbedded shale and limestone lenses. The Fountain Formation is equivalent to the Casper Formation.

2.2.2.5 Permian System

In the western part of the RMPPA, Permian rocks are represented by the Phosphoria Formation and the Goose Egg Formation. In the Washakie Basin, the Phosphoria consists of about 250 feet of limestone, dolomite, interbedded chert, and minor shale (Watson, 1980; Peterson, 1984). Further east in the Hanna, Laramie, and Shirley Basins the Phosphoria equivalent Goose Egg Formation consists of red shale and siltstone with thin beds of anhydrite and dolomite (Watson, 1980). The Goose Egg thickens from about 350 feet in the Shirley Basin to over 500 feet in the Laramie Basin. In the Denver-Cheyenne Basin, the Permian rocks are represented by the Satanka Shale and the Forelle Limestone (Love and others, 1993). The Satanka Shale is composed of red shale and siltstone and evaporite deposits (Watson, 1980). Permian rocks may exceed 1,000 feet in thickness in eastern Laramie County (Rascoe and Baars, 1972).

2.2.3 Mesozoic Era

2.2.3.1 Triassic System

The Dinwoody Formation, Chugwater Group, and the Nugget Sandstone represent Triassic rocks in the western and northern parts of the RMPPA. The Dinwoody consists of dolomite that grades southward to red shale and anhydrite (Watson, 1980). The Chugwater Group is composed of members that consist of red shale, limestone, and sandstone (Watson, 1980). The Nugget Sandstone is present in the western part of the RMPPA but thins to the east and may interfinger with the upper member of the Chugwater Group. In the Denver-Cheyenne Basin, the Triassic rocks are referred to as the Chugwater Formation. The Chugwater is similar to the Goose Egg Formation and consists of red shale, limestone, and sandstone (Watson, 1980).

2.2.3.2 Jurassic System

The Jurassic Formations in the planning area consist of the Nugget Sandstone Sundance Formation, and Morrison Formations. The total aggregate thickness of the Jurassic rocks across the area is 350 feet or less and thins to the south (Peterson, 1972). The Nugget Sandstone also is lower Jurassic and is not present east of the Rawlins area (Love and others, 1993). The middle Jurassic Sundance Formation consists of sandstone and shale. The Canyon Springs Sandstone in the lower part of the Sundance Formation is fairly widespread across the area. The Canyon

Springs often consists of a calcareous, oolitic sandstone with well-rounded and frosted quartz grains (Watson, 1980). Generally, the upper portion of the Sundance Formation has more shale.

The Morrison Formation, which is upper Jurassic, is characterized by shale of various colors (often red, green, and purple) with interbedded sandstone, siltstone, and conglomerate (Watson, 1980). In the eastern Hanna Basin at Como Bluff, outcrops of the Morrison Formation have yielded abundant dinosaur bones (Mears and others, 1986).

2.2.3.3 Cretaceous System

When describing Cretaceous rocks, they are usually divided into upper and lower Cretaceous. The thickness of lower Cretaceous rocks in the planning area ranges from about 500 feet in the northwestern portion of the planning area to about 250 feet in the southeastern corner of Wyoming (McGookey and others, 1972). Upper Cretaceous rocks may be up to 16,000 feet thick in the Hanna Basin and in other parts of the planning area range from 8,000 to 10,000 feet thick.

2.2.3.4 Lower Cretaceous

The lower part of the lower Cretaceous are sandstones that are loosely correlated and referred to as the Lakota Sandstone, and Fall River Sandstone. The Lakota and Fall River are sometimes indistinguishable, but the Lakota is often conglomeratic. The sandstones are occasionally separated by a shale called the Fuson Shale, but it is often not present (McGookey and others, 1972; Watson, 1980). These sandstones are sometimes referred to as the Cloverly Formation in the western and northern parts of the planning area (Love and others, 1993). Above the Lakota and Fall River Sandstones is the Thermopolis Shale that is a black marine shale. In the Denver-Cheyenne Basin, this shale has been called the Skull Creek Shale. Above the Skull Creek and Thermopolis Shales is the Muddy Sandstone, a widespread sandstone of variable composition. In the Denver-Cheyenne Basin, the Muddy Sandstone is referred to as the “J” Sandstone, a subsurface terminology (Watson, 1980).

2.2.3.5 Upper Cretaceous

In the western parts of the RMPPA, the upper Cretaceous consists of the Mowry Shale, Frontier Formation, Niobrara Formation, Steele (Baxter) Shale, the Mesaverde Group, the Lewis Shale, and the Lance Formation. The Frontier Formation is composed of sandstone, dark shale, and local coals (Watson, 1980). The Mowry Shale overlies the Muddy and is composed of black siliceous shale characterized by numerous bentonite beds. The Niobrara Formation and Steele Shale are composed of gray to black marine shale. The top of the Niobrara is often composed of limestone or calcareous shale (McGookey and others, 1972). Overlying the Steele Shale is the Mesaverde Group that consists of the Haystack Mountain Formation, Allen Ridge Formation, the Pine Ridge Sandstone, and the Almond Formation (Love and others, 1993). The Mesaverde Group is a designation for widespread upper Cretaceous sedimentary rocks in the Greater Green

River Basin consisting of sandstone, carbonaceous shale, and coal (Ver Ploeg, 1992). After the Mesaverde is the Lewis Shale, which is a dark gray marine shale that contains isolated sandstone bodies and siltstone beds. Bentonite beds also are present in the lower part of the Lewis. Overlying the Lewis Shale in the western part of the planning area is the Fox Hills Sandstone. The uppermost Cretaceous in the western part of the planning area is the Lance Formation. The Lance is made up of carbonaceous shale, sandstone, siltstone, and coal (Watson, 1980). In the Hanna, Shirley, and Laramie Basins the last upper Cretaceous units are the Medicine Bow and Ferris Formations that are composed of carbonaceous shale, coal, and sandstone.

In the Denver-Cheyenne Basin portion of the planning area, the lowest upper Cretaceous units in ascending order are the Graneros Shale, Greenhorn Formation, Carlile Shale, and Niobrara Formation. The aforementioned units consist largely of limestone, shale, chalk, and occasional sandstone. Above the Niobrara Formation is a dark gray marine shale called the Pierre Shale. Within the middle part of the Pierre are a number of sandstones that in the Denver-Cheyenne Basin are referred to as the Hygiene and Terry sandstones (Watson, 1980). These sandstones are correlative to the Parkman and Teapot Sandstones of the Powder River Basin. Overlying the Pierre Shale is the Fox Hills Sandstone. The Lance Formation overlies the Fox Hills Sandstone in the northern part of the Denver-Cheyenne Basin (Lilligraven, 1993).

2.2.4 Cenozoic Era

2.2.4.1 Tertiary System

The earliest Tertiary rocks (Paleocene Series) in the western portions of the planning area are in the Paleocene Fort Union Formation that is composed of sandstone, conglomerate, shale, and coal (Watson, 1980). In the Hanna, Shirley, and Laramie Basins the Paleocene is represented by the Ferris and Hanna Formations. The Ferris, which also may be upper Cretaceous in part, consists of carbonaceous shale, sandstone and conglomerate, and numerous coalbeds (Love and others, 1993; Watson, 1980). The Hanna Formation is later Paleocene and is similar in lithology to the Ferris Formation. Love and Christiansen (1985) indicate that large quartzite boulders are present in the Hanna Formation in areas near the Medicine Bow Mountains. There are no lower Tertiary rocks in the Denver-Cheyenne Basin (Lilligraven, 1993).

Eocene Series rocks in the western part of the RMPPA are the Wasatch and Green River Formations which attain a thickness of 4,500 to 5,000 feet in the Great Divide Basin and Washakie Basins (Roehler 1992). The Wasatch and Green River Formations thin rapidly to the east and are generally not present at the eastern boundary of the Green River Basin. The Wasatch Formation is generally described as being composed of mudstone, red sandstone, carbonaceous shale, and sub-bituminous coal (Watson, 1980). The main body of the Green River Formation is further west of the RMPPA and occupies the central and southwest portion of the Green River Basin. The Green River Formation is composed of numerous members that are generally composed of shale, oil shale, marlstone, and occasional sandstone and some members of the Wasatch and Green River Formations are interbedded (Roehler, 1992).

In the Shirley and Laramie Basins, the Eocene is represented by the Wind River and Wagon Bed Formations. The Wind River Formation is described as being composed of sandstone, conglomerate, mudstone, carbonaceous shale, and minor coal (Watson, 1980). The Wagon Bed Formation consists of bentonitic claystone and conglomerate (Love and Christiansen, 1985). In the RMPPA, the Wind River Formation is only found in the Shirley and Laramie Basins. In the Denver-Cheyenne Basin, there are no Eocene rocks (Love and others, 1993).

Oligocene White River Formation is present in the western part of the RMPPA and in the Hanna, Shirley, and Laramie Basins. The White River consists of bentonitic mudstone, sandstone, and altered and unaltered volcanic debris (Watson, 1980). The Bishop Conglomerate, which is equivalent to the White River, is found in the Washakie Basin and is composed of quartzite, chert, and limestone clasts in a sandstone matrix (Love and Christiansen, 1985). The White River Formation in the Denver-Cheyenne Basin is composed of the Chadron and Brule Members. The Chadron is highly variable and consists of sandstone and clay. The Brule is composed of calcareous clay and silt and volcanic ash. The White River in the Denver-Cheyenne Basin may contain vertebrate fossils in isolated localities (Watson, 1980).

In the western parts of the RMPPA, the Miocene is represented by the Browns Park Formation and Split Rock Formations and are composed of tuff (material derived from volcanic eruptions), tuffaceous sandstone, mudstone, and quartzite (Love and Christiansen, 1985). The base of the Browns Park usually has a conglomeratic zone (Watson, 1980). An upper Miocene unit, the North Park Formation is limited to the Saratoga Valley and is composed of tuffaceous sandstone, siltstone, claystone, and conglomerate. In the Denver-Cheyenne Basin, the Miocene Ogallala Formation covers the surface in most of Laramie County (Love and Christiansen, 1985). The Ogallala is composed of tuffaceous mudstone, sandstone, and conglomerate. In northeastern Laramie County, the upper Oligocene and Miocene Arikaree Formation is present and is composed of soft sandstone, tuffaceous claystone, and siltstone.

2.2.4.2 Quaternary System

Unconsolidated Quaternary deposits consist of alluvium, terraces, colluvium, gravels, pediments, and glacial deposits (Love and Christiansen, 1985). Alluvial deposits are generally associated with alluvial valleys of the major rivers and tributaries. Glacial deposits are limited to the Medicine Bow Mountains and Sierra Madre and are largely composed of boulders, cobbles, and fine materials that were scoured from the mountains by the glaciers.

2.3 Structural Geology and Tectonics

Figure 2-3 shows the major structural elements of the RMPPA. The Laramie and Medicine Bow Mountains and Sierra Madre are composed of Precambrian rocks that have been uplifted by low-to high-angle reverse faults. **Figure 2-4** shows a diagrammatic cross-section across the RMPPA. These major mountain ranges are typical of the nature of the predominant structural style found in mountain ranges of Wyoming, Colorado, Utah, and Beartooth Mountains of Montana. The cores of the ranges contain Precambrian rocks that have been uplifted many thousands of feet through movement on low-angle to high-angle reverse faults. The nature of the faulting in these mountain ranges was first postulated by Berg (1961) on the structure of the Wind River Mountains. He described the main fault as a low-angle reverse fault or thrust fault based on seismic records. The exact geometry of the thrust is more complicated than the first proposed model and the Precambrian wedge on the west flank of the mountain range is probably highly fractured (Berg, 1983). These mountain ranges are unique to the Western Hemisphere in structural style (Grose, 1972).

In addition to the major mountain ranges, there are smaller scale uplifts with Precambrian cores within the RMPPA such as the Ferris, Seminoe, Shirley Mountains, and the Rawlins Uplift. The Rawlins Uplift is an asymmetric anticline bounded by a reverse fault on the west. An anticline is a geologic structure in which the rocks have been folded in a convex upward shape (Gary and others, 1974). The Ferris, Seminoe, and Shirley Mountains are uplifted Precambrian blocks that were originally part of the Sweetwater Uplift that also was uplifted during the Laramide Orogeny. The Laramide Orogeny involved basement core uplifts along low- to high-angle reverse faults that began at the end of Cretaceous. Later in Tertiary time the uplift subsided (Blackstone, 1971). The Ferris and Seminoe Mountains are bounded on the north by normal faults that mark the boundary of the south side of the Granite Mountains, remnants of the subsided Sweetwater Uplift (Mears and others, 1986). This type of subsided block is called a graben.

In addition to major faults at the boundaries of the mountain ranges and smaller uplifts, there is a major shear zone in the RMPPA called the Cheyenne Belt **(Figure 2-3)**. The Cheyenne Belt is a series of southwest to northeast trending fault blocks that cut through the Precambrian rocks of the Sierra Madre, the Medicine Bow Mountains, and the Laramie Mountains (Houston, 1993). The Cheyenne Belt separates metamorphic sedimentary rocks on the north side from largely igneous rocks to the south of the belt.

On the west side of the RMPPA are sub-basins on the eastern edge of the Greater Green River Basin called the Washakie and Great Divide Basins. The Washakie and Great Divide Basins are separated by a structural high called the Wamsutter Arch that generally trends from west to east paralleling Interstate 80 (I-80). The Washakie Basin is bounded on the south by another west to east trending structural high called the Cherokee Arch. The Cherokee Arch lies generally along the Wyoming-Colorado state line and separates the Washakie Basin from the Sand Wash Basin

Figure **2-3** Major Structural Elements of the Rawlins RMPPA

Figure **2-4** Diagrammatic Cross-section of Southeastern Wyoming in northwest Colorado (Law, 1995). Other smaller basins entirely within the RMPPA are the Hanna, Shirley, and Laramie Basins. In the eastern part of the RMPPA is the Denver-Cheyenne Basin that occupies northeast Colorado, southwest Nebraska, and southeastern corner of Wyoming. Within these basins are anticlines commonly along the basin margins. These anticlines are generally asymmetric and faulted at depth and provide traps for hydrocarbons.

2.4 Geophysics and Geochemistry

No information on geophysics and geochemistry was obtained for this project.

2.5 Historical Geology

2.5.1 Cambrian through Mississippian Periods

During Paleozoic time, present-day Wyoming and much of the Rocky Mountain west were located along a fairly stable continental shelf (Lageson and Spearing, 1991). The area was generally inundated by shallow seas, and fluctuations in sea level resulted in the deposition or erosion of sediments. The rocks that were deposited on this shallow continental shelf were the result of numerous changes in sea level referred to as transgressions (relative rise in sea level); or regressions (relative falling of sea level or movement of coastlines seaward). Changes in sea level also caused many deposits to be eroded, resulting in unconformities (or gaps) in the rock record. The limestone, dolomite, and shale deposited from Cambrian to Mississippian are typical of rocks that were originally deposited in a shallow marine environment. In the RMPPA, sedimentary Ordovician and Silurian rocks are present only as xenoliths in diatremes that may been emplaced in Silurian or Devonian time (Boyd, 1993).

2.5.2 Pennsylvanian-Permian Periods

The sandstones of the Pennsylvanian represent an influx of sediment from an aeolian (wind-blown) sand sea to the west of a north-south seaway along the eastern border of Wyoming. The geological setting was similar to the Persian Gulf at present with Wyoming no more than 15 degrees north of the Equator (Trotter, 1984). Erosion from the uplifts resulted in the deposition of the Tensleep Sandstone and equivalents across the Rocky Mountain region. Locally, in the Laramie and Denver-Cheyenne Basins, the Fountain Formation is composed of clastic debris shed from the Ancestral Rockies. The Permian rocks indicate alternating shallow marine to continental environments as indicated by the shale, limestone, and anhydrites in the Phosphoria and Goose Egg Formations and Satanka Shale (Boyd, 1993).

2.5.3 Triassic-Jurassic Periods

Shallow marine conditions appear to have been predominant in early Triassic with deposition of the Dinwoody Formation, however without the organic-rich material as was available during deposition of the Phosphoria Formation. Conditions in the later Triassic changed greatly compared with earlier Triassic. During much of the late Triassic and Jurassic Periods, the Wyoming shelf was emergent and much of the deposits laid down were terrestrial in origin typified by the red beds and evaporites of the Chugwater Group (Picard, 1993). In the western part of the RMPPA, the Nugget was deposited in late Triassic-early Jurassic mainly in an aeolian environment as sand dunes. The Sundance Formation deposits are representative of a transgressive-regressive sequence during later Jurassic. This seaway incursion was the first advance of the Western Interior Seaway from the north. The Canyon Springs Sandstone Member was deposited during the advance of the sea onto the Wyoming shelf (Picard, 1993). At the end of the Jurassic terrestrial conditions predominated resulting in the Morrison Formation which is characterized by stream deposits that were laid down on an alluvial plain.

2.5.4 Lower Cretaceous Period

During Cretaceous time, a feature known as the Western Interior Seaway developed from the Gulf of Mexico to the Arctic Ocean (McGookey and others, 1972). During the Cretaceous there were numerous episodes of transgressions and regressions that resulted in the deposition of thousands of feet of sedimentary rock. The lower part of the Cloverly Group (Lakota Conglomerate) was deposited in alluvial fan and fluvial environments on the western shore of the seaway (Steidtmann, 1993). Following the deposition of the Dakota Conglomerate, the first major Cretaceous transgression began resulting in the deposition of the marginal marine Fall River Sandstone then the Thermopolis-Skull Creek Shales. A regression followed that resulted in the deposition of the widespread Muddy Formation.

2.5.5 Upper Cretaceous-Tertiary Periods

At the close of the lower Cretaceous, sea level rose and the Mowry shale was deposited. The Frontier Formation resulted from several transgression-regression cycles and from west to east grades from fluvial to marine (Steidtmann, 1993). The near shore and transitional marine deposits of the Frontier Formation in the western parts of the RMPPA grade to the east into the Graneros Shale and Greenhorn Limestone which represent shallow marine conditions. After the Frontier, the Niobrara transgression resulted in the deposition of the marine Carlile Shale, Niobrara Formation, Steele Shale sequence (McGookey and others, 1972). Following the Niobrara Transgression, a regressive sequence composed of sandstone and shale was deposited in near-shore and marginal marine environments (Steidtmann, 1993). In the western part of the RMPPA, this regressive sequence is called the Mesaverde Group. However, to the east, the Mesaverde equivalents, the Pierre shale and associated sandstones, are marine in origin. The last major Cretaceous transgression resulted in the deposition of the Lewis Shale. Within the Lewis Shale are sandstones and siltstones that were deposited in marine and transitional marine environments (Van Horn and Shannon, 1989).

Throughout the Cretaceous, mountain building occurred west of the Green River Basin in the area of the western Wyoming-eastern Idaho Thrustbelt. As the mountains were uplifted, erosion occurred and sediment was shed into the shallow Cretaceous seaway. In the RMPPA, the uppermost Cretaceous unit are the Lance Formation and Medicine Bow Formations which are composed of alluvial plain deposits marking the end of the Cretaceous (Lilligraven, 1993). Also at the end of the Cretaceous and the beginning of Tertiary time, another episode of mountain building was occurring in the area. This episode of mountain building is referred to as the Laramide Orogeny (Lageson and Spearing, 1991). The uplift of the Precambrian basement occurred in the structural style described above; movement of Precambrian basement blocks along low- to high-angle reverse faults. This period of mountain building resulted in the mountain ranges of the Southern and Middle Rocky Mountains. The uplifted blocks of basement rock were eroded and the sediment was deposited resulting in the Fort Union, Wasatch, Ferris, Hanna, and Wind River Formations. As mountain building subsided, the area of the Green River Basin became a large lake. Sediments associated with this lake are represented by the Green River Formation in the western part of the RMPPA. The Green River Formation contains abundant fossils and organic-rich rock referred to as oil shale.

In later Tertiary (Oligocene-Miocene), large volcanic eruptions occurred to the west and north of the area. Prevailing winds carried the ash aloft over an extensive area and thick layers of ash were deposited as a result of these eruptions. These ash deposits are found in the White River Formation. Also in later Tertiary time, one more episode of uplift occurred, again resulting in the deposition of material in the basins resulting in the Browns Park, North Park, Ogallala, and Arikaree Formations. Erosion of the Tertiary deposits by the end of Tertiary and the beginning of Quaternary resulted in the emergence of the present-day topography. The “Gangplank” in Laramie County is an erosional remnant of Tertiary rock and is evidence that by late Tertiary, the Rocky Mountains were nearly buried in debris that was shed from them (Blackstone, 1996). Erosion along the mountain fronts has removed the mantle of Tertiary deposits in most places resulting abrupt changes in elevation along the mountain fronts.

2.5.6 Quaternary Period

During Quaternary, there were several episodes of glaciation. Evidence of the several glaciations is exhibited in the Medicine Bow Mountains and Sierra Madre. Valley glaciers and icecaps over the mountain ranges probably began to recede about 15,000 years ago (Knight, 1990). The glacial deposits consist of lateral moraines, end moraines, and glacial outwash deposits that were laid down during successive glacial episodes. Small glacial lakes were formed in the Snowy Range in the core of the Medicine Bow Mountains. Continued erosion of the mountain ranges has resulted in the deposition of alluvial and terrace deposits in the basins.

3.0 DESCRIPTION OF MINERAL RESOURCES

Categorization of mineral resources as "locatable," "leasable," or "salable" is based upon provisions of the Act of May 10, 1872, otherwise known as the General Mining Law of 1872. The General Mining Law of 1872 declared "all valuable mineral deposits in lands belonging to the United States……to be free and open to exploration and purchase." The federal regulations further defined a "locatable mineral" or a "valuable mineral" as being whatever is recognized as a mineral by the standard authorities, whether metallic or other substance, when found in public lands in quantity and quality sufficient to render the lands valuable on account thereof."

Whether or not a particular mineral deposit is locatable depends on such factors as quality, quantity, mineability, demand, and marketability. Over time, the number of locatable minerals originally authorized by the General Mining Law of 1872 has been substantially reduced by several subsequent acts, with two of the primary acts being as follows:

- the Mineral Leasing Act of 1920, as amended; and
- the Materials Act of July 31, 1947, as amended.

The Mineral Leasing Act of 1920, as amended, authorized that deposits of oil, gas, coal, potassium, sodium, phosphate, oil shale, native asphalt, solid and semi-solid bitumen, and bituminous rock including oil-impregnated rock or sands from which oil is recoverable only by special treatment after the deposit is mined or quarried, and the deposits of sulfur in Louisiana and New Mexico may be acquired only through a mineral leasing system.

The Materials Act of July 31, 1947, as amended by the Act of July 23, 1955, further excluded common varieties of sand, stone, gravel, pumice, pumicite, cinders and clay. However, *uncommon* varieties of sandstone, gravel, pumice, pumicite, cinders and clay remained as "locatable." Those minerals considered non-locatable generally have a normal quality and a value for ordinary use, and include ordinary deposits of clay, limestone, fill material (e.g., sand and gravel), etc. (Maley, 1977).

The minerals occurrence and development potential for fluid minerals in the Rawlins RMPPA have been evaluated in the RFD report for oil and gas prepared by the Wyoming Reservoir Management Group in the BLM Casper Office. That information serves as the basis for related sections of this document.

The mineral resource potential for non-fluid minerals within the Rawlins RMPPA also has been evaluated in detail. A wide range of non-fluid minerals is present within the RMPPA, and such minerals, where present, occur within each of the classification categories to include leasable, locatable, and salable minerals.

In general, it can be stated that those non-fluid minerals of greatest economic significance within the RMPPA are coal, gypsum, limestone, aggregates, dimension, and decorative stone. While a number of other non-fluid mineral commodities are known to be present within the RMPPA, most occur in minor deposits. Other mineral types and occurrences are of sub-economic classification and as such are unlikely to be considered for development or exploitation within the projected planning period.

Coal has been a major mineral commodity within the RMPPA, largely being produced from Hanna Basin area mines. Historic production (of a limited scale) also has occurred elsewhere within the RMPPA.

Gypsum is produced in the Laramie area and utilized as a retarder in portland cement. Also, limestone is quarried from the Laramie area for utilization in the manufacture of cement.

Aggregate occurrences (though variable in quantity and type) are present throughout the RMPPA, and are subject to increasing consumptive demand as a result of expanding oil and gas development. This can generally be attributed to aggregate materials being utilized as roadway sub-base, base, and surfacing, with the increased demand being a result of the expanding infrastructure (collector, local, and resource roads) necessary to support the oil and gas industry.

Similarly, dimension, and decorative stone occurrences, while not of widespread occurrence, are being subjected to increasing demand for architectural and landscaping applications.

It also should be noted that prior to the early 1980s, when uranium markets took a significant downturn, Wyoming (inclusive of the RMPPA) was a major producer of uranium. There has been commercial-scale production of uranium from the Shirley Basin, and there are potentially economic deposits known to be present elsewhere within the area. Currently, there is no uranium production within the RMPPA, and that is not anticipated to change in the foreseeable future; however, uranium prices and demand are subject to fluctuating international demand and environmental/political factors, making future production estimates largely unpredictable.

3.1 Leasable Minerals

Leasable minerals are governed by The Mineral Leasing Act of 1920. The Mineral Leasing Act of 1920, as amended, authorized that specific minerals no longer be locatable; but instead shall be disposed of through a leasing system. Minerals designated as leasable under this law include:

- oil and gas;
- coal;

- native asphalt, solid and semisolid bitumen and bituminous rock including oil-impregnated rock or sands from which oil is recoverable only by special treatment after the deposit is mined;

- phosphate;

- sulfur (in the states of Louisiana and New Mexico); and

- chlorides, sulfates, carbonates, borates, silicates, or nitrates of potassium and sodium.

By far, the most significant leasable minerals known to be present within the RMPPA are oil and natural gas. Other leasable minerals are present, albeit to a significantly lesser degree. These other leasables include coal, oil shale, phosphate, sodium sulfate and other saline minerals.

