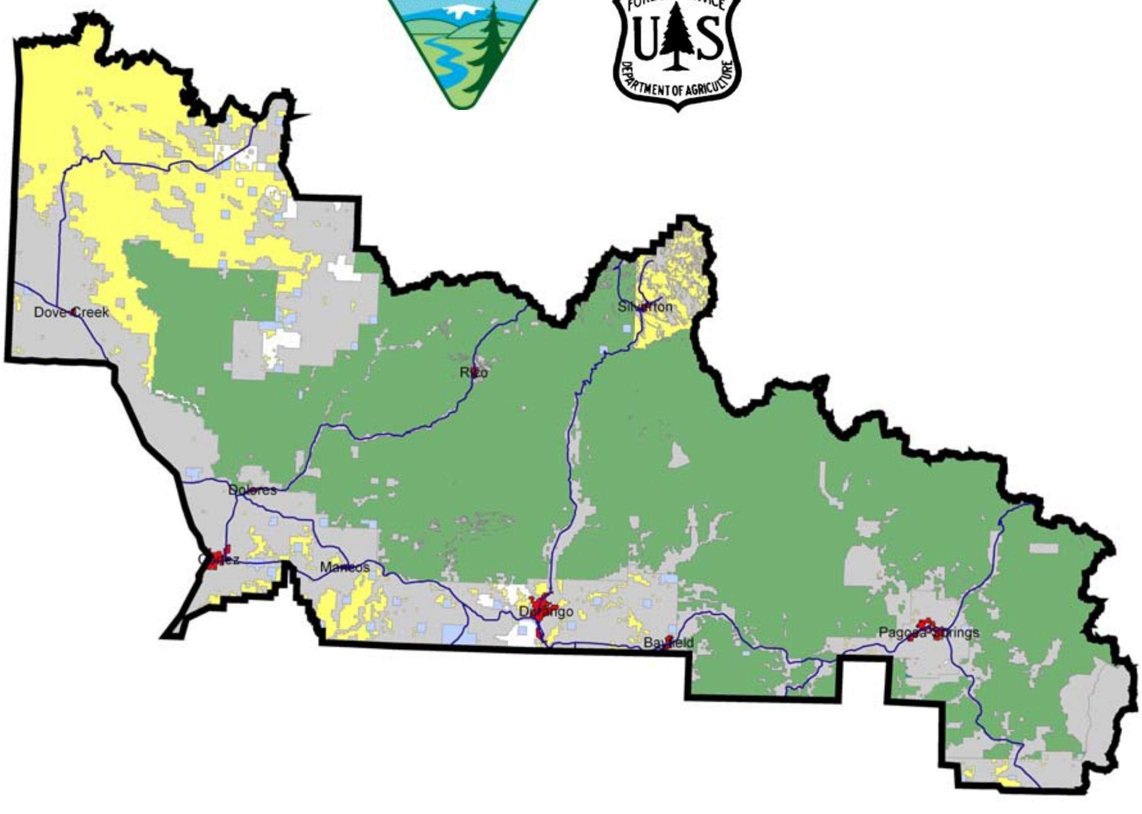
OIL AND GAS POTENTIAL AND REASONABLE FORESEEABLE DEVELOPMENT (RFD) SCENARIOS

IN THE

SAN JUAN NATIONAL FOREST AND BLM PUBLIC LANDS, COLORADO



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APPENDICES

FIGURES (APPENDIX G)

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1.0 SUMMARY

This Reasonable Foreseeable Development (RFD) Report summarizes the geologic setting, major plays, historical and current oil and gas activity, and currently recognized resource occurrence in the San Juan Public Lands RFD Area (RFD Area) (Figure 1). The RFD then presents the critical data that is required to conduct an analysis of Reasonable Foreseeable Development scenarios for fluid energy resources in the RFD Area and concludes by forecasting the RFD and potential disturbances related to development for the RFD Area. The RFD Area consists of 2,362,408 acres of San Juan National Forest (SJNF) and adjacent Bureau of Land Management (BLM) lands, as well as private property (1,025,121 acres), tribal lands mainly in the HD Mountains and Chimney Rock areas (1,377 acres), Colorado Division of Wildlife land (39,758 acres), and state, county and city lands (41,652 acres). The RFD area lies on the periphery of two major oil and gas provinces, the San Juan Basin Province and the Paradox Basin Province, and parts of the lightly explored San Juan Sag. The 2000 Energy Policy and Conservation Act (EPCA) oil and gas inventory analysis prepared` by the U.S. Geological Survey (EPCA 2003; USGS 2005) indicates that both provinces contain substantial known and undiscovered oil and gas resources. These resources occur in areas along the eastern edge of the Paradox Basin Province, which underlies the western RFD Area, and beneath the northern margin of the San Juan Basin Province, which makes up the southern part of the RFD Area.

Parts of the RFD Area that have high and moderate potential for oil and gas occurrence and development are the San Juan Basin Province clastic terrane, largely from source and reservoir rocks in the Cretaceous section, the San Juan Sag, from the Cretaceous and Jurassic section, and the Paradox Basin Province carbonate terrane, largely from source and reservoir rocks in the Pennsylvanian with lesser contributions from the Permian and Mississippian section.