3.1.1 Oil and Natural Gas

3.1.1.1 Origin, Occurrence, and Trapping of Oil and Natural Gas

Origin of Petroleum

Crude oil and natural gas are composed chiefly of hydrocarbon compounds and are found primarily in sedimentary rocks. The prevailing theory of the origin of petroleum hydrocarbons is that they are derived from organic matter. This is substantiated by the fact that the largest petroleum accumulations occur in sedimentary basins with widespread organic debris and that petroleum hydrocarbons have been found closely associated with organic matter. The organic matter accumulates in deposits that eventually become source rocks for petroleum. Source rocks are generally derived from organic-rich sediments that are deposited in an environment that precludes oxidation and this is normally in sedimentary basins or coal swamps. Potential source rocks are subjected to increasing temperature and pressure as they become buried by other sediments and by basin subsidence. Given high enough temperature and pressure, precursor petroleum compounds begin to form from the organic material in the rock. With increasing temperature and pressure, these organic compounds are thermally altered to form petroleum and natural gas. Hydrocarbons formed in this manner are termed *thermogenic* and are generated at temperatures above 200 degrees Farenheit (°F) (Wiese and Kvenvolden, 1993). The hydrocarbons mobilize and may migrate away from the source rocks into more porous and permeable rocks called reservoir rocks. Methane, a large component of natural gas, also can be formed from the bacterial decomposition of organic material in the absence of oxygen. This type of methane is termed *biogenic* and is found in the earth at low temperatures that preclude the killing of anaerobic bacteria below about 200°F.

Four essential physical elements of a petroleum reservoir are reservoir rock, connected pore spaces that are able to store hydrocarbons, the presence of hydrocarbon fluids or gases in the connected pore space that can be moved through the rock, and a trap that prevents the further migration of hydrocarbons (Levorson, 1967). Both source and reservoir rocks are widespread throughout the Rawlins RMPPA as evidenced by the oil and gas fields so far discovered and the evidence of hydrocarbons in much of the stratigraphic section of rocks found in the area. Important source rocks are the Phosphoria Formation and Cretaceous shales and coals.

Another element of a hydrocarbon reservoir can be stated thusly: A reservoir is “a rock from which oil or gas can be produced at a profit” (Berg, 1986, p. 33). This definition is important because in the history of petroleum exploration, known hydrocarbon-bearing strata have been bypassed or written off because either it was technologically or economically unfeasible to produce them. Later, such strata may invite renewed interest because of either more favorable commodity prices, changes in technology, or the existence of a transportation infrastructure (natural gas pipelines). An excellent example of this is coalbed methane (CBM) that was only recently recognized as a source of primarily gaseous hydrocarbons.

Trapping Mechanisms

The fourth fundamental element of a petroleum reservoir is the trap. Water is the dominant subsurface fluid and hydrocarbons are lighter than water. Therefore the tendency is for hydrocarbons to migrate vertically through the subsurface. Because of this tendency for vertical movement, any physical feature that impedes that movement will create a trap. There are three basic types of traps: structural traps, stratigraphic traps, and combination traps (Levorson, 1967). **Figure 3-1** portrays the most common trap types. Coal provides a fourth kind of trap where adsorption of the gas onto the coal constitutes the trapping mechanism and structural stressing or high pressure may increase the capacity of the coal to trap gas. Coal is both a source rock and reservoir rock.

One type of structural trap is formed as a result of the folding of reservoir strata. Hydrocarbons migrate into the reservoir and are held there by less permeable rock on top of the reservoir. Anticlines are a common form of structural trap. Exposed structures are readily apparent and have received the earliest and most extensive exploration effort. Buried, or subsurface structures are more difficult to locate, requiring detailed geophysical and geologic analysis. Anticlinal structures are common along the basin margins and many have yielded significant oil and gas resources. The central region of the Rawlins RMPPA has numerous examples of anticlinal traps. They are also found in the interbasinal areas such as the Rawlins Uplift, Wamsutter Arch, and Cherokee Arch.

Another common form of structural trap forms when a reservoir is sealed by movement of a fault that places less permeable strata opposite the reservoir or the fault itself is the sealing agent. This

Figure **3-1** Trap Types

presumes that the strata over the reservoir will not allow the hydrocarbons to escape. Anticlinal structures, possibly modified to some extent by faulting at depth, are common traps in the Rawlins RMPPA.

Another type of trap is the stratigraphic trap. Stratigraphic traps occur because of a lateral change in the physical characteristics of the reservoir or a change in the continuity of the rocks (Levorson, 1967). No matter what has caused the change in physical characteristic or change in continuity, ultimately it is the change of permeability that traps the hydrocarbons. Changes in permeability occur as a result of the complexity of the original depositional environment such as stream deposits or unconformities, which may result in the truncation of permeable strata with subsequent deposition of an overlying impermeable deposit. A change in permeability also may result from later alteration (diagenesis) that causes a reduction in pore sizes that decreases the potential flow paths through the reservoir to form a barrier to petroleum migration. Stratigraphic traps are not apparent at the surface as in the case of the surface anticlines, but in special cases may be indicated by geophysical data. The discovery of stratigraphic traps often depends upon detailed mapping of the subsurface using information derived from previously drilled wells to look for potential discontinuities or changes in rock types that may create traps. Under special conditions, modern geophysical methods also have the ability to identify changes in rock type that may be indicative of potential stratigraphic traps at depth. Sandstones that pinchout or are highly laterally variable have created numerous stratigraphic traps in the western portions of the RMPPA in the Great Divide and Washakie Basins.

Combination and Unconventional Traps

Many traps are not strictly structural or stratigraphic, but have elements common to both **(Figure 3-1)**. There are all gradations of traps and often it is difficult to precisely determine the primary trapping mechanism. Unconventional traps are those traps that may or may not possess some of the typical elements found in conventional traps. One type of unconventional trap with implications to the RMPPA is what is termed the “basin-centered” trapping of natural gas. In the basin-centered model, there is no obvious seal or permeability barrier and the traditional concepts of structural and stratigraphic trapping are of lesser importance (Law, 1995). Instead of a continuous seal, hydrocarbons are trapped in widespread low-permeability reservoirs. Other attributes of basin-centered accumulations of gas include the following: the accumulations cover large areas of the deepest parts of basins, there is no gas-water contact below the accumulation, there is little or no water production, abnormal pressures are present (higher or lower than expected gradient), the gas is the pressuring agent, the gas is sourced from immediately adjacent rocks, and the gas is thermogenic in origin.

3.1.1.2 Historical Development and Production

The Rawlins RMPPA has had a long history of oil and non-CBM natural gas production. Since the 1920s, the area has produced 525 million barrels of oil and 4.2 trillion cubic feet (TCF) of gas from a number of fields. A list of fields and units in the area is on **Table 3-1**. The following discussion summarizes the major producing areas in the RMPPA. Based on production figures through year 2,000, four of Wyoming's top 25 gas producing fields are within or partially within the RMPPA. The fields and year 2001 production rank are as follows: Echo Springs (12), Standard Draw (13), Wild Rose (14), and Wamsutter (15) (Wyoming Oil and Gas Conservation Commission [WOGCC] 2002a). In addition, the RMPPA contains two of the top 25 oil fields in the state; Lost Soldier (2) and Wertz (23).

Before an oil or gas well is drilled, the WOGCC must approve an Application for Permit to Drill (commonly referred to as an APD). A memorandum of understanding between BLM and WOGCC regulates this approval. In the case of wells drilled on BLM-managed lands, the WOGCC can only regulate the spacing and location of a well and provide a unique well identification number. The WOGCC also regulates underground injection, but the BLM regulates all aspects of drilling and surface use for wells drilling on BLM-managed lands. If the well will be on federal lands, an APD also must be approved by the BLM. Historically, federal applications to drill have been about 44 percent of the total number of applications filed in the Rawlins RMPPA. Not every approved application is actually drilled. Since 1987, about 70 percent of the approved applications in the RMPPA have actually been drilled. **Figure 3-2** shows the yearly total of new wells drilled since 1910. It does not include workovers (maintenance operations), recompletions (completion of zones not previously produced), or wells that were reentered and deepened. Records indicate that before 1910 only one well had been drilled. Note that **Figure 3-2** shows that there has been a pronounced upward trend in wells drilled.

Figure 3-3 shows the relative depths of wells drilled since 1990. "Percent of Wells Drilled" was used because some wells did not have readily available depth information. Seventy-four percent of the wells drilled were between 8,000 and 12,000 feet deep. The average total depth was 9,249 feet. As the number of wells drilled has increased during this period, the depth of the wells also has increased.

As new wells are drilled and completed, wells are being plugged and abandoned. The great majority of these are wells that are either unproductive (dry holes), or have become depleted and are no longer economic. **Figure 3-4** shows the wells drilled and wells abandoned since 1980. Abandonments have been 37 percent of the total number of wells drilled. The number of abandoned wells would be slightly greater than shown in **Figure 3-4** because about 12 percent of the wells reported as abandoned did not have an abandonment date and could not be plotted. The number of wells abandoned is more consistent year-to-year than the number of wells drilled. Historically, about 53 percent of the wells drilled have been abandoned (**Table 3-2**).

Table **3-1** Oil and Gas Fields and Cumulative Production in the Rawlins RMPPA

Figure **3-2** Number of New Wells Drilled, by Year, in the RMPPA

Figure **3-3** Well Depth Distribution for Wells Drilled Since 1990 in the RMPPA

Figure **3-4** Wells Drilled and Wells Abandoned in the RMPPA from 1980 to 2001

Within the RMPPA, 5,515 wells are present in five categories **Table 3-2**. To date, 59 percent of all wells have been drilled on federal lands, with the other 41 percent drilled on fee or state lands. Fifty-two percent of all wells have been abandoned. Wells have been abandoned because of the following:

- no hydrocarbons were encountered, or hydrocarbons were not present in economic quantities;
- the wells were initially capable of producing hydrocarbons, but they became uneconomic to produce at a latter date; and
- mechanical difficulties with a wellbore prevented economic hydrocarbon production.

Table 3-2
Rawlins RMPPA Well Status on April 1, 2002

	Federal	**Fee or State**	**Total**
P&A Wells	1,991	893	2,884
Dormant Wells	33	32	65
Completed Wells	1,123	1,231	2,354
Notices of Abandonment	31	40	71
Drilling Wells	69	72	141
Total Wells	**3,247**	**2,268**	**5,515**

Source: WOGCC, 2002a, Wyoming State Office RMG.

A map of the RMPPA **(Figure 3-5)** shows the locations of all wells drilled. For this map, wells were divided into two categories; active and abandoned. This map shows that drilling activity has been concentrated in three regions. The first and most heavily drilled region is in the eastern Green River Basin and includes the Great Divide Basin, Wamsutter Arch, Cherokee Arch, and Washakie Basin. This region is located in the westernmost part of the RMPPA. In spite of the heavy drilling in parts of these areas, there are some townships in this region that have been only lightly tested.

The two other regions of concentrated activity lie in the eastern part of the RMPPA and in a region across its center. These regions have been less heavily explored and developed than in the region on the west. Many townships within these two regions have been only lightly tested. Outside of these three regions, many townships have not been tested with even one well.

Figure 3-6 shows RMPPA production of natural gas by year, from 1974. Production was flat early on, but began a steady increase in 1978 that carried through 1981. After a period of fluctuation during 1982-1985, production increases resumed. During the 1986 through 1997 period, production increased at a nominal annual rate of 4.2 percent. Gas production was 7.5 times higher in 2001 than in 1974. The decline in production during 2000 and 2001 was mostly due to

Figure **3-5** Wells Drilled for Oil and Gas

Figure **3-6** Yearly Total Gas Production and Production from Federal, Private, and State Lands in the Rawlins RMPPA decline in production from private wells. Gas production from the RMPPA in 2001 was 11 percent of Wyoming's total gas production.

Figure 3-7 shows oil production from wells on federal, private, and state minerals, by year, from 1974. During the period from 1978 to 1995, production fluctuated around an annual rate of 8 million barrels. Beginning in 1990, annual production began declining and has declined at a nominal rate of 2.8 percent per year through 2001. About half the oil produced in the RMPPA during 2000 and 2001 was from the Lost Soldier-Wertz Fields near Bairoil, Wyoming. In 2001, only 7 percent of Wyoming's total oil production came from the RMPPA.

Producing oil and gas wells in the RMPPA have increased at a nominal rate of 3.1 percent per year between 1974 and 2001 (**Figure 3-8**). Forty-five percent of the producing wells are federal.

Rawlins Uplift Area

The Rawlins Uplift essentially provides a platform area that is between the Great Divide-Washakie Basins and the Hanna Basin. The fields in this area are generally anticlinal traps that produce out of multiple reservoirs. Oil was first discovered in the Rawlins RMPPA in 1916 at Lost Soldier Field when oil was produced from sandstones in the Frontier Formation (Skeeters and Hale, 1972). Lost Soldier Field is an anticlinal trap with seven producing zones from Cambrian to upper Cretaceous. Production has also been obtained from fractured Precambrian rock in this structure. Through February 2002, the field has produced over 251 million barrels of oil and 439.8 billion cubic feet of gas (BCFG) (WOGCC 2002b). Another early development in the RMPPA occurred at Hatfield Dome, 10 miles south of Rawlins. Significant gas was discovered at Hatfield Dome in 1915 when a Frontier Formation well flowed from 10 to 20 million cubic feet per day (Bauer, 1992).

Hanna Basin

There are only a few oil and gas fields discovered to date in the Hanna Basin, but development came relatively early. Allen Lake Field was discovered in 1918 and Simpson Ridge was discovered in 1923 (Skeeters and Hale, 1972). As of the present day, the oil and gas fields are concentrated around the edges of the basin in anticlinal traps. Since the Hanna Basin has a very thick sedimentary rock section (over 40,000 feet), the basin is relatively unexplored.

Laramie Basin

Oil production began in the Laramie Basin at Rock River field in 1918 (Skeeters and Hale, 1972). Quealy Dome, discovered in 1934 by the California Company, is notable because it was the first field in Wyoming that was discovered using seismic exploration techniques (Berg, 2002). The oil

Figure **3-7** Yearly Total Oil Production and Production from Federal, Private, and State Lands in the Rawlins RMPPA

Figure **3-8** Total Producing Wells and Federal, Private, and State Producing Wells in the Rawlins RMPPA, by Year fields in the Laramie Basin are primarily basin-margin structural traps located in anticlines on the west side of the basin.

Great Divide – Washakie Basins

Early production in these basins was found at Wamsutter Field, discovered in 1950 with production from upper Cretaceous reservoirs: Lewis Shale, Mesaverde, and Almond Formations (DeBruin, 2002; WOGCC 2002b). Within the Rawlins RMPPA, early production came from South Baggs and Savery Fields, both discovered in 1954. These fields have produced mainly out of upper Cretaceous sandstones, but South Baggs has Tertiary and Mississippian production as well. Although Table Rock Field is technically on the Rock Springs uplift and lies mostly in the Rock Springs Field Office area, part of it extends into the Rawlins RMPPA. It was discovered in 1946 and produces from Tertiary, Cretaceous, and Paleozoic reservoirs (DeBruin, 2002; WOGCC, 2002b). There were sporadic discoveries in the basins in the 1950s and 1960s, but in the 1970s, significant discoveries were made at Siberia Ridge (1975), Echo Springs (1975), Wild Rose (1975), Hay Reservoir (1976), and Standard Draw (1978). Much of the production is from low permeability upper Cretaceous stratigraphic traps. The Almond Formation is an important gas-producing unit as well as sandstones within the Lewis Shale. Many of the reservoirs in this area are considered tight-sands because of the low permeability and reservoirs below 9,000 or 10,000 feet may be over-pressured (Law and others, 1989).

Denver-Cheyenne Basin

The Denver-Cheyenne Basin encompasses a large area of northeastern Colorado, southeastern Wyoming, and southwestern Nebraska. The portion of the basin located in the Rawlins RMPPA is a relatively small part of the entire basin. In that portion of the basin within the RMPPA, oil was first discovered in 1922 at Butler Field (WOGCC, 2002b). The oil and gas resources are found in structural and stratigraphic traps and production is primarily from lower Cretaceous sandstones. Important structural traps are Horse Creek and Borie Fields, discovered in 1942 and 1949, respectively. These fields produce from lower Cretaceous reservoirs in anticlines along the east flank of the Laramie Mountains. An unconventional trap was discovered in 1981 at Silo Field when oil was found in fractured shale reservoir of the Niobrara Formation. Silo Field has produced nearly 10 million barrels of oil and nearly 8 BCFG (WOGCC, 2002b).

Deep Wells

Dyman and others (1990) characterized deep wells as those wells drilled to depths greater than 15,000 feet. **Figure 3-9** shows areas of the RMPPA that may contain potential reservoir rock below 15,000 feet and those that do not contain potential reservoirs at those depths. Only about 25 percent of the RMPPA has potential reservoir rock below 15,000 feet. These areas are in deeper parts of the Great Divide, Washakie, and Hanna Basins and along the Wamsutter Arch, Figure **3-9** Deep Wells (>15,000 feet) and Deep Reservoir Potential which separates the Great Divide and Washakie Basins. Seventy-five percent of the RMPPA, which includes the margins of the three deep basins, structural uplifts, and the Denver-Cheyenne, Laramie, and Shirley Basins, does not contain potential deep reservoir sediments. Data for the discussion of deep wells in the RMPPA was obtained from IHS Energy Group (2002) and WOGCC (2002a).

The Potential Gas Committee (PGC) (PGC, 2001) projected large amounts of total undiscovered natural gas resources in the conterminous 48 states, below 15,000 feet. For the entire Greater Green River Basin, the PGC estimated almost one-third (8.4 TCF of a total of 26 TCF of gas) of the potential resource lies below 15,000 feet. These potential resource estimates were projected for areas much larger than that of the RMPPA. Since the Denver-Cheyenne Basin does not contain potential deep reservoir rocks, their estimate of a potential gas resource of 3.70 TCF was just for shallower potential reservoirs. Information presented below will show where deep gas resources presently are known to exist within the RMPPA.

Deep wells drilled in the Rawlins RMPPA are shown on **Figure 3-9**. Information relating to these wells is presented in **Table 3-3**. Thirty-eight deep wells have been drilled. To date, 15 wells have been drilled between 15,000 and 16,000 feet, 11 have been drilled between 16,000 and 17,000 feet, 6 have been drilled between 17,000 and 18,000 feet, and 5 have been drilled between 18,000 and 19,000 feet. The deepest well, and only well drilled to a depth greater than 19,000 feet, was the Frewen Deep No. 1. That well was drilled to 19,299 feet in the Frewen Field, on the north edge of the Washakie Basin. The Frewen Deep No. 1 also is the deepest producing well in the RMPPA. It was originally completed as a Cretaceous Lakota Formation gas producer between 19,054 and 19,126 feet. This zone produced 168 million cubic feet of gas (MMCFG) and 8 barrels of oil before it was abandoned.

Two of the 38 wells have recently been drilled and they are considered suspended until testing has been completed and a final status is determined (**Table 3-3**). Twenty-seven of the 36 completed wells (75 percent) were originally completed as gas wells. Eighteen of those 27 wells (67 percent) produce from zones deeper than 15,000 feet. Production in these deep wells has been predominantly gas. Gas has been encountered in 10 different formations, with the Nugget productive in 8 wells. Oil has been produced in small amounts from deep zones in 9 of the 18 wells.

The following discussion describes the deep wells that have been drilled in the RMPPA.

<u>Hanna Basin</u>

Only 3 deep wells (Pass Creek Unit No. 1, St. Mary's Unit No. 1, and Seminoe Unit No. 1-25) have been drilled in the Hanna Basin (**Table 3-3**). All were drilled as part of federal exploratory unit agreements. None have been productive nor had hydrocarbon shows in zones deeper than

Table **3-3** Summary of Data for All Deep Wells (>15,000 Feet) Drilled in Rawlins RMPPA

15,000 feet. The Seminoe Unit No. 1-25 was completed as a shallower Lewis Shale gas producer. It was completed in 1983 and was the last deep well drilled in the Hanna Basin.

Wilson and others (2001) have reviewed the potential for a deep basin-centered gas accumulation in the Hanna Basin. Limited data indicates that a gas-charged, overpressured interval may occur along the southern and western margins of the basin. In this area, the Cretaceous Mowry, Frontier, and Niobrara Formations lie in this potential gas-charged overpressured interval, at depths below 10,000 feet. In the center of the basin, Wilson and others (2001) project possible gas-charged overpressuring at depths below 18,000 to 20,000 feet. The potential Niobrara, Frontier, and Mowry reservoirs have not yet been commercially productive in other known basin-centered gas accumulations.

Great Divide Basin

Seven deep wells were drilled (**Table 3-3**) in the east and north parts of the Great Divide Basin (**Figure 3-9**). Three of the 7 wells produce, although only two were completed as producers from reservoirs at depths greater than 15,000 feet. Production from these wells has been small.

The first deep test was the Bull Springs Rim No. 1-19. It is the deepest well drilled in the basin and it also produces from the greatest depth. The Cretaceous Niobrara Formation produces from 15,383 to 15,478 feet in this well.

To date, the oldest formation encountered was the lower Cretaceous Cloverly, in the Bull Springs Rim No. 1-19. The other six wells only drilled to upper Cretaceous aged sediments. All 7 wells were drilled in the 1975 to 1980 period.

Wamsutter Arch

The Wamsutter Arch occupies a small part of the Rawlins RMPPA and is a low relief anticlinal structure separating the Great Divide and Washakie Basins. Three deep wells have been completed on the crest of this structure (**Table 3-3**). These wells are productive, but from zones less than 15,000 feet deep. In the Sidewinder No. 1-H and No. 2-H wells, portions of the wells were horizontally drilled. All wells were drilled to lower Cretaceous formations, with the first completed in 1997.

Washakie Basin

Most of the deep wells (25 of 38 wells, **Table 3-3**) in the RMPPA are scattered across the Washakie Basin **(Figure 3-9)**. Twenty-one of these wells were drilled in the 1975 to 1996 period. Three new deep wells were drilled in 2001.

The first deep well in the Washakie Basin was the South Baggs Unit No. 8 drilled to 16,248 feet in 1960. It drilled completely through the sedimentary section into Precambrian basement rocks. The upper Cretaceous Lewis Shale was found to be productive at depths less than 15,000 feet in the well.

Deepest production is in the Frewen Deep No. 1. This well was completed as a lower Cretaceous Lakota Sandstone gas well in 1989. It produced in an interval from 19,054 to 19,126 feet and has since been abandoned.

Eleven deep wells have been drilled within that portion of the Table Rock field that lies within the RMPPA **Table 3-3**. Table Rock Unit No. 123 was recently drilled and is waiting on wellbore tests. The other 10 wells were all completed as deep producers; 8 in the Triassic Nugget Sandstone, and 1 each in the Pennsylvanian Weber Sandstone and Mississippian Madison Limestone. Most of the deep production in the RMPPA has come from these wells. Hydrocarbons are produced from an anticlinal structure at Table Rock field. Gas from the Weber and Madison contains about 2 percent hydrogen sulfide (Dickinson, 1992).

Formations productive at Table Rock field have not been found to be productive in other parts of the Washakie Basin. A number of different formations have been found to be productive outside Table Rock field. Those productive formations are: the Upper Cretaceous Lewis Shale, Mesaverde Group, and Niobrara Formation; the Lower Cretaceous Lakota Sandstone; and lower Pennsylvanian rocks.

Deep gas production in the RMPPA part of the Washakie Basin has totaled 93.953 BCFG to January 2002. Only a small amount of oil (11,098 barrels) has been produced from these wells.

Secondary and Tertiary Recovery Projects

Primary production includes the initial stages of reservoir production when the hydrocarbons can be fairly easily moved to the wellbore either by the natural forces in the reservoir or through artificial lift (pumping). Primary recovery sometimes only recovers a fraction of the hydrocarbons originally in place in the reservoir. In order to more efficiently extract the oil as the reservoir energy is depleted, oil and gas operators often conduct secondary recovery operations. Secondary recovery involves the injection of water, gas, or steam to help push the oil to production wells. Beyond secondary recovery, there are tertiary recovery methods that often involve the injection of miscible fluids to combine with the oil to try to move the oil to production wells. However, a point is reached at which no more oil can be recovered under existing technologies. There are a number of secondary and tertiary recovery projects in the RMPPA as listed on **Table 3-4**. A major tertiary recovery project in the RMPPA is at Lost Soldier Field where carbon dioxide (CO_2) gas is injected into various formations to enhance recovery of oil. The CO_2 is produced from the Madison Formation reservoirs in the Big Piney – La Barge area in Sublette County (DeBruin, 2001). After

Table **3-4** Secondary and Tertiary Recovery Units in the RMPPA processing and treatment at the Exxon/Mobile Shute Creek gas plant, the CO_2 is transported to Lost Soldier field via a 20-inch pipeline (DeBruin, 2002).

Pipelines, Natural Gas Storage, Natural Gas Processing

There is an extensive system for gas processing transportation within the Rawlins RMPPA as would be expected with the level of production. There are a number of gas gathering systems within the production areas that feed into transportation lines. Associated with the gas gathering pipelines are compressor and gas processing facilities. Compressors are used to move the gas through the pipelines and the processing facilities are used to remove liquid hydrocarbons (condensate and natural gas liquids) and excess water. Along the I-80, there are several major gas transportation pipelines up to 36 inches in diameter (DeBruin, 2002).

The WOGCC (2002b) lists three gas storage projects in the RMPPA at Bunker Hill, Mahoney Dome, and Wertz. The Wertz gas storage project is listed as inactive and the status of the other two projects was not indicated in the WOGCC statistics (2002b).

There are six natural gas processing plants in the RMPPA, the largest is located at Rawlins and has a capacity of 230 MMCFG per day.

Federal Unit Agreements

Non-CBM and CBM federal unit agreements lie within the Rawlins RMPPA boundaries. Sixty-five active (non-CBM) federal unit agreements lie within or partially within the RMPPA **(Figure 3-10)**. These units cover an area of 324,060 acres, or about 3 percent of the Field Office area. Companies operating these units are; Benson-Montin-Greer, BP America Production, Braden-Deem Inc., Cabot Oil & Gas Corp., Chevron Texaco, Coral Production Corp., Devon SFS Operation Inc., Double Eagle Petroleum Co., EOG Resources Inc., Ensign Operating, Goldmark Engineering Inc., Kaiser-Francis Oil Co., Hudson Group LLC, Marathon Oil Co., Merit Energy Co., Questar Exploration and Production, Richardson Production, RME Petroleum Co., Rock River Operating Co., Sonoma Energy Corp., Stanley Energy Inc., Stone Energy LLC, Tom Brown Inc., Westport Oil & Gas Co. Inc., Windsor Oil & Gas Inc., Wold Oil Properties Inc., Xeric Oil & Gas Corp., and Yates Petroleum Corporation.

Most of the units are located in the eastern greater Green River Basin area, with two in the Denver Basin, and three each in the Hanna and Laramie Basins. Nearly all of these units are at a mature stage of development. In recent years some new exploratory unit agreements have been proposed and approved in the Washakie Basin portion of the greater Green River Basin. These units are in early stages of exploratory activity.