As part of this RFD, many of the oil and gas operators in the RFD Area were interviewed (Appendix C). Summaries of the interviews will be found in Appendix D. The operators concluded that they anticipated growth in their activities over the next 15 years and that some of them would use enhanced technology (i.e., directional drilling, and secondary and tertiary recovery) as part of their future development activities, and that they believe there are additional developable oil and gas resources in the RFD area. New lease activity in the coal-bed methane (CBM) area of the San Juan Basin Province and in the Paradox Basin Province (Figure 3) clearly indicates an increasing interest in coal-bed methane and conventional oil and gas. Pending lease applications also evidence new exploration interest in the San Juan Sag.

In the RFD Area, approximately 1339 wells have been drilled (Figure 2). Development activity has accelerated in the last five years with an average of 34 new wells annually since 1999 (Table 1). There is a clear relationship between steadily rising price and increasing, well development activity in the RFD Area during the last five years. Current (October 2005) oil and gas prices are considerably above 2004 values, with gas currently in the $13.50-$14.00/thousand cubic feet

(MCF) range and oil at about $62/barrel (BBL), (US EIA 2005), with limited likelihood of a substantial retreat in price in the near term due to changes in international demand and supply. In 2004, 331,000 BBL of oil and 89 billion cubic feet (BCF) of gas were produced in the Area. This RFD predicts that some 10 trillion cubic feet (TCF) of gas and at least 20 million barrels of oil (MMBO) are available for development in the Area over the next 15 years.

Current production in the RFD Area is split into two major types: conventional oil and gas in the Paradox Basin Province, and coal-bed methane (CBM) in the San Juan Basin Province. Oil production is largely from the Paradox Formation in the Paradox Basin Province, with about 70 wells currently producing approximately 330,000 BBL annually, averaging about 5000 BBL per well. Natural gas in the Paradox Basin Province in the RFD Area comes largely from the Permian and Pennsylvanian sections, with about 90 wells producing 22 BCF of gas annually, averaging about 250 MCF of gas per well. Conventional oil and gas production in the RFD Area has stabilized in Montezuma and Dolores counties, having declined from mid-1990s levels; oil and particularly gas production has increased in San Miguel County over the past decade. La Plata and Archuleta counties have seen large increases in coal-bed methane and declining conventional oil and gas production. Currently, approximately 350 wells in the two counties produce 65 BCF of gas (mainly CBM) and 2300 BBL of oil per year.

Power capacity is adequate to handle additional production estimated in the RFD Area without construction of new power lines. Additional gas pipeline capacity will be required. Gas transmission out of the Blanco Hub may be a problem when California takes a larger share of its gas from LNG, creating capacity issues upstream and downstream of the Blanco Hub. Proposed CBM gas production from the HD Mountain area may also be constrained by pipeline capacity.

Based on the resource occurrence potential in the RFD Area and oil and gas price and development trends, the following RFD projections are made:

- Coal-bed methane development in the San Juan Basin Province will grow at an average of 60 wells per year at current spacing. This projection is taken from the 300 wells analyzed as the industries' proposed action in the Northern San Juan Basin Draft Environmental Impact Statement (SJPL 2004).
- If 80 acre spacing is applied north of the Ute line, an additional 450 CBM wells could be drilled within the Fruitland Formation, located in the San Juan Basin Province of the RFD Area. The drilling of an additional 90 wells per year would occur from 2009 through 2014 allowing time for regulatory changes to be adopted. Drilling approximately 450 CBM wells north of the Ute Line in addition to the 300 CBM wells at current spacing would allow a total of 750 CBM wells to be drilled within the San Juan Basin Province of the RFD Area. This would result in an average annual production increase of

10 billion cubic feet (BCF) of gas and a total annual production of 220 BCF by 2021. The total production of CBM during the next 15 years is projected to be 2.5 TCF of gas.

- Additional exploration for conventional oil and gas in the northern San Juan Basin Province may result in an average of two exploratory wells per year over the next 15 years. Production will likely focus on the Fractured Mancos, Dakota and Mesaverde plays.
- The San Juan Sag play in the RFD Area may see exploration and development activity at about two wells per year, ultimately yielding total production of 10 MMBO and 9 BCF of gas by 2021.
- The Paradox Basin Province plays will grow at an average of 25 wells per year, for a period of 15 years including 140 new wells in the Mancos-Dolores lease nomination area, resulting in an annual production increase of 25,000 BBL of oil and 2.5 BCF of conventional gas. This will result in a total annual production of 730,000 BBL of oil and 65 BCF of gas by 2021. The total production during the next 15 years in the RFD Area of the Paradox Basin Province is projected to be 8.7 MMBO and 740 BCF of conventional gas.

In summary, the RFD projection predicts 1185 new wells by 2021 that will ultimately produce at least 19 MMBO and 3.25 TCF of gas, which is approximately 95 percent of the developable oil resource and 30 percent of the natural gas resource predicted by the U.S. Geological Survey (USGS 2005) for the RFD area. The total disturbance for new wells including 80 acre in-fill spacing is projected to be 212 acres/year, with a total disturbance of 3181.2 acres over the 15-year period. New gas pipelines are estimated to produce disturbance ranging from 424-937 acres. This estimate is based on a per well disturbance factor derived from the aggregate surface disturbance of wells, pads, roads, gathering land trunk lines, surface and ancillary facilities.