Figure **3-10** Non-CBM Federal Unit Agreements

As of August 9, 2002, there are three established exploratory units for CBM and six others pending. There is one established unit in the Hanna Basin, two authorized and five pending units on the eastern side of the Washakie Basin, and one pending unit on the east side of the Wamsutter Arch. **Figure 3-11** shows the locations of CBM federal units in the RMPPA. A more detailed discussion of these units is in Section 3.1.1.4.

3.1.1.3 Origin and Occurrence of Coalbed Methane

The presence of methane in coal seams has long been recognized as a potential hazard in the mining of coal (Diamond, 1993). The extraction of methane from coal was originally practiced to provide a margin of safety for coal mining by removing as much methane as possible prior to mining. It was recognized that there was a potential significant gas resource in coals. In the early1980s, Congress considered CBM as an “unconventional” gas resource and enacted tax incentives for the production of gas from coal seams. The tax incentives were extended, but eventually expired in 1991. The tax incentive spurred industry to develop technologies to produce the resource and major coalbed producing areas resulted in the Black Warrior Basin of Alabama and the San Juan Basin in southwestern Colorado and northwestern New Mexico (Rice and others, 1993).

The methane in coal seams occurs as a result of the process that turns plant material into coal (DeBruin and others, 2001). The process of turning peat and other plant material into coal is called coalification. As accumulated plant material is buried and subjected to increasing temperature and pressure it is turned into varying ranks of coal. The coal rank is reflective of the amount of burial and therefore temperature and pressure to which a coal has been subjected. The gas in the coal can either be biogenic and thermogenic, depending on the particular circumstances of the burial and exhumation history of a coal seam. In addition to methane, other gases generated in the coalification process are nitrogen and CO_2. The nitrogen and CO_2 are generated under thermogenic conditions. Other heavier hydrocarbon gases and oil may be generated depending on the organic materials in a particular coal deposit (Rice and others, 1993; Garcia-Gonzalez and others, 1993).

The methane generated in the coalification process can be stored in several ways: as free gas in tiny pores and fractures in the coal, as a dissolved phase in interstitial water in the coal, or adsorbed onto the surface of the coal. Because most coals have abundant microfractures, or cleat, there is abundant surface area on which gas can be adsorbed. This feature of gas storage allows coals to store a much higher volume of gas than conventional gas reservoirs (Rice and others, 1993).

In order to extract the gas from the coal, it is necessary to lower the hydrostatic pressure in the coal. Lowering the pressure is accomplished by producing the water that is in the coal. Extraction of the gas often involves the pumping of large amounts of water in the initial stages of

Figure **3-11** CBM Unit Agreements

development. **Figure 3-12** shows a production profile for a typical CBM well showing relative production rates of gas and water over time. The highest initial water production rate for a CBM well in the Rawlins RMPPA was reported as 2,127 barrels of water per day (WOGCC, 2002a). However, water production rates are usually less than 1,000 barrels per day with maximum rates on the order of 600 barrels per day. Once wells reach economic production, water production rates decline substantially. Water quality can range from 380 milligrams per liter (mg/l) of total dissolved solids (TDS) to 2,720 mg/l with average TDS in the RMPPA of 1,246 mg/l. Water quality may be better in the coal seams that are closer to the surface, indicating potential recharge from meteoric water. Water disposal options, which are highly dependent on water quality and economics, can include discharge to the surface or subsurface injection into disposal wells or into aquifer recharge wells. Surface disposal options may require pre-treatment prior to disposal to meet discharge permit requirements. All disposal options require permits.

3.1.1.4 CBM and Production in the Rawlins RMPPA

Potential CBM-bearing formations in the RMPPA are the Mesaverde, Lance, and Fort Union Formations in the Washakie Basin and the Hanna, Medicine Bow, and Ferris Formations in the Hanna Basin (DeBruin and Jones, 1989). A detailed description of these coal-bearing units is in Section 3.1.3. Evidence for the presence of methane in coals came from “gas kicks” during drilling of exploration borings or gas explosions observed in coal mines in the Hanna Basin (DeBruin and others, 2001). Gas contents measured in coals from southwestern Wyoming range from 100 to 541 standard cubic feet per ton (Law, 1995).

Although there is substantial interest in CBM development in the RMPPA, there has been little production. Only 0.179 BCFG and 10.3 million barrels of water have been produced in the RMPPA (WOGCC, 2002a).

At present, two CBM exploratory unit agreements have been authorized and five are pending (**Figure 3-8 and Table 3-5**). Authorized and pending units cover an area of about 140,800 acres.

The Magic Unit has only recently been proposed and details about it are still confidential. This unit lies along the crest of the Wamsutter Arch, between the Great Divide and Washakie Basins.

The authorized and pending units are located along the east flank of the Washakie Basin. They are part of a larger proposal by Petroleum Development Corporation and others that are currently exploring the feasibility of developing gas resources in the coals of the Mesaverde Formation in an area between townships 13 to 20 north and ranges 89 through 92 west. A separate EIS is being prepared for this proposed project. Initial wells for pilot tests in the north and middle parts of the project area have been drilled and testing is planned to begin in 2002. The Sun Dog unit operator plans to drill wells for a pilot test in 2002.

Figure **3-12** Typical CBM Well Production Profile

Table 3-5
Rawlins RMPPA CBM Methane Unit Agreements

Unit Name	Operator	Size (acres)	Date Received	Date Approved
Blue Sky	Pet. Dev. Corp.	24,878.60	05/13/2001	11/13/02
Magic	Yates Pet. Corp.	15,980.29	02/25/2002	Pending
Muddy Mountain	Pet. Dev. Corp.	23,464.41	05/13/2001	Pending
Point Rocky	Pet. Dev. Corp.	19,030.06	05/13/2001	Pending
Sand Hills	Pet. Dev. Corp.	14,485.48	05/13/2001	Pending
Smiley Draw	Pet. Dev. Corp.	19,576.15	05/13/2001	Pending
Sun Dog	Pet. Dev. Corp.	23,468.74	05/13/2001	12/22/2001
	Total Acres	140,883.73		

Source: Rawlins Field Office, Wyoming State Office RMG.

3.1.2 Coal

There are six identified coalfields within the RMPPA. Of these, the Hanna Field has been the most significant in terms of historic (and projected) coal production (**Figure 3-13**). Most activity within the remaining fields has typically been of small-scale, or in some cases, the coal resource has yet to be economically exploited.

In recent years, there has been a contraction of the coal sector within the RMPPA's Hanna Coalfield. As of 1979, five mining companies were still active in the Hanna Field (Glass and Roberts, 1979), but by the year 2002, there are only two active coal mines in the Hanna Field. With the mid-2000 closure of the RAG Shoshone No. 1 Mine (underground), there remain only two operational Hanna Coalfield mines (the Seminoe No. II and the Medicine Bow mines), both of which are surface coal mines operated by Arch of Wyoming, Inc. It is indicated that remaining economic reserves (estimated at an aggregate 2 million tons) at these two mines will sustain production for an estimated 2 years.

Coal is classified by rank, in accordance with standard specifications of the American Society for Testing Materials (ASTM). Most of the Wyoming coals are of bituminous and sub-bituminous rank. The reader is referred to ASTM D-388 for detailed information regarding coal classification specifications and considerations. While it should be noted that there are minor variants on classification on the basis of certain physical properties, a brief synopsis of the classification system (in general decreasing order of rank) is as follows:

I. Anthracitic
   1. Meta-anthracite
   2. Anthracite
   3. Semi-anthracite

Figure **3-13** Wyoming Coalfields

II. Bituminous

1. Low volatile bituminous	(> 78 percent but < 86 percent Fixed Carbon)
2. Medium volatile bituminous	(> 69 percent but < 78 percent Fixed Carbon)
3. High volatile "A" bituminous	(> 31 percent but < 69 percent Fixed Carbon)
4. High volatile "B" bituminous	(> 13,000 but < 14,000 Btu/lb[1] moist)
5. High volatile "C" bituminous[1]	(> 11,000 but < 13,000 Btu/lb moist)

III. Sub-bituminous

1. Sub-bituminous "A"[1]	(> 11,000 but < 13,000 Btu/lb moist)
2. Sub-bituminous "B"	(> 9,500 but < 11,000 Btu/lb moist)
3. Sub-bituminous "C"	(> 8,300 but < 9,500 Btu/lb moist)

[1]British thermal units per pound.
[2]Classification varies on the basis of agglomerating and weathering properties.

Within the RMPPA there are five significant coalfields containing coal resources of sub-bituminous to bituminous rank (Berryhill and others, 1950), as follows:

- Hanna Coalfield;
- Great Divide Basin Coalfield;
- Rock Creek Coalfield;
- Kindt Basin Coalfield;
- Little Snake River Coalfield; and
- Goshen Hole Coalfield.

The following sections provide brief descriptions of these coalfields. Information for these sections was primarily from Berryhill and others (1950) and Glass and Roberts (1979).

3.1.2.1 Hanna Coalfield

The Hanna Field is a structurally downwarped area of about 750 square miles (T21-24N, R79-86W) in the northern half of Carbon County, south-central Wyoming. The field is bounded on the north by the Shirley, Freezeout, Seminoe, and Ferris Mountains; on the west by the Rawlins Uplift; and on the south by the Medicine Bow Mountains. To the east, it merges with the Laramie Basin. The field is drained by the Medicine Bow River and several intermittent streams, all tributaries of the North Platte River, which flows in a northerly direction near the western edge of the field. The Union Pacific Railroad crosses the field from east to west, passing through the town of Hanna.

The topography in the central part of the field is of the "plains" type but is more rugged around the periphery. Along the southern side of the field, low ridges are prominent. In areas of T21N, R81W and northward a prominent ridge called Simpson Ridge (or the Saddleback Hills) extends north-northeasterly along an anticlinal axis. This ridge separates the largest coal-bearing area (Hanna Basin) on the west, from the smaller (Carbon Basin) to the east. Another small basin, the Walcott Basin, is southwest of the Hanna Basin.

The Mesaverde Formation (of upper Cretaceous age), which crops out at intervals around the edges of the field, is the oldest coal-bearing formation. Above the Mesaverde are the non-coal-bearing Lewis Shale and Foxhills Sandstone and the coal-bearing Medicine Bow, Ferris, and Hanna Formations. The Lewis Shale, Foxhills Sandstone, and the Medicine Bow Formations are upper Cretaceous. The basal part of the Ferris Formation also is considered to be of upper Cretaceous age, and the main part of the formation is considered to be of Paleocene. The Hanna Formation is Paleocene and lower Eocene.

A total of 130 coalbeds have been mapped in the four coal-bearing formations. Of this total, a third or more may lie at the same stratigraphic position as other numbered beds. The coal is of workable thickness at numerous places in the Hanna field, but as a rule the beds are not persistent for long distances. The highest-rank coal, high volatile “C” bituminous, occurs in the Mesaverde Formation; the thickest and most extensive beds are of sub-bituminous rank and occur in the Ferris and Hanna Formations. Throughout the field, many of the coal lenses cannot be traced because of poor exposures.

Description of the coals present within each formation is as follows.

Mesaverde Formation Coal

The Mesaverde Formation, which is 2,200 to 2,700 feet thick, crops out generally as ridges in the border areas of the field, where at places it also constitutes the central part of local anticlines. The formation consists of three members, each composed largely of sandstone and shale, but the middle member differs from the others in its fresh and brackish water invertebrate fossils, in its dominantly brown color, and in the large content of carbonaceous material. The coalbeds, which occur in the middle member of the formation and locally, in the upper member, are thin, irregular, and generally impure. At least four of the coalbeds are more than 3 feet thick. The maximum thickness of any bed is about 8 feet, as observed in T24N, R84W. The coal generally is of high volatile “C” bituminous rank. An analysis, on an as-received basis, of coal from the Mesaverde Formation in the Wissler mine indicates 10,290 Btu/lb heat value, 1.1 percent sulfur, and 7.8 percent ash.

Medicine Bow Formation Coal

The Medicine Bow Formation consists of 4,000 to 6,200 feet of shale and sandstone and numerous beds of coal that occur in a brown sandstone unit in the lower 1,500 feet of the formation. The unit contains at least 15 coalbeds that are more than 3 feet thick and attain a maximum thickness of about 11 feet. The beds are irregular in extent; at some places the unit contains no coal, whereas at others it has more than 12 beds. The coal is of sub-bituminous “A” rank. The average of two analyses, on an as-received basis, of coal from the Medicine Bow Formation indicates 11,050 Btu/lb heat value, 0.8 percent sulfur, and 3.8 percent ash.

Ferris Formation Coal

The Ferris Formation is about 6,500 feet thick and is composed of shale, sandstone, a basal conglomerate, and numerous thick beds of coal, which occur in the upper 5,400 feet of the formation above the basal conglomerate. A minimum of 20 beds in the formation are more than 3 feet thick, and as a rule the beds are thicker and more extensive than those in the Mesaverde and Medicine Bow Formations. Several beds are more than 5 feet thick, and the maximum thickness observed is 23.4 feet of clean coal, which is separated by 10 feet of shale near the middle and by 2 feet of shale near the top (T22N, R83W). The thickest bed extends at mineable thickness for about 7 miles along the outcrop, and, although it is generally separated into benches, at least one bench contains more than 5 feet of clean coal at most places. Others of the more than 18 beds of mineable thickness coal exposed in this township are thinner and less persistent and contain numerous partings. The beds in the general area dip about 10 degrees to 25 degrees northeast. The coal is of sub-bituminous rank.

Hanna Formation Coal

The Hanna Formation, which unconformably overlies the older rocks, consists of about 7,000 feet of alternating conglomerate, sandstone, and shale and contains numerous beds of coal. At least 30 coalbeds reach thickness greater than 3 feet, and the maximum thickness of clean coal is more than 30 feet. The thickest bed (seam) in the field is the Hanna No. 2, which crops out in the western part of T22N, R81W. At one exposure north of the town of Hanna, this bed contains more than 30 feet of coal without partings but north of the town its outcrop is generally burned. Southwest of the town the Hanna No. 2 seam is about 35 feet thick, including several shale partings each about 1-foot thick. But, 2 miles to the south the coal reportedly thins to 12 feet. It dips about 12 degrees to 20 degrees eastward. The coal is of sub-bituminous “A” rank; an analysis, on an as-received basis, of coal from the Hanna No. 2 seam (from within the Hanna No. 4 mine) indicates 11,200 Btu/lb, 0.5 percent sulfur, and 5.5 percent ash.

The Hanna field has been a major Wyoming coal producer, and total production ranked fourth behind that of the Rock Springs, Kemmerer, and Sheridan (Powder River Basin) fields. Its relative importance as a major coal producer has declined since the advent (late 1970s) of large-scale surface mining in the Powder River Basin.

Remaining Reserves – Hanna Field

The 1979 estimated remaining strippable resource and reserve base for the Hanna Coalfield was established at 648 million tons (Glass and Roberts, 1979). However, that may have been a liberal estimate, given that recorded production data (Lyman and Hallberg, 2000; Wyoming Coal Information Committee, 2002) and BLM estimates indicate that the following production occurred during the period 1975-2000. (Note: indicated tonnages are approximate and subject to rounding.

Mine	**Production (tons) 1975-2000**
Energy Development Company (3 mines)	8,000,000 (closed 1984)
Seminoe I (Arch)	18,200,000 (closed 1984)
Seminoe II (Arch)	33,500,000 (still operational)
Shoshone I (RAG)	43,000,000 (closed 2000)
Medicine Bow (Arch)	42,000,000 (still operational)
	144,700,000

[1]The Medicine Bow and Seminoe II mines remain operational with a projected 2-year mine life (based on an estimated aggregate of 2 million tons of recoverable reserves remaining).

In conjunction with the forthcoming closure of the Seminoe II and Medicine Bow mines, Arch of Wyoming, Inc. is apparently evaluating development of the nearby Carbon Basin coal project (Elk Mountain/Saddleback Hills Coal Lease – WYW139975). This lease tract contains an estimated 149.7 million tons of in-place federal coal resources, a portion of which is amenable to surface mining methods, while the remainder would be recoverable utilizing underground mining methods.

3.1.2.2 Great Divide Basin Coalfield

The Great Divide Basin field includes about 1,800 square miles in the northeastern part (T21-28N, R88-95W) of the Green River region.

The field is largely in Sweetwater County, but extends northward into Fremont County and eastward into Carbon County. It is bounded on the north by the Granite Mountains, on the east by the Rawlins Hills, and on the south by the Wamsutter Arch. The structure of the Great Divide Basin field is a broad downwarp overlain by flat-lying younger rocks. The oldest rocks in the basin crop out along the eastern edge of the downwarp; in this area the beds dip generally 25 degrees to 80 degrees westward, and in at least one place are overturned.

The Mesaverde Lance, Fort Union, and the Wasatch Formations contain coalbeds of mineable thickness in the field. The Mesaverde, which crops out along the eastern edge of the field, consists of about 2,000 feet of strata at the northern end of its outcrop and about 4,600 feet at the southern end. It is composed of alternating beds of sandstone and shale and is divided into three members, the upper two of which are coal bearing. The coal in these two members occurs in three zones: a lower zone at the base of the middle member, a middle zone at the base of the upper member, and an upper zone near the top of the upper member.

The lower coal zone contains four to six irregular beds of impure coal that are poorly exposed but apparently are not of mineable thickness. The coalbeds in the middle zone are generally thin in the few places where they are exposed, but they are believed to be thicker in the southeastern part of the field, where one bed contains 8.2 feet of clean coal and two 1-inch partings. The upper zone contains a minimum of four thin beds of coal, all of poor quality. Analyses of the coal in the Mesaverde are not available, but it is probably similar in rank to the high volatile “C” bituminous coal of nearby fields.

A sequence of shale, sandstone, and coal of the Lance Formation crops out in a north-trending belt in the eastern part of the Great Divide Basin field. It is separated from the Mesaverde Formation by the Lewis shale, which is 2,000 feet thick in the area. The coalbeds occur throughout the sequence and are especially numerous in the southern part of the field. The average thickness of 39 measured sections, located in all but one of the townships where the sequence is exposed, is 6.2 feet of clean coal. The maximum thickness of any bed is 12 feet, and the minimum is 10 inches. Some of the thicker beds are separated into benches by thick shale partings, but most sections show at least one bed of mineable thickness free of partings. A 1,800-feet measured section in the sequence (T25N, R89W) shows six coalbeds more than 2.5 feet thick, the thickest being 6 feet. An analysis, on an as-received basis, of weathered coal from the formation in the northeastern part of the field indicates 9,023 Btu/lb heat value, 0.3 percent sulfur, and 4.1 percent ash.

Rocks considered to be of Fort Union Formation unconformably overlie the Lance Formation in the eastern part of the field and crop out in a belt that trends generally north. This sequence consists of alternating beds of sandstone, shale, conglomerate, and coal. The lower 800 to 1,800 feet is composed of shale and conglomeratic sandstone and contains no coal. Above this lower barren unit coal occurs in two members that are separated by a non-coal-bearing member of soft shale and sandstone. In the southeastern part of the field both coal-bearing members contain workable beds. The lower member contains no coal in the northern part of the field, where it is the only part of the formation exposed. The average thickness of eight measured sections in both members, mostly in the southeastern part of the field, is 4.6 feet of clean coal. The maximum thickness is 20.7 feet.

The Eocene Wasatch Formation is flat-lying upon older dipping strata, crops out over a large part of the Great Divide Basin field. The Wasatch includes about 900 to 1,800 feet of sandstone, shale, conglomerate, and coal and includes a basal conglomerate that is thin in the southern part of the field where it is comprised of granite pebbles, but thickens northward and becomes coarse. The coalbeds are in a zone that overlies this basal member and are confined to the southern and western parts of the field. The average thickness of 12 measured sections is 5.1 feet of clean coal, the maximum being 16.1 feet. At many places along the outcrop the coal is burned.

3.1.2.3 Rock Creek Coalfield

The Rock Creek field covers about 450 square miles in the north-central part of the Laramie Basin, largely in Albany County but partly in Carbon County. The Union Pacific Railroad crosses the northeastern part of the field. The surface of the field is a gently rolling plain, which is covered with gravel over large areas. As a result, outcrops of the coal-bearing rocks are few in number and small in extent. The thickest and best-exposed coalbeds are in the northwestern part of the field (T20N, R76W and T19N, R77W) in the Mesaverde Formation and in the Hanna Formation. In these townships, the dips of the strata range from about 8 degrees to 20 degrees, generally to the southeast.

The Mesaverde Formation consists of 1,250 feet of sandstone, sandy shale, carbonaceous shale, and coal. The Pine Ridge sandstone at the top of the Mesaverde is about 80 feet thick in T20N, R76W and contains at least four coalbeds of “workable” thickness. The thickest coalbed exposed in the Pine Ridge sandstone member is in this township, where the coal attains a maximum thickness of 8 feet. The beds occur at several horizons in the sandstone, but they vary in thickness and probably are not continuous for long distances. Early mining operations (small, local operations) in the field were in coal ranging in thickness from about 4 to 7 feet.

The Hanna Formation, in the Rock Creek Coalfield, consists of sandy shale, sandstone, carbonaceous shale, conglomerate, and coal. One coalbed of mineable thickness crops out in places in the western part of T19N; R77W, where it reaches a maximum thickness of 9.5 feet, exclusive of several partings that total 2.2 feet. The coal is of sub-bituminous “B” rank, with representative analyses indicating 8,843 Btu/lb heat value, 0.9 percent sulfur, and 12.1 percent ash.

Coal is exposed locally in townships south and west of those discussed, but generally the gravel cover prevents determination of the thickness and extent of the beds. Mining within the Rock Creek field has been confined to small, local operations, and production has been limited.

3.1.2.4 Kindt Basin Coalfield

The Kindt Basin field is an eastward extension of the Green River (coal) region. The Green River region comprises approximately 15,400 square miles in southwestern Wyoming, and extends into Carbon County, being generally bounded on the east by the Rawlins Uplift and the Sierra Madre. The Kindt Basin field occupies approximately 200 square miles, mostly in T19-20N, R84-87W in west central Carbon County. The field is immediately south of the Union Pacific Railroad and southeast of the Town of Rawlins. The coal-bearing Mesaverde Formation crops out over most of the field, the limits of its outcrop determining the northern and southern boundaries. Along the eastern side of the basin Tertiary rocks conceal the Mesaverde Formation. To the west, the Kindt Basin adjoins the Little Snake River field.

In the Kindt Basin Coalfield, the Mesaverde Formation ranges in thickness from about 2,700 to 3,600 feet and consists of three members composed mostly of alternating beds of sandstone and shale. The lowest member, about 700 feet thick, contains no coal; the middle and upper members contain coal at irregularly spaced intervals. The coalbeds are lenticular and may show at least one shale parting that is variable in thickness. The coalbeds, exclusive of partings, are 2 to 6 feet thick. On the north side of the Kindt Basin field the coalbeds dip at 45 degrees to 75 degrees southward; on the south side the dip is about 11° northward.

The coal is of high volatile “C” bituminous rank. An analysis, on an as-received basis, from the Dillon mine indicated 11,010 Btu/lb heat value, 0.5 percent sulfur, and 8.4 percent ash.

3.1.2.5 Little Snake River Coalfield

The Little Snake River field, which is south of the Great Divide Basin field, includes more than 1,500 square miles in parts of T12-20N, R87-95W. The field is in the southeastern part of the Green River region, south of the Red Desert and west of the Sierra Madre. It extends from the Colorado state line on the south to the Union Pacific Railroad on the north. The strata generally dip westward toward the central part of the Green River region at angles ranging from nearly horizontal to as much as 35 degrees west.

The Mesaverde Formation and two overlying upper Cretaceous and Tertiary units contain workable coalbeds, many of which, especially the two higher units, are burned at the outcrops. The Mesaverde Formation consists of about 2,000 feet of strata, and is composed mainly of sandstone and shale. It crops out in a general north-trending band along the eastern edge of the field and is divided into three members, of which the middle and upper contain coal of mineable thickness. At the southern end of the field, several sections (probably in the middle member) show workable coalbeds that contain 2.8 to 12.2 feet of coal with no partings. The coalbeds in the middle member decrease in number and become thinner toward the north where the coal is of poor quality.

The upper portion of the Mesaverde contains several coalbeds in its area of outcrop in the Little Snake River Coalfield. In a measured section (T17-18N, R90W) the member contains four beds 5 to 11 feet thick. In the southern part of the field three measured sections each show more than 5 feet of clean coal.

The exposures of coal in the Mesaverde Formation are not continuous, and the beds are believed to be lenticular. However, where one bed thins, another is likely to thicken, and as a result the total thickness of the coal may remain fairly consistent over considerable areas. The coal is of high volatile “C” bituminous rank. Available analyses of coal in the Mesaverde from this field are of weathered samples; analyses on an as-received basis indicate 10,492 Btu/lb heat value, 0.9 percent sulfur, and 7.0 percent ash.

Rocks of the Lance Formation, separated from the Mesaverde Formation by about 1,600 feet of Lewis Shale, include about 3,500 feet of sandstone and shale and small amounts of coal. The coalbeds are poorly exposed, are covered in many places by surficial material, and generally occur between beds of shale that weathers rapidly. One measured section of a coalbed (T12N, R90W) which is probably in this sequence in the southern part of the field, shows 6.5 feet of clean coal. A bed about 5 miles to the north contains only 2 feet of coal, but two beds measured still farther north show a minimum of 5 feet and one shows 8.2 feet. At least some of the coal in the formation is of sub-bituminous “B” rank. The only available analyses (from the northeastern part of the field) indicate on an as-received basis, 9,722 Btu/lb heat value, 0.3 percent sulfur, and 3.8 percent ash.

The Tertiary (Paleocene) Fort Union Formation in the Little Snake River field is about 5,000 feet thick and consists of sandstone, shale, clay, and some conglomerate. It isdivided into three members, the lower and upper of which are coal bearing. Sandstone, some of which is conglomeratic, is abundant in the lower and upper members; conglomeratic sandstone and, locally conglomerate occur at the base of the formation. The non-coal-bearing middle member generally consists of clay shale, sandy clay, and local beds of sandstone. The sequence, which probably contains more coal than any other in the field, crops out extensively in the northern part of the field, but because of overlap by younger rocks the exposed part decreases southward to a narrow band.

The lower member of the Fort Union Formation, as measured in T17-18N, R91W, includes (within an interval of about 160 feet) a minimum of three workable coalbeds averaging 8, 5, and 3.5 feet in thickness. South of the locality, some coalbeds in the lower member are more than 5-feet thick and are possibly continuous for long distances. In the upper member, one zone (T18N, R92W) contains within an interval of about 60 feet several layers of shaley coal but only about 3 feet of good coal. This member is largely concealed in the western part of the field by younger coal-bearing rocks.

The coal in the sequence ranges in rank from sub-bituminous “C” to “A.” The average of five analyses, on an as-received basis (weathered samples from the lower member) indicates 8,789 Btu/lb heat value, 0.9 percent sulfur, and 8.3 percent ash.

3.1.2.6 Goshen Hole Coalfield

The Goshen Hole field includes approximately 250 square miles (T19-23N, R60-64W) in southern Goshen County in an area underlain by the Lance Formation. The area is about 75 miles southeast of the southern end of the Powder River Basin.

The coal bearing rocks in the Goshen Hole field are exposed in a topographic basin. Most of the coal outcrops are along Horse Creek, where several mines have been opened in the past. No coal more than 2.5 feet thick is known to occur in the field, though it is reported that a well near Meriden, in the southern part of Goshen County, penetrated once coalbed 4 to 5 feet thick and several thinner beds, all within 1,000 feet of the surface.

Because of the thickness (thinness) of the coalbeds at the surface, no resource/reserve data has been obtained representative of the Goshen Hole field. No analyses of coal from the field are available, but the coal is presumably of sub-bituminous rank like coal of the same age and geologic relationships elsewhere in Wyoming.

3.1.3 Oil Shale

The USGS estimates Wyoming's oil shale resource at 320 billion barrels in rock yielding fifteen gallons per ton or more within the Green River Basin and Washakie Basin (Brobst and Pratt, 1973).

The Green River Formation (Eocene age) is host to oil shale occurrences within the Luman Tongue, Fontenelle Tongue, Tipton Tongue, Tipton Shale Member, and Laney Shale Member. Presence of the oil shale bearing rock (with no implication as to yield or quality inferred) has been confirmed (Bradley, 1964; Love and Christensen, 1985).

In general, the oil shale occurrences occupy an extensive portion of the Washakie Basin (centered on the Adobe Town area), and there are discontinuous or intermittent occurrences present in the northwest portion of the Great Divide Basin.

These two areas encompass the following townships (listed in a general west-to-east sequence):

<u>Washakie Basin Oil Shale Occurrence</u>
T12-17N, R99-100W
T12-18N, R98W
T12-19N, R94-97W
T13-17N, R92-93W

Green River Basin Oil Shale Occurrence
T25N, R94-96W
T23N, R96W
T23N, R95W

3.1.4 Phosphate

Phosphate rock is the source for calcined phosphate compounds, roughly 90 percent of which are used as the major component of fertilizer. The remaining 10 percent of phosphate production is used to produce industrial chemicals such as elemental phosphorous or phosphoric acid (Stowasser, 1989).

Primary phosphate production in the United States (U.S.) centers in southeastern Idaho, where phosphatic ores are mined from the Permian Phosphoria Formation. The formation is estimated to encompass an area in excess of 175,000 square miles, and extends easterly (at significant depth) into the Great Divide – Washakie Basin areas of the RMPPA where it grades into the Goose Egg Formation. The Phosphoria Formation is not present in the central or eastern portions of the RMPPA.

The Phosphoria Formation consists of oolitic, phosphatic limestones and shales with interbedded shales, mudstones, and dolomitic limestones. The deposits are typically overlain by a cherty member, and underlain by either a limestone or a quartzite. The formation varies in thickness from a few to as much as 200 feet in some localities. Commercial grade phosphate is usually restricted to a comparatively narrow bed either near the top or bottom of the formation (Cochran, 1950).

Phosphate rock is classified by grade, on the basis of tri-calcium phosphate [$Ca_3(PO_4)_2$], or bone phosphate of lime (BPL) content, as follows: “low grade” (30 to 49.9 percent BPL); “medium grade” (50 to 69.9 percent BPL); or “high grade” (70 percent or greater BPL). Phosphate beds containing over 65 percent BPL content are generally considered to be of potential commercial grade.

The principal constituents of phosphate rock are lime, phosphate, silica, CO_2, organic matter, magnesia, alumina, iron oxide, and fluorine (listed in approximate order of abundance). In addition, appreciable quantities of vanadium are found in thin beds within the Phosphoria Formation. Investigation by the Geological Survey of Wyoming has determined that the phosphatic shales can contain as much as 0.01 percent to 0.02 percent U_3O_8 (uranium oxide) (Cochran, 1950; McKelvey, 1946).

3.1.5 Other Leasables

A number of saline minerals categorized as leasable minerals are present within the RMPPA, including sodium sulfate and potash. These minerals are typically present as evaporite deposits in Quaternary playas (i.e., sodium sulfate), or in bedded deposits in sedimentary rocks (i.e., potash) of Pennsylvanian age.

3.1.5.1 Sodium Sulfate

Sodium sulfate is an industrial chemical used in soap and detergents, in pulp and paper treatment, and in glass and other products (Kostick, 1989). Pure sodium sulfate is found in nature as the mineral thenardite (anhydrous). Hydrous sodium sulfate (mirabilite) is produced in Wyoming at the Pratt sodium sulfate deposit near Natrona in Natrona County. Other sodium sulfate rich soda lakes are found throughout Wyoming (Harris and others, 1985). Although none are being mined at the present time, known locations of soda lakes or soda salt deposits within the RMPPA include the following:

Within T22N, R96W	Red Desert Basin (west edge of RMPPA)
Within T20N, R95W	About 6 miles west-northwest of Wamsutter
Within T21N, R94W	About 9 miles northwest of Wamsutter
Within T24N, R95-96W	Lost Creek Lake
Within T25N, R88-89W	About 3 miles north-northeast of Separation Point
Within T22N, R84W	Midway between Fort Steele and Seminoe Reservoir
Within T15N, R75W	Soda Lake (Harmony vicinity, north of Laramie River)

3.1.5.2 Potash

Potash (K_2O, or potassium carbonate) is an evaporite mineral product used almost exclusively in fertilizer. Beds of potash are present in the subsurface in Goose Egg Formation equivalent rocks (Permian in age) in eastern Wyoming.

One indicated potash occurrence deposit (which is within the RMPPA) generally encompasses areas extending east-to-west (from the Wyoming-Nebraska state line) to approximately R67W, and, extending from the N½ of T16N to include all of T17-19N. Oil wells have penetrated this section, and a few cores of potash-rich rock have been recovered.

Although New Mexico currently produces most of the potash consumed in the U.S. and potash has not been produced from Wyoming in the past, these beds may be an economically viable resource of potash (Harris and King, 1986).

3.1.5.3 Geothermal Resources

According to the Geothermal Steam Act of 1970 as amended, (84 Stat, 1566; 30 U.S.C. 1001-1025), geothermal resources are: 1) all products of geothermal processes, embracing indigenous steam, hot water, and hot brines; 2) steam and other gases, hot water, and hot brines resulting from water, gas, or other fluids artificially introduced into geothermal formations; 3) heat or other associated energy found in geothermal formations; and 4) any byproduct derived from them. The Act provides the Secretary of the Interior with the authority to lease public lands and other federal lands, including National Forest lands, for geothermal exploration and development in an environmentally sound manner. This authority has been delegated to the BLM. BLM implements the Act through the regulations contained in 43 Code of Federal Regulations (CFR) Part 3200.

Geothermal leases are issued through competitive bidding for federal lands within a known geothermal resource area (KGRA), or noncompetitively for federal lands outside of a KGRA. There are no KGRA's within the RMPPA. The Rawlins Field Office will authorize exploration and development activities on geothermal leases. The Wyoming State Engineer regulates all water resources and the necessary permits would have to be obtained from this agency prior to development.

Geothermal energy in the RMPPA is the heat energy that is available from deep basin centered reservoirs or shallower hydrothermal convective systems that are connected to the deep basin reservoir systems. With aquifer flow from the deeper parts of the basin, shallower areas along the basin margins may access the geothermal energy of the moving water as a hydrothermal convective system. Beyond the basin margins, the aquifers are generally too deep to be economically drilled for the available low to moderate temperature geothermal resources (Heasler, 1983). Water quality as related to the TDS, pH, and reactivity or hardness could have wide ranges from different aquifers. Flow rates are also widely variable but some reservoirs have good productivity. Because of the low to moderate temperatures, water quality and flow rates will be a big factor in the economic viability of this resource. Water quality and flow rates affect the capture of the energy from the water and subsequent disposal of the effluent. Water flow rates and quality in the RMPPA has a large range from very good to poor (Heasler, 1983).

In the Rawlins RMPPA, only one geothermal resource has been documented (James, 1979). The Saratoga geothermal resource consists of a number of springs flowing from the Miocene North Park Formation along the North Platte in the downtown area of the town of Saratoga. The main spring and adjacent pool was originally used by Indians before white pioneers "discovered" the spring and later named the town Saratoga after the hot springs in New York State (James, 1979). Several wells have also tapped this resource and all are used for hot water supply to swimming pools (James, 1979). The report by James (1979) suggests that this geothermal resource would be used for district heating of municipal buildings and homes in the town of Saratoga. The City Clerk of the Town of Saratoga states that this project was never initiated.

Potential geothermal resources in the Rawlins RMPPA are restricted to basin margins of the deeper basins and areas in which Paleozoic reservoirs allow an aquifer of adequate capacity and high quality water. Only the Paleozoic time period have the necessary widespread and high quality reservoirs with the Tensleep (Casper) Sandstone and Madison Limestone being the primary formations. Reservoirs of other geologic ages are generally much more limited, have poor reservoir characteristics and would probably have poor water quality.

The Denver Cheyenne Basin in the eastern portion of the RMPPA has neither the depth nor the Paleozoic or other relatively continuous reservoirs to have potential geothermal resources. The Shirley Basin has the necessary reservoir rock but is not deep enough to generate the geothermal resource. There is some evidence that would suggest a hydrothermal convective system in the Laramie basin (Hinckley and Heasler, 1984) but the resource would have to be pumped and the economics would not be attractive. The Hanna Basin has anomalous geothermal gradients (Hinckley and Heasler, 1984) on its margin, which suggests a hydrothermal convective system. The basin margin of the shallow Kindt Basin has the only known geothermal resource in the RMPPA with the Saratoga Hot Springs and this is probably a hydrothermal convective system from the adjacent deep basins. It is unlikely that any new resource will be developed in the Kindt Basin unless an oil and gas well discovered a geothermal resource and it was completed for geothermal use. The deep Great Divide and Washakie Basins with their associated shallow margins and arches may have geothermal resource potentials but again it is unlikely that commercial ventures could be economically justified due to the relative isolation and limited application of the resource.

3.2 Locatable Minerals

Wyoming is a uranium province. Uranium was discovered in the Powder River and Wind River Basins during the 1950s, and continued exploration for uranium resulted in discovery of additional sedimentary uranium deposits in the major basins of central and southern Wyoming. The Rawlins RMPPA contains its share of sedimentary uranium deposits in the Shirley Basin, the Great Divide Basin, the Red Desert area, and around Baggs in the Poison Buttes area. In addition to uranium, the Rawlins RMPPA encompasses deposits of titaniferous magnetite, stratabound gold, copper-gold deposits, and diamonds hosted in kimberlite pipes (**Figure 3-14**). Commercial development of the sedimentary uranium and the titaniferous magnetite deposits has occurred over the past 50 years. The other locatable mineral deposits have seen only limited production and sporadic exploration. Locatable mineral deposits in the Rawlins RMPPA are summarized in **Table 3-6** and plotted on **Figure 3-15**, with locations summarized in **Table 3-7**.

Figure **3-14** Potential Mineral Resources

Table **3-6** Locatable Minerals Deposits in the Rawlins RMPPA

Figure **3-15** Locatable Minerals

Table **3-7** Locatable and Salable Minerals Deposit Location Index

3.2.1 Sedimentary Uranium Deposits

In the Rawlins RMPPA, sedimentary uranium deposits are found in the Shirley Basin, the Great Divide Basin, the Red Desert, and in the Poison Buttes and Ketchum Buttes areas near Baggs and Saratoga, respectively. Sedimentary uranium deposits in Wyoming are epigenetic sandstone-hosted deposits formed by groundwater movement in paleochannels along the margins of major depositional basins, most of which are Tertiary in age.

Groundwater carrying uranium moved downward and towards the basin center from either volcanic or Precambrian basement sources. This relatively oxidized groundwater followed old alluvial channels (paleochannels) formed when the basin was subsiding. As the groundwater moved basinward, it encountered more reducing conditions and the uranium in the groundwater is reduced and deposited as pitchblende, uraninite, and coffinite in a “roll-front” type setting within the paleochannel. These roll-front settings are relatively easy to identify in outcrop and in drill cuttings because of the rapid transition from oxidizing conditions characterized by iron oxides to reducing conditions characterized by clay alteration, a dark color or stain, and a noticeable increase in radioactivity.

3.2.1.1 Shirley Basin Deposits

Shirley Basin is a major uranium district in Wyoming located about 32 miles north of Medicine Bow. Commercial production of uranium began in the 1950s and continued until the early 1980s. In 1965, the Atomic Energy Commission estimated the reserve in Shirley Basin to be about 50 million pounds of U_3O_8 at $8/lb. This was approximately one-sixth of the known uranium reserve in the U.S. at that time (Harshman, 1972b). Production has come from mines owned or operated by Kerr McGee, Petrotomics, Utah Construction and Mining, and Pathfinder (Harshman, 1972a). These sedimentary uranium deposits are hosted in the Tertiary Wind River Formation. The deposits are in “stacked paleochannels” formed in alluvial/lacustrine sedimentary environments that developed as the Shirley Basin subsided and was filled with fluvial and lake-bed sediments during the Tertiary.

There are three major zones of altered and mineralized sand extending over a depth range of about 400 to 1,500 feet. These zones are vertically stacked and form a linear trend 6 miles long extending northwest down the approximate center of the basin. The largest of these zones is 5 miles long, 3 miles wide, and 70 feet thick. Mining grades during the 1950s and 1960s ranged from 0.1 to 0.7 percent U_3O_8. Grades in drill intercepts ranged up to 20 percent U_3O_8. Uranium is associated with copper, selenium, and vanadium minerals in the ore zones. The age of the deposits is approximately 18 to 20 million years before present (Harshman, 1972a). Published past production is 9.3 million pounds of U_3O_8 as of 1969 (Crew, 1969). It is estimated that about 10 million more pounds of U_3O_8 were produced in the 1970s and early 1980s, before the collapse of uranium prices. The mines are currently shut down and undergoing reclamation because of the low price of uranium. Should the price of uranium return to levels comparable to those found in the mid to late 1970s, uranium mining could resume. Future extraction could employ in-situ solution mining of the uranium, rather than the open-pit mining that characterized the 1950s and 1960s. It is estimated that about half of the estimated resource of 50 million pounds of U_3O_8 still remains in Shirley Basin.

3.2.1.2 Poison Buttes Deposits

The Poison Buttes deposits are found in the Tertiary Browns Park Formation west of Baggs, Wyoming. These are disseminated epigenetic uranium deposits formed in the tuffaceous eolian sands of the Browns Park Formation. Mineralization consists of autunite, uranophane, and schroeckinite in the upper oxidized portions of the deposit and coffinite in the lower parts of the deposit (Hausel, 1982; Harshman, 1968). During the 1970s, Urangesselschaft identified a major deposit containing a reserve of 8 to 15 million pounds of U_3O_8 and planned a mine with 2,000 tons per day production capacity. The sharp drop in uranium prices in the 1980s put the development of this deposit on hold. Past production in the district has been estimated at about 176,000 tons of ore during the period from 1954 to 1967 (Hausel, 1982).

3.2.1.3 Red Desert Deposits

These sedimentary uranium deposits are not commercially viable because of their low grade. Uranium is associated with lignite coal deposits in the Wasatch and Green River Formations. Disseminated uranium in the lignite beds has grades ranging from 0.003 to 0.007 percent U_3O_8. Estimated resources of uranium are 24,000 tons (Wyant and others, 1956).

3.2.1.4 Great Divide Basin Mineralization

Uranium mineralization in the Great Divide Basin consists of sandstone-hosted and evaporative epigenetic uranium shows or prospects scattered throughout the Tertiary Battle Spring, Green River, and Bridger Formations. No resources have been identified. The strongest showing of uranium is the evaporative mineralization at the Lost Creek Schroeckinite deposit, where uranium grades range from 0.013 to 0.28 percent U_3O_8 in the Green River Formation. The Battle Spring and Bridger Formations are found farther north, outside of the Rawlins RMPPA, in the Green Mountain-Crooks Gap area of Wyoming, where they are host to major uranium deposits. The evaporative deposits in the Great Divide Basin are due to uranium-rich waters migrating to the surface and evaporating in areas of groundwater seeps and pools. Larger, more economic deposits of uranium may exist at depth.

3.2.1.5 Sedimentary Uranium Prospect Areas

Exploration for uranium in the Rawlins RMPPA during the 1950s and again in the 1970s uncovered a number of areas with strong uranium showings. These areas are dotted with uranium prospects, but have no identified resources. Notable areas of uranium showings include: 1) the Ketchum Buttes area north of Encampment, Wyoming, where disseminated and roll-front uranium mineralization have been found in the Tertiary Browns Park Formation; 2) the Desert Rose area southwest of Laramie, Wyoming, where sandstone uranium prospects are found in the Cretaceous Cloverly Formation; 3) the Miller Hill area near Rawlins, Wyoming, where disseminated uranium is found in the Tertiary Browns Park Formation; and 4) the area around Encampment and Riverside, Wyoming, where sandstone-hosted uranium prospects are found in the Tertiary Browns Park Formation.

3.2.2 Titaniferous Magnetite Deposits

3.2.2.1 Iron Mountain District

Titaniferous magnetite deposits are found in the Laramie Range and within the Precambrian Laramie Anorthosite, located northeast of Laramie, Wyoming. This intrusive mass contains layers and lenses of titaniferous magnetite formed as magmatic segregations when the igneous mass cooled. Subsequent folding and deformation of the intrusive mass have resulted in the layers of magnetite being distributed along the anticlinal axis of the intrusive in the Iron Mountain District of the Laramie Range (Hausel, 1990). The magnetite is associated with ilmenite, olivine, and anorthisite feldspar. Past production has come from the Shanton, Iron Mountain, and Sybille mines. Past operators have been Anaconda and the Union Pacific Railroad and production to 1968 has been estimated at 1.1 million tons of magnetite ore (Hausel, 1990). Estimated reserves are 30 million tones of massive magnetite ore averaging 45 percent iron and 20 percent TiO_2. Disseminated ore is estimated at 148 million tons at 20 percent iron and 9.7 percent TiO_2.

The Iron Mountain District encompasses 350 square miles and contains both massive and disseminated ore in 30 identified mines and prospects (Hausel, 1990). Besides ilmenite, pyrrhotite, chalcopyrite, pyrite, and sphalerite are found in the ore zones. Vanadium grades in the ore zones range from 0.03 to .75 percent V_2O_5. Three main mines with proven resources have been identified. The Iron Mountain Mine (T19N, R71W) has a past production of 674,000 tons of ore (1963-1966). Massive ore is found along an antiform for a distance of 1,700 feet and to a thickness of 200 feet. The identified resource is 30 million tons at 16 to 23 percent TiO_2 and 0.5 percent V_2O_5. The Shanton Mine (T18N, R71W) has two massive ore zones 400 by 60 feet and past production of 14,500 tons (1972-1974). Titanium grades are 15 to 21 percent TiO_2. The Strong Creek Deposit (T19N, R72W) is a disseminated deposit rich in sulfides that has a proven resource of 300 million tons at 13 to 45 percent iron and 5 to 30 percent TiO_2 (Hausel, 1990).

3.2.2.2 Sheep Mountain Black Sandstones

This deposit is found in sandstones of the upper Cretaceous Mesaverde Formation at the north end of Sheep Mountain in section 10, T15N, R77W. The sandstone outcrop extends for 4,300 feet with an exposure width of 50 feet. The maximum exposed thickness is 17 feet. The sandstones contain 67 percent heavy minerals of which 28 percent are titaniferous magnetite. Samples of the unit have averaged 15.6 percent TiO_2, 40.4 percent Fe, and 0.0015 percent U_3O_8 (Houston and Murphy, 1962). No resources have been identified and there is no past production.

3.2.3 Stratabound Gold Deposits

Stratabound gold deposits within the Rawlins BLM district are found in the Ferris Mountains and the Seminoe Mountains. Both of these areas are Laramide-age uplifts where Precambrian metasedimentary rocks are exposed. No resources have been delineated, but older mines with limited past production and exploration during the 1980s have uncovered similarities to stratabound gold deposits in Canada that are known to host considerable reserves of gold.

3.2.3.1 Ferris Mountains

The stratabound gold deposits in the Ferris Mountains have been described as “vein-like” deposits and beds in Precambrian metasediments and granites” (Lovering, 1929; Hausel, 1980). The “veins” in the metasediments are actually exhalative iron-formation jasperoid gold and copper beds that have been deformed by many periods of folding. Gold is disseminated in the oxide iron-formation jasperoid-rich beds; the copper is found in chalcopyrite zones within these exhalative beds. The Spanish Trail Mine is the only mine in the Ferris Mountains developed on these beds for the purpose of extracting gold. The past production is not known, but is probably not considerable, given the size of the mine workings. Numerous prospects and pits are found throughout the area.

3.2.3.2 Seminoe Mountains

The Seminoe Mountains constitute an uplifted Archean metamorphic province (Precambrian) containing amphibolite – grade metasedimentary rocks, exhalative banded iron-formation beds containing basalts with copper and gold. The district was discovered in 1871. Early ore grades from the Desert Treasure and King Mines were in the range of 5 to 12 ounces/ton gold. By 1886, the Desert Treasure Mine had 200 feet of workings and a 10-stamp mill. By 1896, the King Mine had reached 700 feet of workings. Development of the area was hindered by frequent Indian raids (Hausel, 1994).

The Penn Mine at Bradley Peak has been studied in some detail because it is the largest mine developed on these iron-formation gold-bearing beds. This mine encompasses the old King Mine.

Past production has been estimated at 530 ounces of gold (Hausel, 1994). There is an estimated 100 million tons of iron ore at 28 to 68 percent iron as a resource in the Bradley Peak area. Gold values from samples taken in the outcrop of the iron-formation beds range up to 2.7 ounces per ton gold. Gold in the banded iron-formation beds is associated with pyrite and chalcopyrite. Nephrite jade also is found in the Precambrian metasedimentary rocks. Registered mines in the district include the Penn, Charlie's Glory, the Star, Hope, and Sunday Morning mines. No gold resource has been identified to date.

3.2.4 Copper-Gold Deposits

Copper-gold veins, disseminated ore, and mineralized shear zones are found in the Jelm Mountain District, the Cooper Hill District, and the Silver Crown District. All three areas have seen past mining, but only the Silver Crown District has a proven resource of copper and gold.

3.2.4.1 Jelm Mountain District

The Jelm Mountain District lies southwest of Laramie, Wyoming, and consists of oxidized copper-gold-silver-arsenic-bismuth "veins" in a tightly folded Precambrian amphibolite schist (Hausel, 1980). The Annie Mine has 3 to 30 percent copper and up to 0.1 ounce per ton gold. The Wyoming Queen has three shafts to depths of 250 feet. The past production records from both mines are not available. Similar "vein-like" gold and copper deposits are known from the Precambrian of Canada, where they are the source of major gold production.

3.2.4.2 Cooper Hill District

The Cooper Hill District lies southeast of Medicine Bow, Wyoming. Geologically, it is similar to the Jelm Mountain district with mineralized "veins" and shears in folded Precambrian metasedimentary rocks (Hausel, 1994). Three mines, the Charlie, the Emma G, and the Albion Mine have past production, with 30 tons of ore at grades of 0.85 ounces per ton gold recorded for the Albion Mine. Ore grades in samples range up to 0.7 ounce/ton gold and 12.2 ounces/ton silver (Hausel, 1994). The district was discovered in 1896, originally as a placer gold district. A 10-stamp mill was constructed to serve the mines. The quartz-pyrite-chalcopyrite-galena-gold veins are conformable to the folded bedding. Cross-cutting later quartz veins are barren. Adits and shafts were developed on at least seven separate mines in the district (Hausel, 1994). Recorded gold grades from past production range from 0.2 to 1.0 ounce/ton gold. The Rip Van Winkle Mine has a reported ore grade of 31 ounces per ton gold. The remaining gold resources in the district are not known.

3.2.4.3 Silver Crown District

The Silver Crown District lies southwest of Laramie, Wyoming, and consists of a mineralized Precambrian quart monzonite intrusive within the Nash Fork-Mullen Creek Shear Zone. This is a disseminated copper and gold deposit formed during Precambrian island arc volcanism. The Copper King deposit has a proven resource of 35 million tons of ore at 0.2 percent copper and 0.02 ounce per ton gold. The deposit will eventually be mined, when commodity prices for gold and copper increase to levels comparable to those found in the 1980s.

3.2.5 Kimberlite Pipes and Diamonds

Wyoming has two known diamond districts, the Iron Mountain District (Hausel and Roberts, 1984) in the Laramie Range and the Stateline District (Hausel and others, 1985) south of Laramie, Wyoming. Both districts have identified kimberlite pipes, some with diamonds, but neither district has had any production of diamonds. The diamonds are mainly of industrial quality. In the Stateline District, diamond grades range from 0.5 to 1.0 carat per 100 tons of rock. Exploration for diamonds in southern Wyoming is ongoing and a commercial deposit may be found in the next few years.

3.2.5.1 Stateline District

This district lies along the Colorado-Wyoming border and encompasses about 80 square miles. It is associated with the Virginia Dale Ring Dike complex. Kimberlite pipes of Silurian/Devonian age intrude the Sherman Granite, which is Precambrian in age. Forty kimberlite diatremes (or pipes) have been identified and 15 of these carry diamonds (Hausel and others, 1985). The district was discovered in 1975. Although most of the district lies in Colorado, Wyoming is host to many of the diamond-bearing pipes. The longest of the pipes is 1,800 feet in length. The potential for discovery and development of a commercial deposit is considered very good.

3.2.5.2 Iron Mountain District

This area of kimberlite pipes lies about 4 miles northeast of the Iron Mountain Titaniferous Magnetite District. The kimberlite pipes are Silurian/Devonian in age and intrude the Precambrian Sherman Granite. The kimberlite pipes form a northeast trend about 5 miles in length. To date, 57 pipes have been identified, but none are known to carry diamonds. The erosional level of the pipes may be too deep for diamond occurrences (Hausel and others, 1985).