2.0 INTRODUCTION

2.1 BACKGROUND OF RFD

Implementing regulations of the 1987 Federal Onshore Oil and Gas Leasing Reform Act require the U.S. Department of Agriculture, Forest Service (USFS) and U.S. Department of the Interior, Bureau of Land Management (BLM) to analyze the environmental effects from activities which might result from implementation of a proposed leasing program (Federal Register 36 CFR 228 Subpart E). A scenario of the type and amount of post-leasing activity that is reasonably foreseeable as a consequence of leasing under specified conditions provides the basis for analyzing effects from leasing. This report is commonly referred to as a “Reasonably Foreseeable Development Scenario,” or “RFD” and provides an activity scenario based on oil and gas resource occurrence, with development unconstrained by restrictions beyond those provided under standard lease terms and designated wilderness. Information in this RFD report provides a context in which activity scenarios under different levels of management constraints can be developed with respect to projected oil and gas activities. This RFD report describes the surface and subsurface geology of the RFD Area, discusses potential for oil and gas resources to occur within the RFD Area, and presents a reasonable projection of the type and amount of oil and gas exploration and development that might occur in the RFD Area during the next 15 years (through 2020).

This RFD report was prepared using the interagency reference guide “Reasonable Foreseeable Development Scenarios and Cumulative Effects Analysis” final draft dated August 30, 2002 and BLM guidance document IM 2004-089. The guidance provides recommended criteria for an adequate RFD scenario and documents the major terms and concepts associated with cumulative effects analysis and reasonable foreseeable development in the context of oil and gas resource management. This RFD is presented in a non-technical format for the aid of land-use planners and other nonscientific personnel. The introductory text of this report, which describes the geological, physical, and stratigraphic setting, is taken largely from the previous resource assessment of the San Juan National Forest Area by the U.S. Geological Survey (Van Loenen and Gibbons 1994) and the National Assessment of the San Juan Basin and Paradox Basin geologic provinces (Huffman 1995a,b), also by the U.S. Geological Survey (USGS).

The RFD Area is cored with the San Juan National Forest. The periphery of the Area is approximately bounded by (clockwise from the northwest corner of the Area): the western half of the northern boundary of San Miguel County; the northern boundary of the San Juan National Forest; BLM lands north of Silverton in San Juan County; the eastern edge of Archuleta County; the approximate southern edge of the San Juan National Forest, including private and BLM lands north of the Southern Ute Indian Reservation; the northern boundary of Mesa Verde National Park; U.S. Highway 491; an east-west boundary north of the Canyon of the Ancients National

Monument; and the Utah state line. The RFD Area includes seven counties: Archuleta, Dolores, Hinsdale, La Plata, Mineral, Montezuma, San Juan, and San Miguel. Only Archuleta, Dolores, La Plata, Montezuma, and San Miguel counties have relevant oil and gas production.

A digital map of the RFD Area at 1:250,000-scale was used as a base for the compilation. Available information, as of January 1, 2005, both published and unpublished, concerning fluid energy sources in the RFD Area was used in establishing resource potential. The resources assessed in this study are leasable energy resources, which include oil, gas, and geothermal resources. Quantitative estimates of the amounts of oil, gas, and coal-bed gases that could be present in the RFD Area are given.

2.2 DETERMINING OIL AND GAS RESOURCE POTENTIAL

The "Oil and Gas Resource Potential" part of this report (Section 3) describes regions of different potential for accumulations of oil and gas in the RFD Area. A region of defined oil and gas resource potential may include adjacent non-RFD Area lands where the geology and exploration and development activity are important to describing potential for oil and gas resources in the RFD Area. Section 3 also summarizes previous studies, provides descriptions of the stratigraphy, structure, and past drilling activity in the area, with emphasis on potential reservoir rocks, source rocks, and stratigraphic and structural traps. “Major Plays” in the Area are discussed in Section 4 and the “Oil and Gas Occurrence Potential” of the RFD Area is summarized in Section 5.

2.3 PROJECTED OIL AND GAS EXPLORATION AND DEVELOPMENT ACTIVITY

Projecting expected oil and gas activity is necessary to assess potential effects of leasing RFD Area lands for oil and gas exploration and development. The “Scenario for Future Oil and Gas Exploration and Development Activity” part of this report (Section 6) presents the type and level of anticipated activity principally based on geology and past and present activity. Economics and technology, access to an area of interest, and the availability of processing facilities and transportation also play a role in exploration and development activity levels. Some of these factors, such as economics and technology, are difficult to predict due to their complexity, interactive nature, and variability in time. Section 5 is based on what is currently known about geology and activity and was not intended to attempt accurate predictions of future fluctuations in oil and gas markets and political factors or rapid and unpredictable changes in technology or discoveries that may trigger new plays in the area.

2.4 RELATIONSHIP OF POTENTIAL FOR OIL AND GAS RESOURCE OCCURRENCE TO POTENTIAL FOR ACTIVITY

Projected oil and gas activity may not always equate with geologic potential for the existence of hydrocarbons. In some areas where all the geologic factors indicate a high potential for oil and gas resources, other factors, such as inaccessibility, risk, high exploration costs, and low oil and gas prices, may limit the potential for exploration and development activity to occur. Consequently, an area of high potential for hydrocarbon occurrence may have a low potential for exploration and development activities. Conversely, such factors as rapidly escalating product prices or advances in technology could lead to drilling activity in areas considered to have a low potential for oil and gas occurrence. In any case, current projections of activity are based on currently known conditions and reasonable expected changes in technology and price factors.

2.5 GEOTHERMAL ENERGY RESOURCES

Because geothermal fluids are a fluid energy source in the RFD Area, they are discussed briefly here. As little has changed since the last RFD done for the San Juan National Forest (Van Loenen and Gibbons 1994), the following text is taken largely from the 1994 USGS document. Additional discussion of geothermal resources in the RFD Area can also be found in SJPL (2004). As the geothermal energy resource in the RFD Area is small relative to the other fluid energy sources in the Area, no further discussion of geothermal energy is included in this RFD.

2.5.1 Energy Resources

The State of Colorado has high-temperature geothermal resources that are suitable for electricity generation, and extensive low-and moderate-temperature geothermal resources that are viable for agricultural, municipal, commercial, and residential use. The geothermal resources in the RFD Area are low or medium temperature. Geothermal fluid resources that occur in the RFD Area and surrounding areas are warm water emanating from geysers, springs and wells. Most warm springs are located near faults that serve as conduits for upward flow of groundwater that has been heated by deep circulation from mainly volcanic sources.

Two types of geothermal resources are being tapped commercially in the RFD Area: hydrothermal fluid resources and earth energy. Hydrothermal fluid resources provide hot water for spa and pool use as well as space heating in the RFD Area. Earth energy, the heat contained in soil and rocks at shallow depths, is excellent for direct use and with geothermal heat pumps. Direct-use applications require moderate temperatures; geothermal heat pumps can operate with low-temperature resources. A number of residences in the RFD Area are using this resource to supplement space heating.

According to Gibbons (Van Loenen and Gibbons 1994), widely separated areas of the RFD Area contain one or more thermal springs or artesian wells (*ibid*, fig. 67). Characteristics of the spring waters are given in Table 2. Except for the town of Pagosa Springs, where hot water from hot springs is currently used to heat buildings and public sidewalks, the thermal springs are at present either undeveloped or are developed for recreational and therapeutic uses in private and public pools.

Isograds of the geothermal gradient (*ibid*, fig. 67) show a relationship between high geothermal gradient and the occurrence of thermal springs. Most of the RFD Area lies in a region of relatively high geothermal gradient. Only in the extreme western part of the Area, which lacks thermal springs, does the gradient approximate the “earth normal” value of about 14° F per 1,000 ft of depth. However, the relationship between gradient and hot springs is a crude generalization and is commonly inaccurate.

More definite ties are to intrusions and eruptions of igneous rock as sources of heat, and to systems of faults and fractures as conduits for thermal waters. Most of the thermal springs in the RFD Area likely relate to geologically young volcanic or intrusive events. The heat-supplying intrusion may be distant from the thermal springs. McCarthy and others (1982) infer that the Tripp, Trimble, and Stratten thermal springs in the Animas River Valley derive heat and at least some water from the La Plata Mountains area of igneous intrusions about 10-12 mi to the west. The Pinkerton Group of hot springs in the Animas Valley may be from the same source area (McCarthy et al. 1982). However, faults identified at the Pinkerton springs trend northwest in the direction of the Rico and Dunton areas of intrusives in the drainage of the Dolores River. All of the thermal springs of the Animas Valley have water that is rich in sodium chloride, suggesting an origin to the west in the area underlain by the salt-bearing Paradox Formation. Pagosa Springs, with the highest water temperatures of any springs in the region, have no known relation to an intrusive body, although they occur in an area of moderately high geothermal gradient.

Geyser Spring, in the Dunton area, is Colorado's only geyser. Eruptions, at approximately half-hour intervals, are marked by fountaining to a height about 1 ft above the resting level of the geyser pool. Evolution of gas is continuous, greatly increasing during eruptions. The gas consists of carbon dioxide (70%), oxygen (5%), nitrogen (16%), argon (0.3%), and water vapor (9 %) (Gary Landis, USGS, unpublished data 1993). Hydrogen sulfide, recognizable by its odor during geyser eruptions, was not detected in the analysis of the gas, probably because it decomposed completely into products that dissolved into the water taken with the gas sample.

2.5.2 Summary

The potential for noteworthy further development of known hydrothermal resources and the presence of undiscovered hydrothermal resources in the RFD Area are likely slight. Most of the thermal springs yield only moderately hot water in relatively small quantities. Moreover, most are remote from markets. Only three springs, Geyser, Piedra, and Rainbow, are on public land. Heating state-owned buildings in Durango with water piped from thermal springs in the Animas River Valley was evaluated and found to be uneconomic (Meyer et al. 1981). There are no geothermal leases held in the RFD Area today, although large tracts were applied for but withdrawn in 1974 and 1980 (Neubert et al. 1992, p. 284).

TABLE 2
GEOTHERMAL WELLS AND SPRINGS IN THE RFD AREA
(*from* Colorado Geothermal Energy 2005; Colorado Renewable Energy Society 2005; BLM et al. 2002; Gibbons in Van Loenen and Gibbons 1994).