3.2.6 Rare Earth Elements and Yttrium

Wyoming has deposits of rare earth elements and yttrium located in the northwestern and southeastern sections of the state (King and Hausel, 1991). The deposits are generally small, but can be high grade and economic if mined on a small scale. The deposits in northwestern Wyoming are in Tertiary carbonatite intrusions in the southern Bear Lodge Mountains and in Cambrian placer deposits in the Bighorn Mountains. In southeastern Wyoming, the deposits are associated with Precambrian pegmatites in Carbon County and in the Tie Siding area south of Laramie.

The common rare earth elements are lanthanum, cerium, and neodymium. These are often called the Cerium Group, or Light Rare Earth Elements. The Yttrium Group of elements are often considered as Heavy Rare Earth elements and yttrium is usually associated with the Cerium Group elements. Common minerals that carry the rare earth elements and yttrium are allanite, euxenite, samarskite, columbite and tantalite, and monazite. The rare earth elements and yttrium are used in superconductive materials, electronic components including television and computer monitor screens, ceramics, lasers, and as catalysts for distillation of petroleum products. The world supply of known rare earth element deposits is limited, with most mines being found in Russia, China, southeast Asia, California, Canada, and South Africa. Thus, the potential for small but economic deposits of rare earth elements in Wyoming is of considerable interest.

3.2.6.1 Tie Siding Pegmatites

These are Precambrian pegmatities located in T12N, R71W and R72W, and in T13N, R72W in Albany County. The pegmatites are highly radioactive and are found as pod-like masses in the Sherman Granite (King and Hausel, 1991). Pyrochlore, allanite, and zircon have been identified and assays for rare earth elements have ranged up to 1,000 mg/l for lanthanum and niobium, with yttrium at 200 mg/l and ThO_2 assays at 4.1 percent. Seven large pegmatites are known. There has been no reported production.

3.2.6.2 Red Mountain Syenite

This Precambrian intrusive mass is associated with the Laramie Range Anorthosite complex and is found in the eastern half of T22N, R71W. The syenite contains 1.5 to 3.6 percent disseminated allanite that carries rare earth elements. Assays contain up to 731 mg/l neodymium, 119 mg/l samarium, and 754 mg/l cerium (King and Hausel, 1991). No production has been recorded, but the potential size of the deposit makes this area a potential low-grade but open-pit mineable deposit.

3.2.6.3 Big Creek Pegmatite

The Big Creek pegmatite area is located in Carbon County in T13N, R80W and in T13N, R81W. The main pegmatite carrying rare earth elements is the Platt pegmatite found in Section 3 of T13N, R81W. This pegmatite was mined for rare earth elements and produced 10,000 pounds of euxenite between 1956 and 1958 (Houston, 1961). Other minerals in the pegmatite complex are columbite-tantalite, allanite, and monazite. There are many similar pegmatites found throughout the Precambrian terrain located south of Encampment, Wyoming, that contain rare earth elements and have not been adequately explored (King and Hausel, 1991).

3.2.6.4 Fox Creek Pegmatites

The Fox Creek pegmatites are located in T13N, R78W sections 13, 24, and 32 of Albany County. These pegmatites are rich in columbite and tantalite (Harris and King, 1987). The pegmatites have known lengths of 1,300 to 2,100 feet with widths of 50 to 200 feet. The depths are not known, but are at least in the range of 70 to 100 feet based on the shafts and pits that remain in the mined areas. Past production from these pegmatites has been estimated at 85 pounds of high grade, hand sorted columbite-tantalite (Harris and King, 1987).

3.2.7 Alumina Deposits

The Laramie anorthosite complex (situated in the central Laramie Range) contains plagioclase feldspar, an aluminosilicate of calcium-sodium rich feldspar. Anorthosite is an igneous rock composed almost entirely of plagioclase feldspar. The Laramie anorthosite complex is exposed over approximately 350 square miles and crops out along Rogers Canyon Ninth Street Road, about 11 miles northeast of Laramie. Specimens also have been noted along Highway 34 in Sybille Canyon north of Laramie (Housel, 1986).

3.3 Salable Minerals

Salable minerals disposition is addressed under the Materials Act of July 31, 1947, as amended by the Acts of July 23, 1955 and September 28, 1962. These Acts authorized that certain mineral materials be disposed either through a contract of sale or a free-use permit. This group of mineral materials, commonly known as “salable minerals” includes, but is not limited to common varieties of sand, stone, gravel, pumice, pumicite, cinders, clay, and petrified wood in public lands of the U.S. (Maley, 1977).

Salable minerals known to be present within the RMPPA include, but are not necessarily limited to, aggregate, silica sand, dimension stone, vermiculite, pumice and scoria, common clay, and decorative stone (e.g., moss rock, garden boulders, flagstone, etc.). To the extent petrified wood may be present within the RMPPA, it has been considered a paleontological resource rather than a mineral resource. Known deposits of salable minerals are shown in **Figure 3-15**.

3.3.1 Aggregates (Sand and Gravel)

By far, the most significant salable mineral (both in terms of occurrence and demand) within the RMPPA is aggregates, or sand and gravel. Aggregate resources typically occur in one or more of the following forms:

- natural gravel deposits (unconsolidated gravel or loosely or partially cemented gravel that can be removed without benefit of blasting or cutting);
- alluvial sand and gravel deposits (stream channel and flood plain deposits);
- terrace sand and gravel deposits (braided stream and sheet flood deposits of glacial and non-glacial materials derived from mountain ranges);
- glacial gravels;
- older gravel deposits (conglomerate); or
- windblown (dune) deposits.

Within the RMPPA, the aggregates resource base is relatively widespread with respect to sand-like materials (generally present as windblown, terrace, and alluvial deposits); however, coarser (gravel-type) materials are present to a somewhat lesser degree. Where gravel is present, it is generally as an older gravel (conglomeratic) deposit, oftentimes situated beneath surficial deposits.

Former gravel and aggregate deposits within the RMPPA are noted as having been present near Fort Steele (T21N, R85W), near Elmo (T22-23N, R81W), near Creston Junction (T21N, R92W), and in the Red Desert Basin (T21-23N, R95-97W).

Identification of the known aggregate deposits (by type and general location) is provided in the following sections. Due to the variability in gradational attributes, individual deposits will likely require site-specific determinations as to suitability for potential uses.

3.3.1.1 Terrace Deposits – Sand and Gravel

Mapped occurrences of terrace deposits are noted to be present at the following general locations. While mapping (Harris, 1996) indicates the presence of “sand and gravel” deposits at these locations, limited reconnaissance-level field examination indicates a predominance of gradation as sand, rather than gravel, at most locations. These deposits, listed by county, and in a general west-to-east sequence, include the following:

Township/Range	General Locational Description
Sweetwater County	
T25N, R95-86W	North of Lost Creek Basin
T22N, R95-96W	Northeast flank of Red Desert Basin
T20-21N, R92W	Creston Junction area
Carbon County	
T26N, R87W	South flank of Ferris Mountains
T24-25N, R83-86W	Surrounding Seminoe Reservoir
T24-25N, R81-82W	West flank of Shirley Mountains
T19-20N, R80W	Elk Mountain area south of I-80
T24-25N, R78W	North of Medicine Bow, either side of Highway 487
T24N, R77W	TB Flat, between Muddy Creek and Little Medicine Bow River
T22N, R77-78W	Medicine Bow area, south of Highway 287
T20-21N, R77-78W	West of Rock Creek
Albany County	
T22N, R77W	Medicine Bow area, south of Highway 287, west of Wilcox
T20-21N, R77W	Rock River area, west of Rock Creek
T20N, R75-76W	Southeast of Rock River, south side of Highway 30
T21N, R74W	6 miles southwest of Wheatland Reservoir
T18N, R74-75W	Bosler/Cooper Lake area
T17N, R75-76W	West of Laramie River, both sides of I-80
T16N, R74-76W	West of Laramie along Highway 130 extending to Hatton
T14N, R75-76W	North of Highway 230, Harmony/Woods Landing area
T13N, R74-75	Antelope Creek area, south of Highway 230 and West of Highway 287
T13-16N, R73W	Intermittent deposits along either side Highway 287
Laramie County	
T18N, R61-62W	Meriden to Tremain
T12-15N, R60-63W	I-80 corridor Burns to Pine Bluffs south to state line

3.3.1.2 Alluvial Deposits

Mapped occurrences of alluvial deposits are noted to be present at the following general locations. While mapping (Harris, 1996) indicates the presence of “sand and gravel” deposits at these locations, limited reconnaissance level field examination indicates a predominance of sand, rather than gravel, at most locations. These deposits, listed by county, and in a general west-to-east sequence, include the following:

Township/Range	General Locational Description
Sweetwater County	
T24N, R96W	East of Hay Reservoir
T24N, R95W	Mouth of Eagles Nest Draw
T19N, R93W	Echo Springs area southeast of Wamsutter
T25-26N, R89-90W	Bairoil/Lamont area
Carbon County	
T23-24N, R88-89W	Separation Creek area, either side Highway 287
T23-24N, R87W	Separation Lake – Dry Lake area
T22N, R86W	Area north of Sinclair
T12-17N, R91-92W	Along extent of Muddy Creek, east side of Baggs Road
T15-18N, R83-85W	North Platte River and tributaries in Saratoga Area
T19-20N, R83W	Pass Creek, valley extending north-south
T26N, R81W	Grinnell Lake area northeast of Shirley Mountains
T22N, R78W	East of Medicine Bow
T19-20, R78W	McFadden area (Rock Creek/Pierce Reservoir)
Albany County	
T15N, R78W	Centennial area
T25-26N, R77W	Big Charley Lakes/Sheep Creek area
T25N, R74-75W	Laramie Range, headwaters North Laramie River
T17-21N, R73-74W	W of Laramie Range, Wheatland Reservoir to Laramie
T16N, R76W	Little Laramie River, north of Millbrook
T14-15N, R74-76W	Laramie River, Woods Landing to Laramie
T15N, R73-74W	South of Laramie, east of Highway 287

3.3.1.3 Wind-Blown Deposits

The RMPPA has extensive wind-blown deposits of sand, as exhibited by dune formations present south of the Ferris Mountains and west of Seminoe Reservoir, and by surficial deposits in the southwest (Cow Creek) and extreme southwest (Adobe Town) portions of the area. These deposits, listed by county, and in a general west-to-east sequence, include the following:

Township/Range	General Locational Description
Sweetwater County	
T21-23N, R95-96W	Red Desert Basin, southwest of Lost Creek Basin
T13-17N, R94-97W	Intermittent/scattered deposits – Adobe Town area
T16-17N, R93-94W	Vicinity of Barrel Springs Draw(s)
T16-17N, R90-91W	Cow Creek – Muddy Creek area, south of Sulphur
T24-26N, R84-89W	Ferris Mountains – Seminoe Reservoir area (dunes)
T27-28N, R85-86W	North of Ferris Mountains, west of Pathfinder Reservoir
T22N, R86W	North of Sinclair (scattered deposits)
T23N, R85W	Southwest end of Seminoe Reservoir
T22N, R84W	8 miles northeast of Fort Steele (scattered deposits)

3.3.1.4 Conglomeratic or Consolidated Gravels

Includes selective areas of poorly consolidated to consolidated gravels and conglomerates in rocks of Late Cretaceous to Pleistocene age. In some cases, the deposits are likely overlain by thin surficial deposits. These deposits, listed by county, and in a general west-to-east sequence, include the following:

Township/Range	General Locational Description
Sweetwater County	
T25N, R95-96W	Great Divide Basin, north and east of Wamsutter
T23-25N, R94W	Contiguous extension of above
T22-26N, R92-93W	Contiguous extension of above
T21-26N, R90-91W	Contiguous extension of above
Carbon County	
T28N, R81-83W	Extending 8-22 miles east of Pathfinder Reservoir
T27N, R82W	Extending 10-15 miles east of Pathfinder Reservoir
T16-19N, R 79-81W	Kennaday Peak, Medicine Bow River, south of Elk Mountain
T19-20N, R79W	North of I-80 between Elk Mountain and Arlington
T18-19N, R78W	East of Arlington extending south to Sevenmile Creek
Albany County	
T16-17N, R77W	Area south and east of Sevenmile Creek, south of I-80

3.3.1.5 Baked and Fused Shale (aka "Scoria")

Although more properly classified as a salable mineral under the category of "common clay," the baked/fused shale or "scoria" has been included under the category of aggregates. This is because surface outcrops of baked and fused shale (locally referred to as "scoria" or "klinker," but not technically a true volcanic-derived scoria) are important sources of aggregate (as a substitute when economically obtainable aggregate is not readily available) throughout Wyoming. Typically, this material is present in association with coal outcrop or burn lines, and as such, is abundantly present within and around the Hanna Basin coal mines, where it is utilized in the construction of haul roads. In addition, it is present at other locations exhibiting similar coal outcrop or burn lines, including several large deposits in the area stretching from Creston Junction to Baggs. Known, mapped locations of this type of scoria are indicated as follows:

Township/Range	General Locational Description
Sweetwater County	
T20N, R94W	4 miles northwest of Wamsutter, north of I-80
T20N, R94W	2.5 miles northeast of Wamsutter along I-80

3.3.2 Silica Sand

Silica sand of very pure quality is used in making glass and ceramics. In the Rawlins RMPPA, there are two areas of silica sand resources. One area is south of the Shirley Basin in the Freezeout Mountain area (T25N, R79W). The other is the Plumbago Creek deposit in Albany County (T20N, R73W). Both of these are orthoquartzite sands with greater than 70 percent SiO_2 that can be cleaned and purified to 90 to 95 percent SiO_2 by grinding and washing. The proven resource at Plumbago Creek is 64 million tons (Harris, 1988). As with most industrial minerals, production is dependent on local demand.

3.3.3 Limestone and Dimension Stone

Limestone can be quarried for dimension stone, for aggregate, or for industrial uses as lime. Dimension stone can include granite, marble, and certain sandstones suitable for quarrying and use in buildings. In the Rawlins RMPPA, limestone is mined north of Laramie along the west slope of the Laramie Range for use in cement, and dimension stone is quarried from around Rawlins in the Rawlins Uplift (Harris, 1991). Limestone has been quarried along the east and west flanks of the Laramie Range for years (Hagner, 1953) from the Paleozoic Casper Formation. Two limestone quarries are operated north of Rawlins, along the crest of the Rawlins uplift. These quarries are operated by the Wyoming Department of Transportation and Pete Lich and Sons and mainly used for aggregate production. The locations of former and active limestone and dimension stone quarries in the Rawlins RMPPA are shown on **Figure 3-16**.

Figure **3-16** Salable Minerals

3.3.4 Vermiculite

Vermiculite is a name given to a group of hydrated magnesium aluminosilicate minerals that expand when heated. Vermiculite is a family of related minerals; the term also is used for the expanded product in industrial applications (Harris, 1991). Vermiculite is formed by the hydrothermal alteration of biotite and hornblende. Thus, it occurs only in areas of igneous activity and is associated with high temperature fluids. Vermiculite is used as a lightweight aggregate, a soil conditioner in agricultural applications, and in selected industrial applications. The largest resources of vermiculite in Wyoming are in the Encampment area.

The Baggot Rocks vermiculite deposits are located near Riverside, Wyoming, in T15N, R83W. These deposits were formed by the hydrothermal alteration of hornblende and biotite schists adjacent to intrusive Precambrian pegmatites. The two main deposits in this area are the Platte Ranch and Paine vermiculite pits. No resource has been identified, but about 1,000 tons of vermiculite have been mined from the Platte Ranch pit (Hagner, 1944).

3.3.5 Pumice and Scoria

Pumice and scoria are volcanic rocks made of glass and usually full of holes called vesicles. Pumice is used as an abrasive, as a filler in concrete block, and for aggregate. Scoria can be used as a substitute for pumice in most industrial applications. It differs from pumice primarily in its angularity (sharpness) and dark color. Deposits of pumice are found at Sportsman Lake (T13N, R73W) in Albany County, near Creston (T20N, R92W) in Sweetwater County, and near Seminoe Dam (T25N, R84W) and Buzzard Ranch (T26N, R85W) in Carbon County (Harris and King, 1986).

As indicated earlier, there is another type of “scoria” (technically not a scoria since it is not volcanic in origin, but rather a baked and fused shale that is locally referred to as “scoria”) present within the RMPPA. The reader is referred to Section 3.3.1 for discussion of this type of deposit.

3.3.6 Common Clay

Clay minerals are hydrous aluminosilicate minerals with a sheet-like structure. Common clay is an industrial classification (by use) of clay, and it consists of clay or clay-like material that is sufficiently plastic to permit molding (Ampian, 1985). It is composed of the minerals illite, smectite, and kaolinite (Patterson and Murray, 1983). Common clay was produced in almost every county in Wyoming during the early years of statehood, typically for the manufacture of bricks that were used locally (Harris, and King, 1987). Occasionally, clay pits are opened for an immediate local need (e.g., landfill or lagoon liner material, etc.).

There are three former clay sites in Albany County at the Idealite deposit (T14N, R74W, S4), the Hutton Lake deposit (T14N, R74W, S34 and 27) and near Laramie (T16N, R74W, S36). The Cretaceous Frontier and Cloverly Formations and the Jurassic Morrison Formation are the principal sources of clay in Albany County. These former deposits were mined from shallow pits and are now inactive.

In Carbon County, there is a carbonaceous clay deposit in the Mesaverde Formation near Rawlins (T21N, R88W, S25) and clay deposits in the Hanna area (T22N, R81W, S3, 10, and 16) and near Sinclair (T21N, R86W, S21). These clays were used as lightweight aggregate and for brick clay.

Shale is a laminated sedimentary rock that is formed by the consolidation of clay, mud, or silt. In certain areas of Wyoming (generally in association with coal outcrops or burn lines), baked and fused shales are present. Locally, this material is referred to as "scoria" (although not a true "scoria" since it is not of volcanic origin). This material if oftentimes utilized locally as an aggregate substitute. The reader is referred to Section 3.3.1 for discussion of this type of deposit.

3.3.7 Decorative Stone

Decorative stone is any rock product (exclusive of aggregate) that is used for its color or appearance. Although color and appearance are important criteria in selecting decorative rock, the rock must frequently meet strength, durability, and other specifications. These specifications can include the absence of sulfides or minerals that could oxidize and stain or discolor the rock.

A number of decorative rock products are produced from within the RMPPA. A predominant number of decorative stone locales (i.e., marble, quartzite, granite, etc.) are situated within the Medicine Bow National Forest, in areas of the Sierra Madre and Medicine Bow Mountains (not included below). General classifications and locations (Harris, 1996) of other deposits are shown in **Table 3-8**.

Additional decorative rock products that are present within the RMPPA include moss rock and boulders. These rock products are typically utilized for structural, architectural, or landscaping applications.

A sizeable outcrop of moss rock (sandstone) is present in the southwest portion of the RMPPA (T12N, R98W), in the vicinity of the Colorado state line (north of the Powder Wash, Colorado, residence camp). Although BLM mineral disposal sales have occurred in this area, there is evidence to suggest that significant trespass and theft activity also has occurred.

Table 3-8
Locations of Decorative Stone

Rock Product/Classification	Township/Range	General Locational Area
Alabaster	T25N, R80W	East end Shirley Mountains
Decorative Stone	T14N, R78W	3-4 miles west of Lake Owen
Dec. Stone (Leopard Rock)	T22N, R71W	10 miles east of Wheatland Reservoir
Decorative Stone	T28N, R71W	5 miles southeast of Estabrook
Decorative Aggregate	T17N, R78W	6 miles southwest of Morgan
Decorative Aggregate	T14N, R78W	4 miles southwest of Lake Owen
Feldspar (Potassium)	T12-14N, R71-72W	10-15 miles east of Laramie
Feldspar (Potassium)	T15-16N, R70W	12-15 miles east of Laramie
Feldspar (Potassium)	T20, R72W	14 miles northeast of Bosler Junction
Granite, Orbicular	T27N, 87W	Ferris Mountains
Marble	T18N, R78W	West of Morgan
Marble	T20N, R72W	12 miles northeast of Bosler Junction
Marble	T19-20N, R71-72W	10 miles northeast of Bosler Junction
Marble	T24-25N, R70-71W	18 miles west of Curtis
Mineral Pigments (Fe Oxide)	T22N, R88W	4 miles north of Rawlins
Mineral Pigments (Fe Oxide)	T21N, R87W	2 miles north of Rawlins
Mineral Pigments (Fe Oxide)	T22N, R78W	5 miles east of Medicine Bow
Sandstone (“Rawlins”)	T20N, R87W	4 miles southeast of Rawlins
Quartzite	17N, R79W	8 miles northeast of Medicine Bow

3.3.8 Epsomite

Epsomite ($MgSO_4 7H_2O$) also is known as epsom salt. It has been used in relatively small quantities in the past for industrial chemicals and medical products.

In the early years of the 20th century, at Rock Creek Lakes in Albany County and at Poison Lake in Converse County, small plants were constructed to produce epsomite. Small resources of epsomite remain present at these and other sites within the RMPPA.

Epsomite deposits in the Rawlins BLM district can be found in the Red Desert Basin (T22-23N, R96-99W), the Boggy Meadows area near Bairoil (T25N, R88-89W), Taylor Draw near Medicine Bow (T22N, R76W), Rock Creek Lakes (T23N, R76W), Chain Lakes (T23N, R93W), and near Elkhorn Draw in the Laramie Peak area (T24N, R75W). Deposits also are found at Union Pacific Lakes and Downey Lakes south of Laramie (T13N, R75W). The Downey Lakes occupy a wind-excavated depression in the Triassic Chugwater Formation (Harris, 1987). The lakes cover about 100 acres and are up to 12 feet deep. The Rock Creek Lakes are north of Laramie and are a group of saline lakes and playas in a closed depression in the Chugwater Formation. The Union Pacific lakes are located 13 miles south of Laramie adjacent to Highway 230. Production was active in this area during 1885 (Harris, 1987). Epsomite resources in Wyoming are small, but capable of supplying a local market if demand should rise. Currently, there is no active epsomite production in Wyoming (Harris, 1991).

In addition, “saline” mineralization (not defined) mineralization (Harris, 1996) is indicated to be present in two small deposits located within T17N, R73-74W, in the vicinity of the town of Howell (west of Highway 287).

3.3.9 Petrified Wood

Petrified wood is organic woody material that has been replaced by microcrystalline quartz or opal. Most Wyoming petrified wood formed 30 to 40 million years ago, a result of trees being buried under volcanic ash. It is mainly considered to be of value to specimen collectors. While it is technically a salable mineral (obtainable subject to limitations under a free-use designation), it has no significant commercial value. It is, however, considered a paleontological resource, and collection is subject to terms and conditions consistent with the preservation of significant deposits as a public recreational resource. The only known concentration of petrified wood in the RMPPA occurs in the Shirley Basin.

4.0 MINERAL RESOURCES DEVELOPMENT POTENTIAL

The most important potential mineral resources in the RMPPA are hydrocarbon resources. The long history of production and developments in the last decade document the presence of source rocks, reservoir rocks, and trapping mechanisms that provide a significant hydrocarbon resource. The non-CBM gas resource has the greatest development potential. Oil and CBM are of lesser importance.

There are a variety of non-fluid minerals that are produced within the RMPPA; foremost amongst these would be coal, mined from the Hanna Coalfield northeast of Rawlins. In addition to coal, a number of industrial minerals are produced (e.g., limestone, gypsum, pumice and scoria, silica sand, decorative stone, etc.). The area is a former uranium producing area and if/when uranium prices rise sufficiently to justify production, it is likely that the area will again be a uranium producer. However, it is unlikely that this would occur within the projected 20-year planning period.

In addition, aggregates will be a significant mineral commodity for the RMPPA due to the projected development associated with oil and gas and CBM. Infrastructure requirements, primarily in the form of access roads, will drive the demand for aggregate resources.

4.1 Leasable Minerals

Leasable fluid minerals (oil and gas) are present in the RMPPA. Oil and gas have been produced for many decades from sandstone, limestone, and fractured shale/chalk reservoirs. Recent assessments by governmental agencies indicate there are significant amounts of undiscovered recoverable hydrocarbon resources in the RMPPA from these reservoirs. Gas produced from coal reservoirs has recently been considered and preliminary data suggests a sizable amount of gas may be produced from coal reservoirs. The discussion of hydrocarbon resource development potential in Sections 4.1.1 through 4.1.4 was provided by BLM's RMG in Casper, Wyoming. All maps, graphs, and discussion are the product of the RMG and it is solely responsible for the content and the conclusions contained therein.

Leasable non-fluid minerals known to be present within the RMPPA are coal, oil shale, phosphate and sodium. With the exception of coal (which is currently mined in the Hanna Coalfield), these minerals, where present, occur in sub-economic deposits. Further, current and projected market conditions are such that exploitation of these mineral resources (within the RMPPA) is highly unlikely within the projected planning period, as discussed below.

4.1.1 Hydrocarbon Plays

In 1995, the USGS conducted an assessment of the oil and gas resources of the U.S. (Beeman and others, 1996; Charpentier and others, 1996; Gautier and others, 1996). The assessment presents information about potential undiscovered accumulations of oil and gas in the Rawlins RMPPA. Information from that assessment is presented below.

The 1995 USGS assessment identified 71 geologic or structural provinces from which hydrocarbon resources are produced. The RMPPA is located partly within two of the provinces. The western and central portions of the RMPPA are located within the Southwestern Wyoming Province (USGS Number 037). The Southwestern Wyoming Province encompasses a number of basins and adjacent uplifts in Wyoming, Colorado, and Utah. The second province (Denver Basin Province, USGS Number 039) occupies the easternmost part of the RMPPA. The Denver Basin Province is a structural basin located in northeastern Colorado, southeastern Wyoming, the southwestern corner of South Dakota, and the Nebraska Panhandle. The Denver Basin also is referred to as the Denver-Cheyenne Basin and that terminology will be used in this report.

Provinces are further divided into oil and gas plays. A play is a set of discovered or undiscovered oil and (or) gas accumulations or prospects that are geologically related. A play is defined by the geological properties (such as trapping style, type of reservoir, nature of the seal) that are responsible for the accumulations or prospects.

Six of nine conventional Southwestern Wyoming Province plays lie partly within the Rawlins RMPPA (**Figures 4-1** through **4-3**). A conventional play contains oil and gas accumulations that have hydrocarbon-water contacts (due to the hydrocarbons being a separate phase and the buoyancy of hydrocarbons in water) and seals that hold or trap the hydrocarbons. Hydrocarbons in conventional plays can be recovered using traditional development and production practices. Data on the six plays is summarized in (**Table 4-1**). Five of six conventional Denver-Cheyenne Basin Province plays also lie partly within the Rawlins RMPPA (**Figures 4-4** through **4-7**). Data on the five plays is summarized in (**Table 4-2**).

The USGS also identified five unconventional basin-centered gas plays in the Southwestern Wyoming Province. All five basin-centered gas plays lie partly within the Rawlins RMPPA boundaries (**Figures 4-8** through **4-12**). In addition, four of the six Southwestern Wyoming Province unconventional coal reservoir or CBM plays lie within the Rawlins RMPPA boundary (**Figures 4-13** through **4-15**). Data on all nine plays is summarized in **Table 4-3**.

The USGS has identified five unconventional continuous-type plays in the Denver Basin Province. Continuous-type accumulations are pervasive throughout a large area and do not owe their existence to the buoyancy of hydrocarbons as a separate phase in water as conventional accumulations do. The reservoir rock of a continuous-type accumulation is everywhere oil or gas

Figure **4-1** Location of USGS Conventional Southwestern Wyoming Province Rock Springs Uplift, Cherokee Arch, and Subthrust Plays

Figure **4-2** Location of USGS Conventional Southwestern Wyoming Province Basin Margin and Platform Plays

Figure **4-3** Location of USGS Conventional Southwestern Wyoming Province Deep Basin Structure Play

Table **4-1** USGS Conventional Play Data for Southwestern Wyoming Province (037)

Figure **4-4** Location of USGS Conventional Denver-Cheyenne Basin Province Pierre Shale Sandstone Play

Figure **4-5** Location of USGS Conventional Denver-Cheyenne Basin Province Dakota Group Play

Figure **4-6** Location of USGS Conventional Denver-Cheyenne Basin Province Basin Margin Structural Play

Figure **4-7** Location of USGS Conventional Denver-Cheyenne Basin Province Permian-Pennsylvanian and Subthrust Structural Plays

Table **4-2** USGS Conventional Play Data for the Denver-Cheyenne Basin Province (039)

Figure **4-8** Location of USGS Unconventional Southwestern Wyoming Province Cloverly-Frontier Basin-centered Gas Play

Figure **4-9** Location of USGS Unconventional Southwestern Wyoming Province Mesaverde Basin-centered Gas Play

Figure **4-10** Location of USGS Unconventional Southwestern Wyoming Province Lewis Basin-centered Gas Play

Figure **4-11** Location of USGS Unconventional Southwestern Wyoming Province Fox Hills-Lance Basin-centered Gas Play

Figure **4-12** Location of USGS Unconventional Southwestern Wyoming Province Fort Union Basin-centered Gas Play

Figure **4-13** Location of USGS Unconventional Southwestern Wyoming Province Isles and Lance Coalbed Gas Plays

Figure **4-14** Location of USGS Unconventional Southwestern Wyoming Province Almond Coalbed Gas Plays

Figure **4-15** Location of USGS Unconventional Southwestern Wyoming Province Fort Union CBM Play

Table **4-3** USGS Unconventional Play Data for Southwestern Wyoming Province (037) charged. Other characteristics include low reservoir permeability, abnormal pressures, and close association of the reservoir with the source rocks from which hydrocarbons were generated. Coal reservoirs CBM plays are a form of continuous-type accumulation but none were recognized in the Denver Basin Province. Two of the five continuous-type plays lie partly within the RawlinsRMPPA and one play lies completely within its boundaries (**Figures 4-16** and **4-17**). Data on the three plays is summarized in (**Table 4-4**).

4.1.2 Hydrocarbon Resources

The USGS 1995 assessment of U.S. oil and gas resources (Beeman and others, 1996; Charpentier and others, 1996; and Gautier and others, 1996) also presents information about the potential resources in each hydrocarbon play. For the assessment, undiscovered technically recoverable resources were defined as estimated quantities of resources hypothesized to exist on the basis of geologic knowledge, data on past discoveries, source, and trapping theories. These resources are to be found in undiscovered accumulations outside of known fields. Estimates of resource quantities were determined to be producible using current recovery technology but without considering economic viability. Only accumulations greater than or equal to 1 million barrels of oil or 6 BCFG are included in this part of the assessment.

USGS hydrocarbon resource estimates are shown for conventional plays in the Southwestern Wyoming Province (**Table 4-5**) and Denver Basin Province (**Table 4-6**). Estimates also are shown for unconventional plays in the Southwestern Wyoming Province (**Table 4-7**) and Denver-Cheyenne Basin Province (**Table 4-8**). Four types of hydrocarbons (oil, natural gas liquids, associated-dissolved gas, and non-associated gas) can be produced in the conventional plays. Non-associated gas production and natural gas liquids can be produced in unconventional plays in the Southwestern Wyoming Province. Oil, natural gas liquids, and gas can be produced in unconventional plays in the Denver-Cheyenne Basin Province. Associated-dissolved gas is produced as a by-product of oil production, non-associated gas is produced as a by-product of condensate production, and natural gas liquids may be produced as a by-product of either type gas production.

For each type of hydrocarbon, a mean estimated resource (**Tables 4-5** and **4-6**) or mean potential reserve (**Tables 4-7** and **4-8**) volume was recorded for each play. Assuming hydrocarbons were evenly distributed across each play area, hydrocarbon volume was calculated from each play that would be contained within the RMPPA. Using **Tables 4-5, 4-6, 4-7,** and **4-8**, it was estimated that the RMPPA area contains a mean volume of 696 million barrels of undiscovered recoverable liquid hydrocarbons. It also was estimated that the RMPPA contains a mean volume of 44 TCF of undiscovered recoverable gas.

Fractile values of F99 to F1 for **Tables 4-5 and 4-6** and F95 to F5 for **Tables 4-7 and 4-8**) were used to describe the range of resource or reserve volumes that could be present in each play.

Figure **4-16** Location of USGS Continuous-type Denver-Cheyenne Basin Province J Sandstone Deep Gas Play

Figure **4-17** Location of USGS Denver-Cheyenne Basin Province Fractured Niobrara-type Plays

Table **4-4** USGS Unconventional Play Data for Denver-Cheyenne Basin Province (037)

Table **4-5** USGS Conventional Play Resources for Southwestern Wyoming Province (037)

Table **4-6** USGS Conventional Play Resources for Denver-Cheyenne Basin Province (039)

Table **4-7** USGS Unconventional Play Resources for Southwestern Wyoming Province (037)

Table **4-8** USGS Unconventional Play Resources for Denver-Cheyenne Basin Province (039)

Fractiles portray the potential distribution of volume of undiscovered resource. For example, F5 means that there is a 5 percent chance that more than the listed amount of resource will occur, and F95 means that there is a 95 percent chance that more than the listed amount of resource will occur. For the Rawlins RMPPA, the range of undiscovered recoverable liquid hydrocarbons was estimated to be between 273 and 1,567 million barrels. The range of undiscovered recoverable gas was estimated to be between 17 and 84 TCF.

Advanced Resources International (ARI) (ARI, 2001) prepared the most recent analysis of the hydrocarbon resource in southern Wyoming and northwestern Colorado. This analysis is part of a larger project planned for the Department of Energy. ARI (2001) used the USGS 1995 assessment, supplemented by data from the Wyoming State Geological Survey, and their own work, to estimate undiscovered, technically recoverable, natural gas resources for the area studied. They did not evaluate proven hydrocarbon reserves or undiscovered, technically recoverable, oil resources. For all of the USGS plays, ARI (2001) assumed a homogenous distribution of resource within play boundaries. Using the three sources of data listed above, they predicted the undiscovered, technically recoverable, gas resource for each township in the region assessed. The total predicted gas resource is 47 TCF in the RMPPA. Advanced Resources International's resource prediction is greater than the 44 TCF predicted from USGS data, but is within their estimated range of 17 to 84 TCF.

Figure 4-18 shows undiscovered, technically recoverable, gas resources. Those gas resources are shown by township, in three resource volume ranges, and in townships where a zero gas resource is predicted. Townships with zero gas resource are located in areas of mountain ranges that are made up of Precambrian granites, where traps and hydrocarbons are not known to occur. Highest predicted volumes of gas are located in townships scattered across parts of the eastern Washakie Basin, Wamsutter Arch, and eastern Great Divide Basin. Mid-range predicted volumes of gas are located in the rest of the Washakie and Great Divide Basins, and in most of the Hanna Basin. Hanna Basin CBM resource estimates, made by the Wyoming Geological Survey, account for a part of the predicted mid-range volumes for that area. The Denver-Cheyenne Basin Province is predicted to contain only low volumes of undiscovered gas. Almost all the "Atlantic Rim" proposed CBM project area lies in the low volume prediction area, along the eastern most margin of the Washakie Basin.

4.1.3 Hydrocarbon Occurrence Potential

Most of the Rawlins RMPPA is considered as having a high potential for the occurrence of hydrocarbons **(Figure 4-19)**. This rating considers a variety of geologic characteristics, including the following:

- the presence of hydrocarbon source rocks;
- the presence of reservoir rocks with adequate porosity/permeability;

Figure **4-18** Undiscovered Technically Recoverable Natural Gas Resources

Figure **4-19** Oil and Gas Occurrence Potential

- the potential for structural/stratigraphic traps to exist;
- the opportunity for migration from source to trap; and
- the presence of other conditions, such as temperature, depth of burial, and subsurface pressures.

All oil and gas plays, as defined by the USGS, are considered as being in areas of high occurrence potential. Approximately 77 percent of the RMPPA falls within this category.

Approximately 23 percent of the RMPPA falls outside of play areas designated by the USGS (Beeman and others, 1996; Charpentier and others, 1996; and Gautier and others, 1996). These areas are mostly located in parts of mountain ranges that are made up of Precambrian granites, where traps, reservoir strata, and hydrocarbons are not known to occur.

4.1.4 Projections of Future Activity

4.1.4.1 Oil and Natural Gas Price Estimates

Oil and gas price estimates are the single most important factor controlling the amount of future oil and gas drilling and production activity in the RMPPA. These prices can be very volatile as shown for gas in **Figure 4-20** and for oil in **Figure 4-21**. Gas prices to 2020 (**Figure 4-20)** were estimated from two sources. Henry Hub, Louisiana futures (the only gas futures contract location in the U.S.) prices for gas are from the Enerfax Daily (2002). The Energy Information Administration (EIA, 2001) estimated a 2020 gas price ranging from $2.94 to $3.65 per thousand cubic feet of gas. Price estimates for Wyoming natural gas require subtracting a price differential from Henry Hub futures and the EIA estimates. This price differential generally reflects transportation costs. A price differential of $0.50 per million Btu (MMBtu) was used for the low estimate projection in **Figure 4-20** and $0.25 per MMBtu was used for the high estimate projection.

The estimated cost of liquefied natural gas delivered to the east coast of the U.S. is about $1.75 to $2.75 per MMBtu (Cook, 2002). The availability of this liquefied natural gas in large quantities is expected to act as a moderating influence on gas prices, not allowing for large long-term price increases. Therefore, any price scenario should not consider long-term prices to exceed about $3.00 per MMBtu for natural gas produced in Wyoming.

Review of **Figure 4-20** price estimates allows some generalization about future gas drilling and production activity in the Rawlins RMPPA. Future price scenarios suggest that gas exploration and production will be positively affected by increased prices only during the next few years. Starting in about 2004, gas production in southwest Wyoming will be mainly a function of the ability of industry to discover and economically develop new accumulations, and the ability to

Figure **4-20** Historical Spot Gas Prices for Northwest Pipeline at Opal, Wyoming, with Projections to 2020

Figure **4-21** Plot of Historical Wyoming Crude Oil Prices, with Projections to 2020 increase drilling, production, processing, and transportation efficiency to take advantage of higher projected prices. Beyond about 2007, prices are expected to remain flat or decline. Those projected future gas prices alone are not expected to buoy exploration and production activity beyond 2007. This analysis assumes that the projected LNG imports will progressively supplant domestically produced gas as demand increases.

U.S. demand for natural gas is expected to increase about 50 percent by 2020. Increases in future natural gas production, to meet increased demand, are projected to come partly from the Rocky Mountain area. Anticipated production increases in Wyoming are expected to be mainly from unconventional energy sources such as CBM and deep basin-centered gas deposits.

Anticipated oil prices are based on a combination of futures prices for West Texas Intermediate crude oil and EIA (2001) estimates. **Figure 4-21** shows historical Wyoming sweet crude oil prices, future prices, and projected prices to 2020. Although oil prices have been in the $17 to $24 per barrel range during the past 12 months and as high as $30 per barrel in the past 18 months, futures prices suggest a steady decline to an average price of about $21.00 per barrel in 2008. The EIA (2001) estimates the price of crude oil will be between $17.06 and $23.79 per barrel in 2020. However, EIA's "High World Oil Price" is projected to be as high as $30.58 per barrel (EIA, 2001) and this should be expected to influence gas prices based on historical correlations. It should be remembered that much of the world's crude oil comes from politically unstable areas. Occasional unforeseen and abrupt price increases should be expected.

4.1.4.2 Leasing

General Leasing Information

After initial project evaluation, research, and subsurface mapping (which frequently includes use of seismic data), leasing is often the next step in oil and gas development. Leases on lands where the U.S. owns the oil and gas rights are offered via oral auction at least quarterly. Lease bids are based on industry speculation about amounts of potential hydrocarbons that may be present. Lowest prices are generally bid on leases with the highest risk of recovering economic amounts of hydrocarbons. Maximum lease size is 2,560 acres and the minimum bid is $2.00 per acre. An administrative fee of $75.00 per lease is charged and each successful bidder must meet citizenship and legal requirements. In addition to the lease bid, a $1.50 per acre per year rental is charged for the first 5 years and $2.00 per acre per year is charged thereafter. Leases are issued for a 10-year term. Each lease contains restrictive stipulations, which protect potentially affected resource values. Leases that become productive are held by production and do not terminate until all wells on the lease have ceased production. A 12.5 percent royalty is paid on all production. Many private oil and gas leases contain a "Pugh clause," which allows only the developed portion of the lease to be held by production. However, federal leases have no such clause, allowing one well to hold an entire lease.

Wyoming federal oil and gas lease sales are held on even numbered months, usually in Cheyenne. However, no lease sale was held in April 1996 due to the partial government shutdown. Since August 1996, only lands requested for lease have been offered. Before that, virtually all lands available for lease were offered at each sale.

Rawlins RMPPA Leasing

In April 2002, there were 2,300 federal oil and gas leases covering 2,113,552 acres in the RMPPA **(Table 4-9)**. **Figure 4-22** shows the location of all federal leased lands. The BLM managed about 99 percent of all federal leases and leased federal lands. The BLM leases average 920 acres in size. Those lands will be covered by decisions made during the plan update. The BOR and the USFS manage the remaining 31 leases. BOR leases average 897 acres in size. There is only one USFS lease and it is 204 acres in size.

Table 4-9
Distribution of Federal Acreage Covered by
Active Federal Oil and Gas Leases in the Rawlins RMPPA

Surface Management	Leases	Acreage
BLM	2,269	2,086,444
Bureau of Reclamation	30	26,904
U.S. Forest Service	1	204
Total	2,300	2,113,552
Held by Production	608	441,562

About 21 percent of the total leased federal acreage (26 percent of the federal leases) is held by production. Each lease that is held by production will not expire until the last well on that lease ceases production. Forty-three percent of the BLM managed lands is leased. The majority of the leased federal acreage is in western Carbon and eastern Sweetwater counties **(Figure 4-22)**.

As federal oil and gas leases expire, those lands may be nominated for leasing again. The number of federal acres in the RMPPA offered for lease, and leased competitively, on a year-by-year basis, is shown in **Figure 4-23**. During 1996-2001 over 1,186 leases were issued for acreage in the RMPPA. Eighty-three percent of the acreage offered was leased competitively. Since 1997, an average of 238,000 acres has been leased each year. The average lease size was about 1,034 acres.

A summary of bonus bid data received from leasing is shown in **Figure 4-24**. The average bid was $32.43/acre, which is nearly the same as the overall Wyoming average. Total bonus bids received were $40 million. This is 20 percent of all the lease bonus revenue received for Wyoming during 1996-2001. The largest per-acre bid was $875 per acre for a 640-acre tract in T17N, Figure **4-22** Location of Federal Oil and Gas Leases

Figure **4-23** Summary of Federal Oil and Gas Lease Sale Results, by Year, for the 1996-2001 Period, Rawlins RMPPA

Figure **4-24** Summary of the Total Amount of Bonus Money Received from Federal Oil and Gas Leasing and the Average Bid by Year, for the 1996-2001 Period, Rawlins RMPPA

R94W. The largest bonus bid was $841,940 for a 1,958-acre tract in T21N, R93W. Half of the bonus dollars came from just 8 percent of the leased acreage.

Half of the bonus money bid for public domain minerals went to the state of Wyoming. Forty percent of the bonus went to the Reclamation Fund administered by the Bureau of Reclamation and the remaining 10 percent went to the General Fund of the Treasury. It is anticipated that the amount of federal oil and gas acreage under lease in the RMPPA between 2001 and 2020 will range between 1.0 and 2.5 million acres. Annual federal acreage leased is projected to average between 100,000 and 300,000 acres. As new producing wells are drilled, the amount of acreage held by production will increase substantially from the current 0.4 million acres. Bids should average between $10 and $50 per acre. Gas prices and exploration success will determine the amount of lands leased and bonus bids received. The size of federal leases will continue to be large, probably in excess of 900 acres. Leasing in the RMPPA should generate a minimum of $20 million during the 2001 to 2020 period. If leasing remains at the bonus rates of the past six years, approximately $132 million could be received in bonus payments during the 20-year planning cycle.

4.1.4.3 Seismic Surveys

Seismic surveys are a critical part of oil and gas exploration. They are authorized on BLM managed surface by approval of Notices of Intent (NOIs) to Conduct Geophysical Operations. The numbers of yearly approved NOIs for the RMPPA are shown in **Figure 4-25** for 1992 to 2001. Approximately 60 percent of the surveys used dynamite and 40 percent used vibroseis methods to obtain data (see Appendix A). About 40 percent of the seismic surveys were three-dimensional (3-D) surveys.

The number of surveys on BLM administered surface in the RMPPA is expected to remain at about the 1997-2001 level (about eight per year) in the short term. As additional seismic data are acquired, the need for new data will decrease assuming that neither new technological breakthroughs nor new exploration plays will occur that require resurveying old areas. The number of surveys should decrease and be closer to the 1992-1996 (about two per year) level during the second half of the planning cycle. Although two-dimensional surveys will probably be run in the future, it is expected that most of the NOIs will be for 3-D surveys. Most will be located in eastern Sweetwater County or the far southwest part of Carbon County.

4.1.4.4 Projections of Future Drilling Activity

<u>Non-CBM Hydrocarbons</u>

It is difficult to predict what will occur a few years into the future. It is even more difficult to predict 20 years ahead. In an attempt to get more insight as to what may occur in the Rawlins RMPPA, Figure **4-25** Approved Seismic Notices of Intent to Conduct Geophysical operations (NOIs), by Year, on BLM Managed Surface in the Rawlins RMPPA geologists and engineers in the oil and gas industry were contacted. Twenty-one oil and gas companies, which operate in the RMPPA, were contacted by letter and asked their opinion of what exploration and development activity will occur and where it is likely to occur. Each company was contacted by telephone about 5 days after the letters were sent. Eight companies provided information useful in constructing development potential maps. Some companies requested that the details of the information they provided be held confidential. Due to time constraints, only a very limited review of technical data was conducted from wells in the RMPPA. Structure contour maps drawn by the Rocky Mountain Map Company (2001) were used as working base maps on which to construct development potential maps.

The BLM anticipates that as many as 4,475 new non-CBM wells may be drilled in the Rawlins RMPPA in the 2001-2020 period. In 2001, industry drilled 252 new wells in the RMPPA. For the rest of the 20-year period, new wells will be drilled at an average rate of 222 per year. This estimate does not include re-completing wells to new formations or zones, plugging back wells to test shallower formations or zones, or re-entering wells to drill deeper.

Figure 4-26 shows the results of mapping areas of development potential for the 2001 through 2020 period. Development potential was projected for the RMPPA including national forest lands. Development potential is mapped as high, moderate, low, and no potential. High development potential areas are those where the average drilling density is projected to be more than 100 wells per township (36 square miles). Moderate development potential areas are those where the drilling density is projected to be between 20 and 100 wells per township. Low development potential areas are those where the drilling density is projected to be fewer than 20 wells per township. No development potential areas are those where no drilling activity is anticipated during 2001-2020. **Figure 4-26** was prepared assuming that there will be no restrictions that will preclude or greatly hinder oil and gas leasing, exploration, and development during 2001-2020.

Mapped boundaries in **Figure 4-26** vary in type, depending on available data and industry information used to define those boundaries. In areas where information available was most limited, boundaries were drawn at the township scale. The no development potential area was defined as those lands not included in hydrocarbon plays defined by the USGS (Beeman and others, 1996: Charpentier and others, 1996: Gautier and others, 1996).

Statistical data on the four development potential areas are summarized in **Table 4-10**. High and moderate development potential areas cover only about one-eighth of the area, while low and no development potential areas cover the remaining seven-eighths.

High development potential is anticipated in the area surrounding the Siberia Ridge-Wamsutter-Echo Springs-Standard Draw complex of fields (**Figure 4-26**). Generally, the nature of drilling activity in this area will be additional infill locations in and around the existing fields. Locally, well density may be up to 16 per square mile or 40-acre spacing.

Figure **4-26** Non-coalbed Methane Development Potential Areas

Table 4-10
Oil and Gas Development Potential Classifications
Determined for the Rawlins RMPPA

Development Potential	Acres (thousands)	Number of Townships	Percent of Field Office
High	340	14.8	3.03
Moderate	1,026	44.5	9.16
Low	7,213	313.1	64.34
No	2,631	114.2	23.47
Total	**11,210**	**486.6**	**100.00**

Drilling activity in the larger area of moderate development potential will vary from relatively dispersed, about four wells per square mile, to more intense drilling activity in local areas. The oil and gas industry will search diligently for production in trapping situations similar to those found in the area of high potential. If similar trapping situations are encountered, well densities could be as high as 16 per square mile. There also will be areas with little or no drilling activity. In areas that are already developed, some of the new wells will be for replacement and infill.

Low well densities are anticipated in the area of low development potential. Wells may be scattered (mainly exploration wells) or locally closely spaced, but the total number of wells will average less than 20 per township. In areas that are already developed, some of the new wells will be for replacement and infill.

No drilling activity during the 2001-2020 period is expected in the area of no development potential. As described above, the USGS has not identified any potential hydrocarbon plays in this area. This area appears to be underlain by non-hydrocarbon-bearing Precambrian rocks. There will probably never be interest in testing this area, based on current concepts of hydrocarbon generation and accumulation. Also based on past history, it is unlikely that any oil or gas drilling will be allowed in the National Forests.

BLM anticipates that average well depths will continue to increase with many new wells drilled in the 12,000- to 14,000-foot range. Deep wells, greater than 15,000 feet deep, will probably be much less common. It is anticipated that only about 30 deep wells will be drilled in the 2001 to 2020 period. They will be scattered throughout those parts of the RMPPA where there is deep reservoir potential (**Figure 3-6**).

It is anticipated that the number of producing non-CBM gas wells will continue to increase at historical trends and also, that as the total number of producing wells increases, gas production in the RMPPA also will continue to increase. Development drilling will continue in the Siberia Ridge-Wamsutter-Echo Springs-Standard Draw complex of fields. Additional reservoirs will almost certainly be discovered in the 2001-2020 period. Gas production increases are expected to continue as short-term prices increase above the 2001 level. Gas production is expected to be between 150 and 350 billion cubic feet per year by 2020. Production increases through 2020 also are expected; however, long-term prices will probably keep these increases to approximately historical levels or less. In other words, it is unlikely that the production increase from 2001-2020 will be larger than production increases during the period from 1981 to 2001. Furthermore, it is highly probable that production will peak before 2020 and begin a long-term downward trend reflecting depletion of the gas reserves in the RMPPA.

BLM expects that oil production will continue to decline. The rate of decline should slow, as condensate production from gas wells becomes an increasingly larger proportion of the oil produced from the RMPPA. The Lost Soldier-Wertz field is presently the major oil producer in the RMPPA. Its production will decline in the future and produce proportionally less of the total oil. Although the overall trend is expected to be downward during 2001-2020, there will probably be some year-to-year increases in oil production.

CBM Drilling

CBM or coal reservoir production is another category of oil and gas exploration and production. This category utilized the same leasing requirements, APD authorization, pipeline outlets, water disposal authorization, and all other aspects of oil and gas exploration and production. CBM drilling activity in the RMPPA is at an early stage. There has been considerable interest in CBM drilling in the RMPPA. The status of wells as of February 2002 is shown in **Figure 4-27**. In 2001, 122 permits were approved, although only 11 had so far been drilled by the end of the year. Historically, 74 percent of the CBM wells permitted have been drilled.

Locations of CBM exploratory units are shown in **Figure 3-11**. These units indicate present areas of high interest for activity. Initial industry drilling proposals have been highest for the Hanna Basin area and for the Atlantic Rim area, which lies along the eastern boundary of the Washakie Basin. **Figure 4-28** shows the areas of anticipated development potential for the period 2001 through 2020. Statistical data on the five development potential areas is summarized in **Table 4-11**. High and moderate development potential areas only cover about 6 percent of the RMPPA. Much of the RMPPA is expected to have little or no coalbed gas development. Low and very low development potential areas cover 41 percent of the RMPPA and no potential areas cover about 53 percent.

Mapped boundaries in **Figure 4-28** vary in type, depending on available data and industry information used to define those boundaries. Section boundaries were used to define the high and moderate development potential areas. Here information allowed potential to be defined by an approximate depth contour, so boundaries were drawn at the section (640 acres) scale. The outer boundary of the low and very low development potential areas are from Jones (1991). This boundary defines the limit of the Green River, Hanna, Rock Creek, and Goshen Hole Coalfields within the RMPPA (**Figure 3-13**).

Figure **4-27** Rawlins RMPPA, Coalbed Gas Wells and Their Status

Figure **4-28** Coalbed Methane Development Potential Areas

Table 4-11
Coalbed Gas Development Potential Classifications Determined for the Rawlins RMPPA

Development Potential	Acres (thousands)	Number of Townships	Percent of Field Office
High	408	17.7	3.64
Moderate	291	12.6	2.59
Low	2,801	121.6	24.98
Very Low	1,804	78.3	16.09
No	5,907	256.4	52.70
Total	**11,211**	**486.6**	**100.00**

Note: Up to 4,425 coalbed gas wells could be drilled during the 2001-2020 period.