Well or Spring	County	Use	Temperature (F)/ Flow (gallons/min)	Energy (Gwh/yr)
Stinking Springs	Archuleta	NA	NA	NA
Dutch Crowley Well	Archuleta	NA	NA	NA
Eoff Well	Archuleta	NA	102/50	NA
Pagosa Springs	Archuleta	NA	129-136/226-265	NA
Dunton HS	Dolores	Spa & pool	108/25	0.1
Dunton Geyser	Dolores	NA	82/25-200	NA
Paradise HS	Dolores	NA	40-46/26-34	NA
Rico HS	Dolores	NA	34-44/54	NA
Hickerson HS	La Plata	NA	NA	NA
Mound/Little Mound HS	La Plata	NA	NA	NA
Piedra HS	La Plata	NA	108/50	NA
Pinkerton HS	La Plata	Space heating	79-91/130	0.6
Stratten HS	La Plata	NA	NA	NA
Trimble/Tripp HS	La Plata	Spa & pool	82-111/~11	2.1
Rainbow HS	Mineral	NA	104/45	NA
Lemon HS	San Miguel	NA	NA	NA

3.0 OIL AND GAS RESOURCE POTENTIAL

3.1 GEOLOGY

3.1.1 Location and Setting

The RFD Area includes about 3.5 million acres of plateau and mountainous terrain that extends nearly 120 miles east to west and 45 miles north to south (Figure 1). The RFD Area lies southwest of the Continental Divide, and all drainage from the RFD Area is into tributaries of the Colorado River. The RFD Area rises from about 6,000 ft elevation in the canyonlands along its south and west sides to high mountains in the east, where many peaks are over 13,000 ft in elevation. Mountains and ranges of the high country include the Needle, San Miguel, La Plata, West Silverton and San Juan, although the entire region is often referred to simply as the San Juan Mountains. Streams, rivers, and glaciers have cut deep canyons that drain the RFD Area into the San Juan and Dolores rivers, which are tributaries of the Colorado River.

The following discussion of the geology of the RFD Area is taken largely from the 1994 USGS Resource Assessment for the San Juan National Forest (Van Loenen and Gibbons 1994). Geologic information has been updated and revised to reflect new information and the larger RFD Area.

The RFD Area is in the Southern Rocky Mountain and Colorado Plateau physiographic provinces. The northeastern part of the RFD Area is in the Southern Rocky Mountain province and includes most of the San Juan Mountains. The western and southern parts of the RFD Area are in the canyonlands and plateaus of the Paradox and San Juan basins of the Colorado Plateau province (Figure 4). Geologically, the RFD Area consists of an uplifted core of Proterozoic rocks, exposed near the center of the Area, which is flanked on the north and east by Tertiary volcanic rocks of the San Juan volcanic field and on the south and west by Paleozoic and younger sedimentary rocks of the Paradox and San Juan basins (Figures 4, 5).

FIGURE 4. Major paleotectonic features of the Four Corners area

FIGURE 5. Geology of the RFD Area and adjacent lands (*from* GREEN 1992)

The areas with high to moderate oil and gas potential are confined to lands within the Colorado Plateau with outcrops of sedimentary rocks. This high/moderate potential area does not include the uplifted pre-Paleozoic terrane of the San Juan Mountains.

The RFD Area shares a boundary with the Uncompahgre National Forest to the north, the Rio Grande National Forest to the east, and the Canyon of the Ancients National Monument to the west. The RFD Area is adjacent to federally managed resource areas that have recently undergone RFD or equivalent analysis, including RFDs for the Grand Mesa, Uncompahgre, and Gunnison

National Forests (GMUG 2004), San Juan Basin (Engler et al. 2001), and Canyon of the Ancients National Monument (BLM 2004); the Northern San Juan Basin Coal Bed Methane DEIS (SJPL 2004); and initial studies of the Carson National Forest (USFS 2003).

3.1.2 Geologic Setting and Framework

The rocks exposed in the RFD Area represent a suite of sedimentary, plutonic, and volcanic rocks that accumulated over a time span of nearly 1.8 billion years. The oldest rocks (Proterozoic crystalline rocks) are exposed in the Needle Mountains in the central region of the RFD Area. These ancient rocks are flanked on the north and east by Tertiary volcanic rocks and on the south and west by Paleozoic and younger sedimentary rocks that were laid down in ancient depositional sites called the Paradox and San Juan basins. Major rivers and streams, assisted by intense glacial erosion, have cut deep canyons throughout much of the RFD Area, producing the landscape seen today.

1. The geologic framework of RFD Area results from a long and complex history of faulting and uplifts, basin development, sedimentation, plutonism, and volcanism. As recorded in the rocks of the Area, the sequence is as follows:

2. Deposition of sedimentary rocks that were later metamorphosed and still later invaded by a succession of plutonic intrusive bodies from 1.7 to about 1.4 billion years ago
3. A gap in the rock record for the next 900 million years due to erosion or nondeposition
4. Alternation of deposition of clastic and carbonate rocks with minor local uplift and erosion between about 550 to 320 million years ago
5. The first cycle of uplift of the Uncompahgre-San Luis Highlands (Figure 4), an element of the Ancestral Rocky Mountains, beginning about 320 million years ago
6. Profound erosion of the uplift and deposition of “redbeds” and other continental clastic sediments from 365 to about 140 million years
7. Deposition of sediment in and adjacent to the Epicontinental Cretaceous sea that covered the region intermittently from 140 to about 70 million years
8. Renewed uplift during the Laramide Orogeny along trends similar to those of the Ancestral Rocky Mountains, accompanied by intrusion of upper crustal plutons about 70 to 65 million years ago
9. Massive volcanism beginning about 40 million years ago and continuing to about 20 million years ago, followed by or accompanied by igneous intrusions

A final pulse of igneous intrusive activity during the period from 10-5 million years ago, followed by fluvial and glacial processes that formed the present-day landscape.

With respect to the development of fluid energy resources in the RFD Area, the most important of the above events are those numbered 3, 4, 6, 7, 8, and 9. Event 3 included development of the carbonate rock terrane, discussed below, which became the host to certain kinds of conventional oil and gas deposits. Event 4, initial rise of the Uncompahgre uplift, brought about erosion of the carbonate rock terrane from the east and northeast parts of the RFD Area. The present-day consequence is that oil and gas in these carbonate rocks can be expected primarily in the central and western parts of the RFD Area.

Event 6, deposition of clastic sediments in and, more importantly for energy wealth, adjacent to the Cretaceous sea, resulted in development of thick coals. These coals are valuable in themselves and form the basis of today's resources of coal-bed gas (commonly called “coal-bed methane” after its principal constituent). Events 7, 8, and 9 are stages in a long period of tectonic and magmatic activity extending from the late Cretaceous (about 70 million years ago) essentially to the present, and produced a large flow of heat to the region, which affected oil and gas development and created a large CO_2 resource as well as geothermal fluids.

3.1.3 Geologic History

The geologic history of the RFD Area began during the Proterozoic Eon when continental-scale tectonism affected a large part of what is now the western United States. Two linear tectonic zones (lineaments) intersect in this area of southwestern Colorado and southeastern Utah. A northwesterly trending zone (Figure 6) forms part of the Wichita lineament, whereas a northeasterly trending zone is part of the Colorado lineament. Faults along the Colorado lineament are thought to have influenced the location of the much younger Colorado Mineral Belt. All tectonic events that affect the geology of the RFD Area closely follow these patterns that were first established in Proterozoic time.

FIGURE 6. Major geological features of the Four Corners area

The Uncompahgre and San Luis uplifts (Figures 4, 6) are structural elements along the northwest-trending Wichita lineament. Throughout geologic time these uplifts and related faults have played a major role in controlling the distribution and, in many cases, the supply of sediments to the RFD Area. Since Proterozoic time, the northwesterly trending uplifts have undergone at least two cycles of uplift and erosion. The first cycle began in late Paleozoic and ended in early Mesozoic when the Ancestral Rocky Mountains formed; the more recent cycle ended near the close of Cretaceous time as part of the Laramide Orogeny.

The San Luis uplift lies southeast of and parallel to the much more extensive Uncompahgre uplift. The two uplifts have similar histories of movement. The San Luis uplift extends from near Rico, southeast through the San Juan Mountains, and into north-central New Mexico. The Grenadier Highlands (represented by the present-day Needle Mountains of the RFD Area) are a part of the

San Luis uplift (Figure 6). These Highlands remained a topographic high throughout most of Paleozoic time and are made up of crystalline rocks of Early and Middle Proterozoic age that are the oldest rocks in the RFD Area. These crystalline rocks originated from sediments, igneous intrusives, and volcanic material that began to accumulate more than 1.7 billion years ago. They consist of at least two sequences of highly deformed metamorphic rocks that were intruded by a succession of plutonic bodies between about 1.7 and 1.4 billion years ago. All of the crystalline rocks were deeply eroded by the beginning of the Paleozoic Era.

The regional depositional history of the Paleozoic Era began in Late Cambrian time when sandstones, derived in part from the old Grenadier (San Luis) Highlands in the northeastern part of the RFD Area and from other Highlands southwest of the Area, were deposited unconformably over the Proterozoic basement. The Cambrian sandstones largely escaped erosion and are preserved as the Ignacio Quartzite. A long interval of tectonic stability ended the Early Paleozoic. Ordovician and Silurian rocks are entirely absent from this region of the RFD Area. Figure 7 summarizes the stratigraphy of the RFD Area.

FIGURE 7. General stratigraphic column for the RFD Area

Deposition resumed in upper Devonian time, as seas, advancing from the west, covered all the Area (Elbert Formation) except the San Luis Highlands. Later, in Devonian and Mississippian time, the San Luis Highlands, along with the rest of the RFD Area, was covered by carbonate sedimentary rocks (Ouray and Leadville limestones) deposited from shallow marine seas. The Uncompahgre-San Luis Highlands were beginning to emerge by this time, and they mark the easternmost advance of the late Mississippian sea. By Middle Pennsylvanian time, the Uncompahgre-San Luis Highlands were a prominent range of the Ancestral Rocky Mountains.

To the west of the rising mountain range and expressing the same tectonism, deep subsidence produced the Paradox Basin. Great thicknesses of shales and evaporite beds filled this basin, which overlaps the western part of the RFD Area. The evaporite beds pinch out along the eastern edge of the Paradox Basin, but thick deposits of coeval carbonates, shales, and sandstones continue eastward across the RFD Area and wedge out against the Uncompahgre-San Luis Highlands. At the end of the Paleozoic Era, the Uncompahgre-San Luis Highlands were rapidly eroded, shedding an apron of arkosic materials southwestward and depositing them in coastal lowlands. These deposits are present today as redbed fanglomerates of the Permian Cutler Formation, which underlies the central and southwestern parts of the RFD Area. Sedimentation ceased by the end of Lower Permian time, and the region became part of a continental landmass.