The Green River and Hanna Coalfields are known to contain potential CBM targets (DeBruin and others, 2001). Those areas of the Green River and Hanna Coalfields not already defined as high or moderate potential, are designated as low development potential. The Rock Creek and Goshen Hole Coalfields have an unknown potential for CBM (DeBruin and others, 2001). They are designated as very low development potential. The area of no development potential, is defined as those lands not included within the Green River, Hanna, Rock Creek, or Goshen Hole Coalfields, as defined by Jones (1991).

It is very early in the life of the CBM play in the Rawlins RMPPA. Very little information is presently available about its viability as an economic play. Although there is very little development history, the BLM anticipates that as many as 4,850 wells may be drilled between 2001 and 2020. Eleven wells were drilled in 2001 (**Figure 4-27**) and approximately 90 wells were drilled in 2002. For the rest of the 20-year period, new wells are expected to be drilled at an average rate of 264 per year. The actual drilling rate in any year could vary widely from this average. Elements that may affect the yearly drilling rate could be the results of the most recent exploratory and development activity; availability of drilling rigs, equipment, and crews; an infrastructure (pipelines) in place to receive new production; permitting delays; or economic conditions.

Drilling density will vary across the RMPPA. High development potential areas could have an average drilling density greater than 100 wells per township during 2001-2020. Drilling density could be 20 to 100 wells per township in the moderated development potential areas. Low development potential areas could have drilling densities up to 20 wells per township and very low development potential areas could have densities up to 2 wells per township. In reality, initial CBM exploration wells may be drilled in pods of 4 to 10 wells or more. When these pods are determined to be commercial, additional surrounding locations also will be drilled. This means that in some townships, actual future well densities may exceed the average density projected above. A lack of exploratory or development interest in other townships may mean that the number of wells actually drilled will be much less than the projected density.

Wells will probably be drilled on 80- or 160-acre patterns. Depths of CBM wells in the Greater Green River Basin area (western part of the RMPPA) will initially be relatively shallow. As shallower prospects get drilled, activity will progress toward deeper parts of the basin. In the Hanna Basin area, CBM targets are presently being tested in the deeper 5,000- to 6,000-foot range. WOGCC records (2002a) indicate CBM wells as deep as about 6,000 feet have been drilled in the RMPPA.

Results from CBM pilot projects in Wyoming suggest that often too few wells have been drilled to adequately evaluate the economic viability of those projects. Past history indicates that pilots should contain from 16 wells (4 interior wells and 12 surrounding wells) to 25 (9 interior wells and 16 surrounding wells) to adequately evaluate an area (Cook, 2002 and Likwartz, 2002). These results suggest that fewer wells may not adequately reduce hydrostatic pressure over a sufficient area. Also, coal heterogeneity may preclude the 1 interior well in a 5- or 9-well pilot from providing the data necessary to adequately evaluate economic viability. For those reasons, CBM pilot projects should contain 16 to 25 wells. This should provide a better chance of obtaining adequate project feasibility data and thus avoid duplicate projects. This would also suggest that past CBM projects in the Rawlins RMPPA might not have adequately tested the economics of the project.

In 2000, CBM was about 7 percent of the total natural gas produced in the U.S. CBM is about 15 percent of total natural gas production in Wyoming. The Wyoming percentage of CBM production has increased substantially during the past 4 years (**Figure 4-29**). It has been estimated that future increases in natural gas production in Wyoming will be mostly from CBM (Cook, 2002). CBM development in new producing areas, such as the Hanna and Carbon Basins and the eastern Washakie Basin, will account for some of the projected future increase in natural gas production.

The PGC (PGC, 2001) has published estimates of CBM resources in the Hanna-Carbon and Green River (including the Wyoming Overthrust Belt) coal regions. Since about 19 percent of the surface area in the CBM plays identified by Gautier and others (1996) lies within the RMPPA, the BLM estimated that about 19 percent of the PGC (2001) gas resource estimate also lies in the RMPPA. Almost all of the estimates of CBM resources in these areas are classified as speculative. The “Most Likely Resource” estimate of CBM resources totals 4,851 billion cubic feet for the Rawlins RMPPA (**Table 4-12**). This is about 14 percent of the total estimate of undiscovered CBM resource in Wyoming, and 3.1 percent of the total estimated undiscovered CBM in the U.S. including Alaska.

The published gas resource estimate for the greater Green River Basin portion of the RMPPA may be too low based on the BLM’s projection of future drilling activity. The USGS is scheduled to have an updated estimate available in October 2002, and the PGC will issue another estimate in the spring of 2003. These estimates may provide information necessary to modify the CBM resources estimate for the RMPPA.

Figure **4-29** Coalbed Gas Production as a Percent of Total Natural Gas Produced in Wyoming

Table 4-12
Estimates of Coalbed Gas Resources in the Rawlins RMPPA

Basin	Minimum Resource (BCFG)	Maximum Resource (BCFG)	Most Likely Resource (BCFG)
Hanna-Carbon	600	9,700	4,371
Greater Green River	12	3,450	480
Total	**612**	**13,150**	**4,851**

BCFG = billion cubic feet of gas

Note: Estimates for Greater Green River Basin are a ratio based on surface area within Rawlins RMPPA. Data are compiled and modified from PGC (2001).

Initial pilot programs indicate that CBM resources are present and will be developed at least in local areas. It is still too early to predict whether or not CBM will develop into a large play in the Rawlins RMPPA. If pilot projects prove that a viable CBM resource over a large area exists and gas prices are favorable, drilling and production could increase at a rapid rate. By 2020, CBM production could increase to half or more of the total gas produced from the RMPPA, and CBM wells could equal the number of non-CBM wells drilled. If long-term gas prices prove to be less than anticipated by the industry, development would be more limited.

Projected Surface Disturbance

General assumptions used to anticipate drilling related surface disturbance is presented in **Table 4-13**. Disturbance guidelines are presented for CBM shallow and deep wells and for intermediate and deep non-CBM wells. Road standards would be in conformance with guidelines issued in BLM Manual 9113 (1985).

Table 4-14 summarizes present well numbers and associated acres of surface disturbance (through 2001) directly associated with those wells. Acres of estimated future surface disturbance are calculated from the assumptions portrayed in **Table 4-13**. In addition, it projects well numbers and associated surface disturbance for the short term (through 2010) and for the long term (through 2020). The projections of well numbers assume that the yet to be drilled wells (4,850 non-CBM wells and 4,425 CBM wells) will be evenly distributed across the 2002 to 2020 period. The future surface disturbance estimate is based on one well per location.

4.1.5 Coal

Records indicate that during the year 2000, there were a total of 21 producing coal mines in Wyoming. There were additional mines that were idle, closed, or reclaimed that remained carried on state records. Year 2000 coal production by coal field is shown in **Table 4-15**. The production statistics for the year 2000 represent a 0.7 percent increase over 1999s production of

Table **4-13** Anticipated Drilling Related Disturbance, in Acres, for Rawlins RMPPA

Table 4-14
Projections of Short-term (2010) and Long-term (2020) Drilling Activity with Associated Surface Disturbance

	Status Through 2001	Short-term Through 2010	Long-term Through 2020
Drilled Wells	5,515	10,178	14,840
Abandoned Wells	2,955	4,680	6,405
Active Wells	2,560	5,498	8,435
Acres of Disturbance	8,163	15,267	22,260

Note: An abandonment rate of 37 percent is assumed in the calculation. Surface disturbance associated with roads, power lines, and compressor stations is not included in these projections.

336,459,938 tons, even though one mine closed and another was idled in 2000. It should be noted that as of 2000, all currently producing mines are surface mines. For comparative purposes, the following production statistics (Wyoming Coal Information Committee, 2002) provide an indication of the relative distribution of coal production within Wyoming.

Table 4-15
Wyoming Coal Production – 2000

Coalfield	No. Producing Mines	Tons Produced	As Percent of Total[1]
Powder River Basin			
Campbell County	12	299,542,969	88.4
Converse County	2	23,599,855	7.0
Sheridan County	1	38,411	0.01
Green River Coalfield			
Sweetwater County	2	9,959,737	2.9
Hams Fork Coalfield			
Lincoln County	1	3,725,983	1.1
Hanna Coalfield			
Carbon County	3	1,985,193	0.6
Totals	**21**	**338,852,148**	**100.0**

[1]Due to rounding, the percentages may not total exactly 100 percent.

It is important to note that the indicated Carbon County production data reflects Hanna Coalfield production. For the year 2000, three mines were operational: the Shoshone Mine (underground; closed mid-year), the Seminoe II Mine, and the Medicine Bow Mine. Since then, only the Medicine Bow and Seminoe II mines (both operated by Arch of Wyoming, Inc.) have remained operational in the Hanna Field. Based on an estimated remaining 2 million tons of recoverable reserves, it is anticipated that these two mines will cease production in approximately 2 years.

Wyoming is the nation's leading coal-producing state. The Wyoming Coal Information Committee predicted a production increase of 3.9 percent for 2001. Actual 2001 production was tallied at 368.9 million tons, an increase of 8.82 percent (Harris and others, 2002). Increases of approximately 1 percent per year for the years 2002-2005 are predicted. Approximately 97 percent of Wyoming's coal production is consumed in electrical generation in over 25 states, Canada, and overseas.

It would be anticipated that most of the production increases would be absorbed by existing (permitted but unused) capacity available within Powder River Basin mines or in other coal producing regions within the state; however, the Seminoe II and Medicine Bow mines will likely remain operational until reserves are fully depleted.

The Seminoe II Mine exploits the Bed No. 78 seam (average thickness 18 feet), the Hanna No. 2 seam (average thickness 30 feet), and the Hanna No. 5 seam (average thickness 14 feet) of the Tertiary Hanna Formation. Overburden removal (average thickness 200 feet; ranging from 150 to 225 feet) is by combination dragline and shovel/truck; coal removal is by shovel/truck. The mine is estimated to have approximately 2 years remaining life. The Medicine Bow Mine is currently extracting coal from Beds 38, 39, 40, 24, and 25, with approximate overburden thickness again ranging from 150 to 225 feet and averaging about 200 feet. The mine is anticipated to have a 2-year remaining life.

4.1.5.1 Coal Development Potential

There are a total of seven coal areas classified as having development potential (see **Table 4-16**). These include the Red Rim, China Butte, Indian Springs, Indian Springs North, Atlantic Rim, Hanna Basin, and Carbon Basin tracts. Of these, the Carbon Basin tract (discussed below) is viewed as having the most probable development potential within the projected 20-year planning period.

The remainder of the tracts, while possessing tonnage and quality characteristics sufficient to categorize them as having development potential, will likely not be developed within the projected 20-year planning period; however, if one or more of these tracts were to escalate to development status, development would have to be managed on a case-by-case basis.

Proposed Carbon Basin Coal Project

Arch of Wyoming LLP has obtained the Elk Mountain/Saddleback Hills coal lease (WYW139975) tract, and is expected to begin development in the Carbon Basin Coal Project at some time following the closure of the Seminoe II and Medicine Bow mines. The Carbon Basin federal lease tract (5,235 acres) is approximately 11 miles south of the current Seminoe II mine. The federal lease tract contains approximately 39 percent of the total estimated reserve, and would be

Table **4-16** Summary of Coal Development Potential Rawlins RMPPA combined with state and private holdings to develop a feasible mining unit. The leased coal is estimated to represent approximately 119.12 million tons of surface and underground recoverable coal. Arch would establish two mines on the tract, the Elk Mountain Mine for surface mineable coal reserves and the Saddleback Hills mine for underground mineable coal. The projected life of the project would be approximately 20 years (BLM, 1999).

The Carbon Basin Coal Project Area encompasses a total of 18,360 acres, including the 5,235 acres in the federal lease tract. The project area is generally located north of I-80, between Highway 115 and the Medicine Bow River. More specifically, it occupies portions of T20-21N, R79-80W.

Surface mining would begin with a dragline pit in the southwestern portion of the area, advancing in a northeasterly direction. An estimated 31.1 million tons of recoverable coal would be surface mined, with the anticipated production rate for the surface operation being 1.3 to 3.1 million tons per year. Underground mine development would occur shortly after the surface mine pits are developed, with portals being established in the pit highwalls. Main entries would be driven by continuous miner; however, full-scale production would utilize a longwall system. Estimated production rates for the underground mine would range from 1.3 to 7.7 million tons per year.

4.1.5.2 Unlikely Coal Development Potential

Cherokee (Creston)

Three coal seams in the Fort Union Formation have been identified in this area. The Cow Butte seam averages 7,417 Btu/lb and 3.26 percent sulfur. The Lower Cherokee seam averages 8,293 Btu/lb and 1.66 percent sulfur. The Upper Cherokee seam averages 7,714 Btu/lb and 1.82 percent sulfur (Janssen, 2002).

Given the indicated coal quality parameters, it is highly unlikely that there would be development of this tract during the 20-year planning period.

Kindt Basin

Coal reserves in this area are in the Mesaverde Group of the Allen Ridge Formation. Two seams have been identified, the Bolten seam and the I seam which occurs about 20 feet above the Bolten. The Bolten averages 3.9 feet thick with a range of 2.0 to 7.6 feet. It occurs near the middle of the area and also near the east end by the North Platte River. In other areas, the Bolten seam is split. The Upper Bolten split averages 3.1 feet thick with a range of 0 (at the split line) up to 6.5 feet. The Lower Bolten split averages 3.4 feet thick with a range of 0 (at the split line) to 7.4 feet. The I seam occurs only locally in the central part of the area and again in the eastern part near the Platte River. The I seam averages 2.3 feet thick where it occurs with a range of 0.7 to

5.5 feet. Bolten seam quality parameters are 11,500 to 11,600 Btu/lb and 1.05 percent sulfur. Total reserves are not known (Janssen, 2002).

Given the minimal seam thicknesses, it is highly unlikely that there would be development of this tract during the 20-year planning period.

4.1.6 Oil Shale

There has been no known commercial production of shale oil from oil shale occurrences within the RMPPA.

As indicated in Section 3.1.4, oil shale bearing rocks of the Green River Formation are present in the Washakie Basin and the northwest portion of the Red Desert Basin.

Though the RMPPA does contain oil shale resources, there are more extensive and higher grade deposits in other parts of the Green River Basin, particularly in Colorado and Utah. Commercial exploitation of oil shale, if it were to occur, would likely take place where these more extensive and higher grade deposits are present. However, production of kerogen, or shale oil, remains in the developmental stages and is considered sub-economic at this time.

The nature of the oil shale deposits within the RMPPA, in conjunction with the status of oil shale development in general, suggests that there is minimal to no potential for commercial exploitation of these oil shale deposits within the projected 20-year planning period.

4.1.7 Phosphate

There has been no known commercial production of phosphate ores from the phosphate occurrences within the RMPPA. As indicated in Section 3.1.5, the RMPPA phosphate occurrences are at considerable depth, and present only in the western half of the area.

Though the RMPPA does contain limited phosphate resources, there are more extensive and higher grade deposits that are currently being commercially exploited. These include a number of mining and processing operations situated near the Wyoming – Idaho state line, and in the Vernal, Utah area. In addition, significant phosphate production emanates from operations in North Carolina and Florida. Thicker phosphate zones containing higher-grade phosphate at these locations, in combination with their existing processing and transportation infrastructure, will ensure that domestic phosphate production will continue to be largely from these locales.

The nature of the phosphate deposits within the RMPPA, in conjunction with the alternatively available domestic resource and production capacity, suggests that there is minimal to no potential for commercial exploitation of the RMPPA's phosphate deposits within the projected 20-year planning period.

4.1.8 Other Leasable Minerals

4.1.8.1 Sodium

There has been limited, small-scale production of sodium sulfate at various locations within the RMPPA, possibly in conjunction with other brine commodities. However, there is no known current commercial production of sodium sulfate products within the RMPPA, nor has there been an indicated leasing interest with respect to these types of deposits.

Sodium production is Wyoming's most important industrial mineral in terms of value and employment. Trona is produced from five underground mines located west of Green River and refined into soda ash and other sodium products. An estimated resource of 134,400,000,000 tons of mineable trona and mixed trona and halite is present in the Green River Basin. A total of 42 trona beds are known to exist within the Wilkins Peak Member of the Green River Formation, of which 25 are considered mineable (Culbertson, 1986; Harris, 1992).

The nature of the sodium deposits within the RMPPA, in conjunction with the alternatively available domestic resource and production capacity, suggests that there is minimal to no potential for commercial exploitation of the RMPPA's sodium deposits within the projected 20-year planning period.

Although there is an extensive area of potash mineralization known to be present in the eastern portion of the RMPPA (in the vicinity of the Wyoming-Nebraska state line), there has been no indicated leasing or other expression of interest relative to potential commercial development.

Potash demand within the U.S. is largely supplied by production originating in New Mexico. To date, there has been no recorded production of potash ores from Wyoming sources.

The nature of the phosphate deposits within the RMPPA, in conjunction with the alternatively available domestic resource and production capacity, suggests that there is minimal to no potential for commercial exploitation of the RMPPA's phosphate deposits within the projected 20-year planning period.

4.1.8.2 Geothermal

The geothermal resources of the RMPPA are of low to moderate temperatures (less than 150°C) resources (James, 1979) and with this characteristic, have limited economic application. The primary applications of low to moderate geothermal resources in other parts of the world are for space heating, horticulture, industrial processes and spas (White, 1973). Geothermal resources are considered to be a renewable resource and could be an alternative resource to oil and gas. Due to the relative isolation from any population centers and little indigenous population within the RMPPA, there does not appear to be any economic future for this resource for the next 20 years.

4.2 Locatable Minerals

Remaining resource potential in the Rawlins RMPPA (but outside of the National Forest) for locatable minerals is found in five main areas: 1) Shirley Basin, 2) the Poison Buttes uranium deposit by Baggs, 3) the Seminoe Mountains, 4) the Iron Mountain Magnetite district, and 5) the Silver Crown Mining District (exclusive of USFS lands). These locations are shown on **Figure 3-13**.

The Shirley Basin uranium deposits were never mined out. Mining ceased in the early 1980s due to a sharp drop in price for uranium. Uncertainty as to the safety of nuclear power plants and the return to “more normal” oil prices undercut the price of uranium and the price plummeted, leading to the closure of most uranium mines in the western U.S. Although there are no published estimates as to the remaining resources in Shirley Basin, a rough estimate would be that about half of the original 50 million pounds of probable resources estimated by the Atomic Energy Commission (Harshman, 1972b) still remain. These resources could be mined by in-situ solution mining methods, should the world demand for uranium and resultant price increase over the next 10 years due to political tensions in the Middle East.

The Poison Buttes uranium deposit contains 8 to 15 million pounds of U_3O_8 at mineable grades. Like the Shirley Basin, this deposit is just waiting for higher uranium prices. Newer mining techniques, such as in-situ solution mining, that were developed after the drop in uranium prices in the 1980s will make this district economic once the demand for uranium returns.

Other areas of remaining or potential mineral resources in the Rawlins RMPPA can be found in Precambrian rocks in the uplifts of the Seminoe Mountains and the Laramie Range Iron Mountain Titaniferous Magnetite district. The Seminoe Mountains have Archean stratabound iron and gold deposits similar to those found in Canada. These deposits have not been developed because of low demand for iron and the relatively low price for gold over the past 10 years. Both of these economic factors could change in the next 10 years.

The iron, titanium, and vanadium resources of the Iron Mountain district have been demonstrated through drilling and simply await a rise in economic demand before they are developed and mined once again. Resource estimates range from 30 million tons of massive ore at the Iron Mountain Deposit with grades of 16 to 23 percent TiO_2 to a disseminated resource at the Strong Creek Deposit with 300 million tons at 5 to 30 percent TiO_2.

The Silver Crown Mining District has a proven resource of 35 million tons of copper at a grade of 0.2 percent copper. This deposit is simply waiting for higher copper prices. The deposit can be mined by open-pit methods, making it very attractive once the price of copper goes above about $1.00/lb.

The Laramie anorthosite complex has been evaluated as a source of alumina; however, technological limitations associated with the alumina recovery processes render the occurrence non-economic at this time. Significant advances in recovery technology would be required before the development potential of this occurrence can be considered significant, and this is not anticipated to occur within the projected 20-year planning period.

4.3 Salable Minerals

The salable mineral category includes, but is not limited to, common varieties of sand, stone, gravel, pumice, pumicite, cinders, clay, and petrified wood. Of these, there are known exploitable occurrences of sand and gravel (or aggregate materials), limestone, sandstone, decorative stone, silica sand, and other similar mineral commodities within the RMPPA (refer to Section 3.3). To a lesser degree, there may be a limited potential for exploitation of common clay. Petrified wood resources, where present, would likely be of interest for hobby or specimen collecting.

Extraction and sale of aggregate materials are governed by the Mineral Materials Disposal regulations codified within 43 CFR 3600 through 3622. These regulations allow for mineral materials disposal through either mineral material sales or non-exclusive disposal.

Mineral material sales can be made on the initiative of the authorized BLM officer or be made subsequent to receipt of a request to purchase by an applicant. Sales can be made under a competitive bid basis or under a non-competitive bid basis, subject to certain volume or weight equivalent limitations.

Non-exclusive disposal of mineral materials can be occur through sale or “free-use,” and can be made from the same deposit within areas designated by the BLM authorized officer. These areas are designated as “community pit” sites (defined sites) or “common-use” areas (generally a broad geographic area), neither of which is necessarily limited in size.

The differentiating factor between a “community pit” site and a “common-use” area is that designation of a community pit constitutes a superior right to remove the material as against any subsequent claim or entry of the lands, whereas designation as a common-use area does not constitute a superior right (however, a person authorized by permit or sale has a superior right against any subsequent claim or entry).

Mineral materials may be disposed through “fair market value” sales from either community pit sites or common-use areas. In addition, “free-use permits” can be issued to any federal or state agency, unit or subdivision, including municipalities and, under certain conditions and limitations to non-profit organizations.

4.3.1 Aggregates (Sand and Gravel)

Natural construction aggregate is one of the most abundant natural resources and one of the most widely used. Aggregates consist of crushed and sized rock (either quarried stone of crushed gravel) or natural sand and gravel, which are not crushed, but sized. Sand and gravel is less expensive than crushed stone aggregate, but crushed stone has the advantage of consistency in size and angularity.

Construction aggregates are the lowest priced of all mined products. Since they are so low priced, transportation costs from the pit to the point of use can become the major part of their cost to the consumer. For example, crushed rock that may cost $2.00 per ton to produce can be subject to transportation costs on the order of $1.00 per ton-mile or greater. As such, at transportation distances of even 2 miles the cost of transportation can easily exceed the cost of production. Therefore, it is imperative that aggregate sources be located as close as possible to the point of use.

It is anticipated that demand for aggregate production within the RMPPA will increase in proportion to expanding gas (and CBM) exploration, development, and production activity. These industries require significant quantities of aggregate products primarily for purposes of constructing and stabilizing drill pad installations and access/service roadways. While the oil and gas industry will be the primary consumer of aggregate products over the projected 20-year planning period, additional consumption also will occur relative to increased town/city public works and county and state highway departments’ requirements. These governmental and quasi-governmental entities require aggregate materials for public works projects, new road construction, and existing road maintenance and resurfacing.

It should be noted that the existing permitted pits (i.e., community pits, free-use pits, common-use pits, and negotiated sale pits) indicated in the following sections are representative of the major producing or known past production areas. However, it should be further stated that there is potential for other deposits to occur throughout the RMPPA where geologic conditions are proven to be favorable, as previously described in Section 3.1.1. Limited information precludes specific identification of these other occurrences at this time.

It is probable that the greatest proportion of oil and gas industry demand for aggregate will be fulfilled through the utilization of existing and development of new “community pits.” A total of five active or pending community pits (representing an original authorized total surface area of approximately 3,000 acres) exist within the RMPPA (**Table 4-17**):

Table 4-17
Designated Community Pits
(Sand and Gravel)

Pit Name	Serial Number	Location	Authorized Acreage
Coal Bank Draw	WYW130911	T12N, R89W	800
Savery Creek	WYW130911	T12N, R89W	Included in above
Big Gulch	WYW130912	T13N, R89W	1,680
Baggs SE	WYW130913	T12N, R90W	520
Dixon Airport S	WYW130913	T12N, R91W	Included in above
Total			**3,000**

No information concerning remaining acreage was available. In general, it can be stated that quality aggregate resources within the central and western portions of the RMPPA are scarce. In these areas, consumption usually targets available resources of scoria (baked and fused shale), crushed sandstone, and/or crushed limestone. All of these materials are inferior to higher quality aggregate resources, and as a result are subject to advanced deterioration and weathering (resulting from heavy equipment traffic), comparatively high rates of dust generation, and increased frequency of maintenance and/or replacement. As such, identification and permitting of quality aggregate sources within these portions of the RMPPA should be considered a high priority.

The estimated gravel resource requirement for the projected 20-year planning period is on the order of 8.5 million cubic yards (yd^3) of material, as follows:

Oil and Gas Industry (Direct) Demand:	1,700,000 yd^3
State/County/Municipal Demand:	6,250,000 yd^3
Other:	500,000 yd^3
Total:	8,450,000 yd^3

Existing community pits, based on authorized acreages, should contain sufficient reserves to satisfy the demand projection. However, utilization of the community pits will be dependent on transportation cost (distance) to point of use. This, in combination with area-specific shortages of quality aggregate will likely result in the establishment of additional pits.

In addition to the above-mentioned community pits, there also are a number of authorized common use pits, free use pits, and negotiated sale pits, as indicated below in **Tables 4-18**, **4-19**, and **4-20**. No information was available concerning remaining acres of reserves in the pits.