The Mesozoic record begins in Late Triassic time, when nonmarine redbeds of the Dolores Formation, similar to those of the earlier Cutler Formation, were deposited across most of the region. Subsequent erosion removed most pre-Jurassic rocks from the Highlands and exposed the

Proterozoic basement rocks. During Jurassic time, the San Juan Basin to the south was subsiding, and nonmarine sediments (Wanakah, Entrada, and Morrison formations) accumulated over almost the entire region. Nonmarine sedimentation was succeeded by both marine and nonmarine sedimentation during the Cretaceous, when an Epicontinental, epeirogenic sea, part of a continental-scale Cretaceous Seaway, intermittently covered this region. Intertidal and marine offshore bar sandstones (Dakota Sandstone and Burro Canyon Formation) were covered with great volumes of marine shales (Mancos and Lewis shales), and nonmarine lagoonal sediments, which include the thick coal beds of the Fruitland Formation, were deposited shoreward of the seaway as the strandline moved back and forth across the region.

In the RFD Area, deposition of sediment from the Cretaceous sea ended about 70 million years ago with the onset of the Laramide Orogeny, a 35-m.y.-long period of tectonic activity. The Cretaceous sea retreated to the northeast for the last time as renewed upwarping, caused by the Orogeny, began from the south and along the Uncompahgre-San Luis uplift. Subsequent erosion removed all the sedimentary rock cover from the Needle Mountains and the area to the north, re-exposing the Proterozoic rocks. Across the RFD Area to the east and southeast of the Needle Mountains, only the upper parts of the thick rock cover were removed, leaving all rock units from Jurassic Entrada sandstone to within the Cretaceous Lewis Shale to be covered later with younger volcanic material. Because of this, the identity of rocks beneath the volcanic cover of the San Juan volcanic field is important in assessing the energy resources of the RFD Area.

Uplift and faulting during the Laramide Orogeny were accompanied by igneous intrusive activity and mineralization. The first volcanoes also appeared in the San Juan volcanic field at this time, as indicated by abundant volcanic debris in the Animas Formation of Early Tertiary and Cretaceous age, even though no evidence of Laramide-age volcanic sites survives in the RFD Area. Emplacement of intrusive stocks and laccoliths caused structural doming of the thick sedimentary section in several parts of the Area. Periods of quiescence, erosion, and basin filling followed the Laramide Orogeny.

The dominance of igneous intrusion in the San Juan Mountains was replaced by a dominance of volcanism, which prevailed for the next 25 million years. During this time, great thicknesses of volcanic material accumulated in the San Juan volcanic field, which once covered a much larger part of the RFD Area than it does today. Lavas and pyroclastic materials were extruded from many centers now marked by calderas that are scattered throughout the volcanic field. Although sites of formerly active centers lie outside the RFD Area, those close by, such as the Platoro and South River calderas to the east and the Silverton caldera to the north, supplied material that covered large areas of the northeastern and eastern parts of the Area. Intermittent intrusive activity and related mineralization within and near the calderas accompanied the extrusive activity. A final pulse of intrusive activity occurred in the RFD Area less than 10 million years ago, when small stocks were emplaced at Rico and Chicago Basin.

Today's landscape is largely the result of sculpturing by glacial and fluvial processes in the RFD Area during the Pleistocene and Holocene epochs. Glacial processes have contributed to erosion of the hard and resistant rocks that make up the mountain ranges. Relatively hard volcanic rocks that form the high plateau of the San Juan Mountains cap the northeastern edge of the Area, along the Continental Divide. The western edge of the volcanic pile is deeply dissected and forms cliffs with vertical faces as much as several thousand feet high. From the base of the cliffs, the softer underlying sedimentary rock section dips gently, with only local interruptions, due to folding and faulting, southwestward across the RFD Area.

3.1.4 Energy Resources

The energy resources of the RFD Area formed from many different processes throughout its geologic history. During Paleozoic time, great thicknesses of carbonate strata were deposited. Later the permeability of these carbonate beds was to make them suitable as reservoir rocks for subsequently generated conventional oil and gas. During Mesozoic time, mostly clastic sediments were deposited, and organic material accumulated to form thick coal beds that later generated coal-bed methane. Some sediments deposited during the Late Mesozoic are highly productive reservoir beds for oil and gas; other beds are thought to be petroleum source rocks. During the Late Cretaceous and Tertiary, extensive hydrothermal systems followed fractures into the RFD Area, where they affected all types of rock. And finally less than 10 million years ago, small plutons were emplaced that supplied heat to hydrothermal systems. Geothermal activity in some parts of the RFD Area may be related to this period of igneous intrusion.

3.1.5 Geologic Terranes

Introduction

As defined in Van Loenen and Gibbons (1994), a terrane is a rock unit or group of related rock units and (or) the area or areas in which they occur. The classification of rocks based primarily on age, which is employed on the geologic map (Figure 5) and stratigraphic section (Figure 7), plays an essential role in defining the geologic framework of the RFD Area. However, it is not the most useful basis for consideration of the energy resource potential of the Area. This purpose is better served by a classification based primarily on rock types and only secondarily on age. The units of such a classification will have as source rocks, host rocks, or both, very different potentials for the development of different kinds of energy deposits. These rock-type based units are called “terranes” in this RFD report. Time spans of terranes may overlap the formal geologic eras or periods and may also overlap one another. The two terranes distinguished in the RFD Area that are relevant to energy resources are, in chronological order of development, the Paleozoic carbonate terrane and the Paleozoic-Mesozoic clastic terrane. Characteristics of each terrane and its relationship to energy resources are discussed in the following section. Figure 7 is a generalized stratigraphic column for the RFD Area. Figures 8A and 8B show the general location of both terranes in the RFD Area.