Table 4-18
Designated Common Use Pits (Sand and/or Gravel)

Pit Name	Serial Number	Location	Authorized Acreage
Powder Wash	WYW093699G	T12N, R96-97W	8,220
Gay Johnson	WYW135292	T21N, R88W	200
Eight Mile Lake	WYW136493	T20N, R88W	1,280
Five Mile Ridge	WYW136493	T20N, R88W	Included in above
Shirley Mountains	WYW136494	T25N, R81W	1,920
RFO Multiple Areas	WYW152999	T15-26N, R71-89W	5,120
Seminoe Dune	WYW135293	T25N, R84W	20
Seminoe Dune	WYW154284	T25N, R84W	20 Grosch
Seminoe Dune	WYW155257	T25N, R84W	2 Dudley
Seminoe Dune	WYW155258	T25N, R84W	2 Carbon County
Total			**16,784**

Table 4-19
Designated Free-Use Pits (Sand and/or Gravel)

Pit Name	Serial Number	Location	Authorized Acreage
Carbon Cty – Merrill	WYW137411	T12N, R81W	10
Carbon Cty – McCarry	WYW141967	T15N, R89W	0.873
Carbon Cty – Browns Hill	WYW143282	T14N, R90W	120
Carbon Cty – Buck Draw	WYW146551	T17N, R85W	40
Carbon Cty – Saratoga	WYW144385	T17N, R84W	5
Carbon Cty – Buzzard	WYW145367	T27N, R86W	120
Carbon Cty – CCRoad	WYW148169	T18N, R88W	1
Carbon Cty – Miller Hill	WYW148169	T18N, R88W	Included in a
Carbon Cty – CCRd305	WYW148710	T28N, R85W	1
Carbon Cty – Collins	WYW148710	T28N, R85W	Included in a
Carbon Cty- Red Hills Q	WYW151840	T25N, R84W	25
Sweetwater Cty – Sun Q	WYW151845	T23N, R88W	15
Wyoming Water Dev. Co.	WYW152331	T16N, R88W	5 High Savery Dam
Red Hills	WYW145972	T25N, R84W	160
Total			**502.9**

Table 4-20
Authorized Negotiated Sale Pits (Various Commodities)

Pit Name	Serial Number	Location	Authorized Acreage
ICM Quarry	WYW146559	T16N, R72W	5 Wyoming Stone Industrialists
Delaney Rim	WYW149123	T19N, R95W	1 J. Reynolds
Turritella Agate	WYW149123	T19N, R95W	Included in above
Sun Quarry	WYW151514	T23N, R88W	15 Rissler & McMurray
Creston Jct.	WYW153012	T20N, R91W	5 K&H Construction
Creston Jct.	WYW155306	T20N, R91W	80 H.B. Lee – Pending
Total			**106**

Estimates for the demand potential for aggregate consumption over the projected 20-year planning period have been formulated on the following bases:

4.3.1.1 Oil and Gas Industry Requirements

The most significant increase in aggregate demand will originate from gas (natural and CBM) development activity occurring in the west-central portions of the RMPPA. Due to the transportation cost sensitivity of aggregates, aggregate sources proximal to these developmental areas will bear the burden of aggregate production before more distant sources are utilized.

The total aggregate demand associated with oil and gas industry requirements consists of gravel utilized to stabilize long-term wellpad locations and roadway infrastructure. That demand is estimated to be approximately 1,700,000 yd^3 (as rounded upward from an estimated 1,680,796 yd^3, as calculated below).

4.3.1.2 Oil and Gas Industry

<u>Aggregate Demand Projections</u>

In order to assemble an aggregate demand projection (for oil and gas industry requirements), a number of assumptions have been made, based upon data pertaining to oil and gas and CBM development projections (see Section 4.1.4.4).

A total of 4,475 non-CBM wells and a total of 4,850 CBM wells are projected over the planning period. Assuming a nominal 63 percent completion rate (inferring a 37 percent abandonment rate) as indicated by historic data, it would be anticipated that approximately 2,819 non-CBM and 3,055 CBM wells, respectively, would be "permanent" installations.

1. Wellpads (Non-CBM) - Based on the indicated average wellpad dimension of 1.5 acres, and assuming a nominal 4-inch lift of surface-stabilizing gravel utilized across a nominal 5 percent of the wellpad surface, each wellpad will require (on average) an estimated 40 yd^3 of gravel material for initial surface stabilization, calculated as follows:

   $$\frac{1.5\text{ acres/wellpad} \times 43{,}560\text{ feet}^2\text{/acre} \times 0.33\text{ feet}}{27\text{ feet}^3\text{/yd}^3} \times 0.05 = 40\text{ yd}^3\text{/wellpad}$$

   Allowing for pad maintenance on a regular basis, a nominal 10 yd^3 per wellpad is assumed to be required every other year. Therefore, the total amount of gravel required (over the 20-year planning period) for wellpad surface stabilization at 3,356 wellpads would be the total of initial surfacing placement plus biennial maintenance, resulting in an estimated total requirement of 469,840 yd^3, calculated as follows:

2,819 wellpads x [40 yd^3/wellpad + 10 (10 yd^3)] = 394,660 yd^3

Wellpads (CBM) – Same assumptions as above, but applying a 25 percent factor (0.25) against total to account for smaller CBM locations.

3,055 wellpads x [40 yd^3/wellpad + 10(10 yd^3] x 0.25 = 305,500 yd^3

Total wellpad requirements are therefore: 394,660 yd^3
+305,500 yd^3
700,160 yd^3

2. *Access roads:* Access roads will (to varying degrees, dependent on classification) require gravel surfacing, primarily in areas of weak soils not conducive to supporting loads or volumes associated with anticipated traffic. BLM road standards (Manual 9113) provide for three types of access roads, as follows:

   Collector Roads: These roads normally provide access to large blocks of land and connect with or are extensions of a public road system. Collector roads usually require application of the highest standards used by the BLM. Design speed is 30 to 50 mph, and subgrade width is a minimum of 28 feet (24-foot full surfaced travelway).

   Local Roads: These minimum volume roads usually provide the internal access network within an oil and gas field. Design speed is 20 to 50 mph and subgrade width is a minimum of 24 feet (20-foot full surfaced travelway).

   Resource Roads: These are normally spur roads that provide point access. Roads servicing individual wellpads typically fall within this classification. Design speed is 15 to 30 mph and subgrade width is a minimum of 16 feet (12-foot full surfaced travelway).

   Projections for access road development indicate an average access road (classified as "resource roads") requirement of 0.4 mile per well. Thus, given the projected incremental total of 2,819 active non-CBM wellpads and 3,055 CBM wells over the 20-year planning period, a total of 2,349 miles of new resource roads are projected [(2,819 x 0.4) + (3,055 x 0.4) = 2,349 miles]. Projected aggregate (gravel) requirements are estimated in the following manner:

   Resource Roads

   Basis: Assume a nominal 10 percent of the projected total resource road miles (2,349 miles x 0.10 = 235 miles) will initially require gravel stabilization (4-inch lift) across the entire 16-foot subgrade width. It also is assumed that infrequent spot maintenance of these roadways will require a nominal 2,000 yd^3 on an annual basis over the 20-year planning period.

$$\frac{(235 \text{ miles} \times 5{,}280 \text{ feet/mile} \times 16 \text{ feet} \times 0.33 \text{ feet}}{27 \text{ ft}^3/\text{yd}^3} + 20\ (2{,}000 \text{ yd}^3) = 282{,}645 \text{ yd}^3$$

Local Roads

Basis: Assume total mileage to be a nominal 25 percent of the projected total resource road miles (2,349 miles x 0.25 = 587 miles) and that a nominal 30 percent of the resulting miles (587 miles x 0.30 = 176 miles) will require gravel stabilization (4-inch lift) across the entire 24-foot subgrade width. It also is assumed that infrequent spot maintenance of these roadways will require a nominal 4,000 yd^3 on an annual basis over the 20-year planning period.

$$\frac{176 \text{ miles} \times 5{,}280 \text{ feet./mile} \times 24 \text{ feet} \times 0.33 \text{ feet}}{27 \text{ feet}^3/\text{yd}^3} + 20\ (4{,}000 \text{ yd}^3) = 352{,}589 \text{ yd}^3$$

Collector Roads

Basis: Assume total mileage to be a nominal 10 percent of projected total resource road miles (2,349 miles x 0.10 = 235 miles) and that 100 percent of the resulting mileage will require gravel surfacing and/or stabilization (6-inch lift) across the entire 28-foot subgrade width. It also is assumed that infrequent spot maintenance of these roadways will require a nominal 7,500 yd^3 on an annual basis over the 20-year planning period.

$$\frac{235 \text{ miles} \times 5{,}280 \text{ feet/mile} \times 28 \text{ feet} \times 0.50 \text{ feet}}{27 \text{ feet}^3/\text{yd}^3} + 20\ (7{,}500 \text{ yd}^3) = 793{,}378 \text{ yd}^3$$

Therefore, the total oil and gas and CBM industry development demand for aggregate is estimated to be the total of all of the above, calculated as follows:

Wellpads	700,160 yd^3
Resource Roads	282,645 yd^3
Local Roads	352,589 yd^3
Collector Roads	793,378 yd^3
Total	2,128,772 yd^3

4.3.1.3 State/County/Municipality Requirements

State/County/Municipality demand projections are based upon an independent estimate for the Wyoming Department of Transportation (WYDOT) and Carbon County (as the primary county to be impacted by projected development activity). [Note: Analysis of data pertaining to BLM mineral material disposal records for the 5-year period 1997-2001 indicates fluctuating mineral disposal volumes under the relevant category “Free-Use Permit – Government Subdivisions” that are likely not indicative of current and future demand scenarios.]

Most aggregate utilized by state/county/municipal entities is consumed in roadway construction, road maintenance, and other related paving or construction applications. As oil and gas development intensifies (as projected), it would be reasonable to anticipate that the need for public road construction, road maintenance, and other infrastructure improvements would increase proportionately.

Typically, major infrastructure improvements are incurred in the early to middle stages of a natural resources “boom” period. As such, the gravel demand estimate for state/county/municipal consumption is based on (an estimated) 2001 consumption (as the base year), with a projected escalation in demand over the first 5 years of the planning period (**Table 4-21**). A leveling of demand is projected for 10 years and then a slight drop-off for the remainder of the planning period.

It has been assumed that approximately 75 percent of Carbon County’s aggregate demand will be met through BLM-sourced material, with the remainder being from private sources. It also has been assumed that WYDOT obtains minimal volume of aggregate through BLM-sourced materials, with the majority of aggregate demand being fulfilled through private sources.

4.3.1.4 Other Demand

There are other aggregate demand requirements that include, but are not necessarily limited to private entity demand (disposal through negotiated or non-negotiated sales) and free-use permit disposal (e.g., non-profit entity demand).

Recent historic sales have been made relative to the Seminoe Sand Dune resource, which has become a highly sought after sand for utilization in golf course construction and maintenance (i.e., sand traps). This demand has been mostly regional; however, it is indicated that the demand region will grow beyond the immediate area (Wyoming, Colorado) to other states.

This demand has been estimated at a nominal 25,000 yd^3 per year over the 20-year planning period, resulting in a total estimated demand on the order of 500,000 yd^3.

Table 4-21
Estimated Gravel Requirements for State/County/Municipal Roads

Year	Volume (yd^3)
2001 (base)	150,000 (estimated – not actual)
2002	200,000
2003	250,000
2004	300,000
2005	350,000
2006	350,000
2007	350,000
2008	350,000
2009	350,000
2010	350,000
2011	350,000
2012	350,000
2013	350,000
2014	350,000
2015	350,000
2016	300,000
2017	300,000
2018	300,000
2019	300,000
2020	300,000
Total	**6,250,000 yd^3**

4.3.2 Silica Sand

Production of silica sand in the U.S. for the year 2000 declined 1.7 percent from 1999, and the trend generally continued through 2001 due to the economy. Declining markets included foundry, fiberglass, hydraulic fracturing, ground filters, and ceramics.

Roughly 40 percent of the silica sand production in the U.S. is based in the midwest (Illinois and Michigan). The unit price of silica sand is relatively low compared with its transportation cost to the consumer. Consequently, most sand does not ship more than 200 miles from its point of origin.

Market drivers for silica sand include construction and automotive production (foundry applications). Concern related to utilization of silica and possible silica dust exposure in the workplace could negatively impact the demand for silica sand. However, increased usage of glass products has reversed the downward trend in glass container markets.

To the extent that Wyoming silica sand sources are in demand, it is anticipated that the demand function will remain relatively stagnant (major markets are addressed through production from the midwest and other sources).

As mentioned previously, there is a specialized market for sand utilized in golf course construction. This sand, present as deposits associated with the Seminoe Sand Dunes, will be mined on an as-needed basis. Since the sand dunes represent a substantial resource base, there should not be significant depletion of available reserves, and siting of sand quarries (or extraction areas) should not pose a concern.

Accordingly, annualized silica sand production within the RMPPA would be anticipated to remain relatively consistent over the projected 20-year planning period. Existing silica sand operations should sustain production requirements for the foreseeable future; however, when additional silica sand operations are determined to be warranted, siting and permitting will be largely dependent on the distance to market and predominant end-consumer.

4.3.3 Limestone and Dimension Stone

Limestone is quarried in the Laramie area for the manufacture of cement, its primary consumptive end-use. However, limestone also is utilized locally, albeit to a significantly lesser degree, as a decorative and/or dimension stone in various applications.

It is likely that those limestone quarries currently operational will remain so as long as there is a demand for production. Although 2001 was a record year for the U.S. portland cement industry (representing a 2.7 percent increase from 2000), forecasts for 2002 indicate a decline of 3.1 percent in portland cement shipments (MacFadyen, 2002). This demand scenario will largely apply to projected limestone production (as associated with the production of portland cement).

Accordingly, annualized limestone production within the RMPPA would be anticipated to remain relatively flat over the projected 20-year planning period. Existing limestone quarries should sustain production requirements for the foreseeable future; however, when additional limestone quarries are determined to be warranted, siting and permitting will be largely dependent on the distance to market and predominant end-consumer.

4.3.4 Vermiculite

Vermiculite occurs in Wyoming in several areas in biotite schist, hornblende schist, diorite and metadiorite, hornblendite, and serpentinite at or near a contact with granite, granite gneiss, granite pegmatite, or vein quartz.

Worldwide production of vermiculite during 2001 declined by 14 percent. It is projected that North American markets will continue to decline due to concerns of asbestos contamination in vermiculite (from the former Libby, Montana, mine; closed since 1990). Current domestic production comes from three producers, one in Virginia and two in South Carolina (Moeller, 2002).

Domestic production was down 25 percent in 2001, and consumption down 8.2 percent. Domestic demand is increasingly being fulfilled by foreign sources, inclusive of South Africa and China.

Vermiculite has been produced in the past from Wyoming sources from deposits near Encampment, west of Casper, and in the central Laramie Mountains. There are probably sufficient resources of vermiculite in the southern Saratoga Valley (near Encampment) to support renewed production (Harris, 1990). However, the nature of the vermiculite deposits within the RMPPA, in conjunction with the alternatively available foreign and domestic resource and/or production capacity, suggests that there is minimal potential for commercial exploitation of the RMPPA's vermiculite deposits within the projected 20-year planning period.

4.3.5 Pumice and Scoria

Pumice and scoria are utilized in industrial applications (as an abrasive), as a filler in concrete block manufacture, and as aggregate. In most industrial applications, scoria can be utilized as a substitute for pumice, differing primarily in angularity and color.

Although deposits of pumice are present within the RMPPA, production has not been significant. Roughly 98 percent of domestic production comes from 15 mines or producers in California, Idaho, New Mexico, and Oregon. Production on an annual basis declined 1 percent last year, and 2002 production is estimated to further decline.

Based on the limited occurrence of pumice and scoria within the RMPPA and the relative availability of regional sources, no significant expansion in commercial exploitation of pumice and scoria resources is anticipated within the RMPPA for the projected 20-year planning period. However, there may be limited, small-scale production to satisfy localized demand.

4.3.6 Common Clay

There were a number of former commercial common clay operations within the RMPPA; however, all are apparently now inactive. It is possible that localized demand for clay materials may evolve for special use applications (e.g., landfill or lagoon liner material).

The major uses of common clay are building brick, lightweight aggregate, and portland cement clinker. Leading producers of common clay are North Carolina, Texas, Alabama, Georgia, Ohio, Missouri, Virginia, Kentucky, California, and Arkansas. Domestic demand for common clay remains fairly strong, and projections are that sales and use will remain relatively steady over the next couple of years.

Based on the limited occurrences of common clay within the RMPPA and the relative availability of suitable and cost-effective alternatives (e.g., synthetic liners, etc.), no significant commercial exploitation of common clay resources is anticipated within the RMPPA for the projected 20-year planning period. However, there may be limited, small-scale production to satisfy localized demand such as cement manufacture.

4.3.7 Decorative Rock and/or Stone

Decorative rock (as either moss rock or boulders) has been produced within the RMPPA for a number of years, with demand increasing proportional to population increases in the region. The moss rock is generally utilized as either a structural or decorative building material, whereas the boulders are generally utilized for landscaping purposes.

Moss Rock: Significant deposits of moss rock (defined as a moss or lichen covered sandstone) are known to occur in the southwest region of the RMPPA in the vicinity of the Wyoming-Colorado state line (north of Powder Wash, Colorado). Under current conditions, recoverable deposits are generally limited to those that are readily accessible (proximal to existing roadways) and obtainable through manual extraction or retrieval. However, as demand for moss rock increases, there will be an increasing need to establish greater accessibility (new roadways) to more remote deposits, or there will likely be increased unauthorized off-road activity and trespass. It is unlikely that recovery methods will vary significantly, as mechanized removal would damage the rock's desirability by scarring or scraping the moss or lichen veneer. As such, manual (by hand) extraction will likely remain the primary mode of removal.

It would be anticipated that moss rock demand would increase at least in direct proportion to population increases and the number of structural building permits issued. In fact, the demand curve may well exceed the region's growth rate as the rock's desirability is increasingly recognized by the existing populace and determined to be desirable for architectural renovation of existing structures. Further, interest in the rock may extend to areas outside of the region (e.g., Colorado and Utah). In fact, it has been noted that there has been significant trespass/theft of moss rock resources in the RMPPA.

Material disposal records maintained by the RMPPA do not clearly indicate the tonnage of moss rock that was extracted/sold during the 5-year period 1997 through 2001; however, estimates place the total in excess of 100 tons per year for most years. It is anticipated that there will be increased demand for the moss rock, reflective of increasing regional population as well as increased or more widespread usage of the moss rock as a building material (inclusive of demand related to neighboring states). With time (owing to stabilization of any population influx), it would be anticipated that there would be a leveling of demand, followed by a marginal drop in demand.

In all likelihood, the relative rate of increase in demand will level off in approximately 8 to 10 years as the oil and gas/CBM driven population growth slows due to maturation of the fields. For purposes of estimating overall demand, it has been assumed that any over-estimate error introduced by reduction in demand (attributable to the leveling effect) would effectively offset any under-estimate error attributable to non-consideration of increased demand originating from outside the immediate area. [Note: No attempt has been made to estimate this external demand factor due to the fact that resource potential and/or limitations external to the RMPPA have not been evaluated as part of this (planning-area specific) mineral report.]

Estimated moss rock demand is anticipated to be on the order of 250 tons (possibly ranging in some years to in excess of 500 tons) per year over the projected 20-year planning period. That demand projection indicates a total of 5,000 tons over the 20-year planning period.

It is anticipated that this volume (tonnage) of moss rock is available in the State Line area. However, in order to maximize the resource base and optimize resource utilization within the already identified areas, consideration will need to be given to: 1) establishing and maintaining routes of accessibility when and where needed, and 2) establishing commercial-scale operations and providing for private product stockpile/transfer points locations (in order to avoid seasonal limitations on production or retrieval of the moss rock products).

As available moss rock inventories immediately adjacent to existing roadways are depleted, it may be necessary to extend existing or construct new spur roads or access drives into the talus fields to enable continued roadside collection of the rock.

Seasonal avoidance criteria will result in the establishment of seasonal limitations on moss rock collection, and in turn, may result in a recognition that offsite stockpiling might be a viable means of ensuring year-round accessibility to the moss rock resource.

Boulders

Significant deposits of boulders (arbitrarily defined as alluvial debris over 18 inches in diameter) are known to occur in and around fringe areas associated with various mountainous areas where present within the RMPPA. Typical of these areas are the Shirley Mountains, Ferris Mountains, Medicine Bow Mountains, and the Sierra Madre. It is likely that numerous other areas exist within the RMPPA where boulders are recoverable, given enhanced accessibility conditions.

Under current conditions, recoverable deposits are generally limited to those that are readily accessible (proximal to existing roadways) and obtainable through manual extraction or retrieval. However, as demand for boulders increases, there will be an increasing need to establish greater accessibility (new roadways) to the more remote deposits, or there will likely be increased unauthorized off-road activity and/or trespass.

It is likely that boulder extraction/recovery methods will continue unchanged. Most boulders are individually obtained through mechanized removal (e.g., backhoe or front-end loader) or, where size and mass allow, by hand. Stipulations imposed on boulder extraction will ensure that a combination of hand and mechanized removal of individual boulders will continue to be the primary mode of removal.

In order to maximize the resource base as well as optimize resource utilization within existing boulder resource areas, consideration will need to be given to: 1) establishing and maintaining routes of accessibility when and where needed, and 2) establishing commercial-scale operations and providing for private product stockpile/transfer points locations (in order to avoid seasonal limitations on production or retrieval of the decorative boulder products).

Further, additional boulder resource areas must be identified and developmental requirements identified. As the available boulder inventories that are immediately adjacent to existing roadways are depleted, it may be necessary to construct spur roads or access drives into boulder fields, where present, to enable continued roadside collection of the boulders.

Seasonal avoidance criteria will result in the establishment of seasonal limitations on boulder collection, and in turn, may result in a recognition that offsite stockpiling might be a viable means of ensuring year-round accessibility to the decorative boulder resource.

4.3.8 Epsomite

A small epsomite production plant was operated at Rock Creek Lakes (Albany County) in the early years of the 20th century. As indicated in Section 3.3.8, small resources of epsomite remain present at this, and possibly other locations.

However, the nature of the epsomite deposits within the RMPPA, in conjunction with the alternatively available domestic resource and production capacity, suggests that there is minimal to no potential for commercial exploitation of the RMPPA's epsomite deposits within the projected 20-year planning period.

4.3.9 Petrified Wood

The only known concentration of petrified wood within the RMPPA occurs in the Shirley Basin. It is not anticipated that the development potential of this resource would exceed that of limited quantity collecting (free-use). Mineral material disposal regulations allow that persons may collect limited quantities of petrified wood for noncommercial purposes under terms and conditions consistent with the preservation of significant deposits as a public recreational resource (40 CFR 3622.1). In that regard, petrified wood is considered to be not only a salable mineral, but also a paleontological resource, and may accordingly be subject to protective measures afforded thereto under certain circumstances.

Under the free-use collection scenario, no permit is required except for specimens over 250 pounds in weight. Other rules apply, as follows:

- One person is allowed to remove a maximum of 25 pounds plus one piece of petrified wood per day, subject to a limitation of 250 pounds per year.

- No explosives or mechanized equipment may be used for the excavation or removal of petrified wood. Light trucks (up to 1-ton capacity) may be used as a principal means of transporting/hauling.

- Free-use petrified wood may not be bartered or sold to commercial dealers.

- Extraction and removal of specimens must be done in a manner that avoids damage to the surface.

There are no specific reporting requirements associated with free-use collection; however, the BLM has the authority to establish and publish additional rules to supplement those contained within 40 CFR 3622.

As such, there is no basis upon which to estimate demand or development potential, other than stating that collection quantities will likely diminish as readily observable and accessible specimens are depleted.

4.4 Mineral Potential Summary

In summary, the primary mineral occurrence and development potential within the RMPPA is associated with oil, natural gas, coal, aggregates, and decorative stone. There are several types other mineral commodities that have well-documented occurrences, but their development potential is limited by poor market conditions. The RMPPA is a proven hydrocarbon producing area for over 80 years, and estimates of undiscovered resources indicate that the area will provide abundant supplies of hydrocarbons (especially natural gas) through the end of the 20-year planning period and beyond. CBM is still an unproven resource, but the RMPPA currently contains several proposed CBM exploratory projects. It is anticipated that hydrocarbon development projects will drive the exploitation of aggregate resources (to supply infrastructure development needs). Because of abundant supplies of coal in the Powder River Basin of Wyoming, coal development may occur only to a limited degree. Although there was past mining of uranium and mineable grades of uranium remain in several areas, world market prices of the commodity will probably preclude development in the foreseeable future. Iron, titanium, vanadium, and copper are present as demonstrated resources, but development of those materials is also subject to world market conditions and not likely to occur in the near future. Diamonds have been found in the RMPPA, but no commercially developable deposits have been discovered to date.

A number of other minerals are present within the RMPPA; however, noted occurrences are typically sub-economic or development potential is "low", based on varying demand parameters (generally dependent on the mineral being considered).

The BLM (1985) in its Manual 3031 (Energy and Mineral Assessment) specifies the following classification system for mineral potential (utilized to rank the potential for presence or occurrence, as opposed to the potential for development or extraction):

Level of Potential

Classification	Level of Potential
O	The geologic environment, the inferred geologic processes, and the lack of mineral occurrences do not indicate potential for accumulation of mineral resources.
L	The geologic environment and the inferred geologic processes indicate low potential for accumulation of mineral resources.
M	The geologic environment, the inferred geologic processes, and the reported mineral occurrences or valid geochemical/geophysical anomaly indicate moderate potential for accumulation of mineral resources.
H	The geologic environment, the inferred geologic processes, the reported mineral occurrences and/or valid geochemical/geophysical anomaly, and the known mines or deposits indicate high potential for accumulation of mineral resources. The "known mines and deposits" do not have to be within the area that is being classified, but have to be within the same type of geologic environment.
ND	Mineral(s) potential not determined due to lack of useful data. This notation does not require a level of certainty qualifier.

Level of Certainty

Classification	Level of Certainty
A	The available data are insufficient and/or cannot be considered as direct or indirect evidence to support or refute the possible existence of mineral resources within the respective area.

B The available data provide indirect evidence to support or refute the possible existence of mineral resources.

C The available data provide direct evidence but are quantitatively minimal to support or refute the possible existence of mineral resources.

D The available data provide abundant direct and indirect evidence to support or refute the possible existence of mineral resources.

Based on the BLM classification system (BLM 1985), the RMPPA mineral potential for those minerals determined present is as follows:

Mineral	Classification	Mineral	Classification
Leasable Minerals		Locatable Minerals	
Oil	H/D	Uranium	H/D
Natural Gas	H/D	Iron	H/D
Coalbed Methane	H/C	Titanium	H/D
Coal	H/D	Gold	H/C
Oil Shale	M/C	Copper	H/C
Phosphate	L/C	Diamonds	H/C
Sodium	M/C	Rare Earths	H/C
Geothermal	L/C	Bentonite	L/C
		Zeolites	M/C
Saleable Minerals			
Aggregates	H/D		
Baked Shale	H/D		
Silica Sand	H/D		
Dimension Stone	H/D		
Vermiculite	H/C		
Pumice and Scoria	H/C		
Common Clay	H/C		
Gypsum	H/D		
Decorative Stone	H/D		
Epsomite	H/D		
Aluminum	M/C		
Jade	M/B		
Petrified Wood	M/B		

5.0 RECOMMENDATIONS

No recommendations or stipulations have been developed at this time. However, appropriate recommendations or stipulations related to the management or future development of mineral resources within the RMPPA will be developed as a result of the RMP process.

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