FIGURE 8. Geologic terranes in the RFD Area (from Van Loenen and Gibbons 1994)

8A Location of Paleozoic Carbonate Terrane

8B Location of Paleozoic-Mesozoic Clastic Terrane

Paleozoic Carbonate Terrane

The Paleozoic carbonate terrane ("carbonate terrane") shown in Figure 8A contains several thousand feet of limestone and dolostone in the RFD Area. The carbonate terrane includes all of the strata deposited from Cambrian through Middle Pennsylvanian time, because most of these strata are carbonate rocks, although clastic rocks are also present. The carbonate terrane is considered permissive terrane for leasable energy resources. The permissive areal extent of the carbonate terrane, surface and subsurface, is shown on Figure 8A. The carbonate terrane is exposed in an arcuate pattern on the flanks of and in small outliers on the uplifted Proterozoic basement rocks in the central region of the RFD Area. Farther west, these rocks are exposed in the cores of the Rico and La Plata domes. In the subsurface, this terrane extends westward past the line defining its permissive extent in Figure 8A and on beyond the western boundary of the map. Its northeastern and eastern limit is where it pinches out due to nondeposition or erosion over the Uncompahgre-San Luis uplift. This pinchout occurs to the west of the area now covered by volcanic rocks except in the north-central part of the RFD Area west of Silverton, where the carbonate terrane underlies Tertiary volcanics of the San Juan volcanic field.

Sediments of the carbonate terrane were deposited in two very distinct environments. From Cambrian through Mississippian time, deposition was in an environment of regional stability. During Pennsylvanian time, however, deposition of carbonates took place in a setting provided by a more localized pattern of uplift and basin formation that marked the latter part of the Paleozoic. Cambrian, Devonian, and Mississippian marine carbonate and clastic rocks were deposited intermittently from shallow seas in a major basin along the western edge of the North American craton. Rock units of this group are the Upper Cambrian Ignacio Quartzite, Upper Devonian Elbert and Ouray Formations, and the Lower Mississippian Leadville Limestone (Figure 7). These formations are meagerly exposed in a few small outcrops in and around the Proterozoic rock of the Needle Mountains. They are absent in the southeastern part of the RFD Area and are deeply buried beneath the western part. The formations are not differentiated on Figure 5 but are combined alternatively in either map unit MDC (Mississippian, Devonian, and Cambrian) or unit MD (Mississippian and Devonian).

The oldest carbonate rocks of the carbonate terrane are intertidal dolostones in the upper part of the Elbert Formation. They overlie older clastic rocks of the terrane, represented by the lower part of the Elbert and by the Ignacio Quartzite. The Elbert Formation is overlain by the Upper Devonian Ouray Limestone, which grades upward into the Lower Mississippian Leadville Limestone. The Leadville represents a deeper marine environment than the Ouray.

An erosional episode followed Leadville deposition, producing a karst surface now buried in shale and regolith of the Pennsylvanian Molas Formation. Following Molas deposition, the uppermost part of the carbonate terrane was laid down in basins that formed adjacent to the developing Uncompahgre-San Luis uplifts. Thick deposits of carbonates, evaporites, and clastic sediments of the Hermosa Formation accumulated in the RFD Area during Pennsylvanian time.

In the central part of the RFD Area, where it is widely exposed, the Pennsylvanian Hermosa Formation is as much as 2,500 ft thick and consists mainly of marine limestones, sandstones, and shales. These deposits were laid down in three parts, beginning with sandstones and shales and thin limestone beds deposited in a shallow-water marine-transgressive environment. These earliest sediments were followed by massive limestones and interbedded black shales deposited in a deeper marine environment. Hermosa deposition ended with sandstone, shale, conglomerate, and thin limestone deposited in a near-shore regressive-marine environment. In the Paradox Basin to the west, where the Hermosa Formation is in the subsurface, the medial limestone unit of the outcropping formation is represented by evaporites.

The Hermosa Formation along the eastern flank of the Paradox Basin, but mostly below the terrane shown on Figure 8A, may contain reservoirs for oil and gas in the “Silverton delta play” and “Carbonate buildup play” discussed in Section 4 of this report.

Paleozoic-Mesozoic Clastic Terrane

The Paleozoic-Mesozoic clastic rock terrane (“clastic terrane”) in the RFD Area (Figure 8B) includes a thick sequence of sedimentary rocks deposited during the later part of the Paleozoic and in the Mesozoic eras. Some of the younger formations, notably the Upper Cretaceous Dakota Sandstone and Mancos Shale (Figure 7), form a gently dipping surface over large expanses of the Area, whereas the older clastic rocks are exposed mainly in canyon walls. The clastic rock terrane is a wedge of continental and marine strata that thickens to the west and south from the Uncompahgre-San Luis uplifts into the Paradox and San Juan basins. The oldest exposed rocks of the sequence crop out around the central Needle Mountains uplift, with progressively younger rocks exposed to the west, south, and east. Clastic rocks are exposed on the surface of nearly two-thirds of the RFD Area. Exposures are absent only over the uplifted areas in the central part, where they have been removed by erosion, and in the eastern part, where the clastic rocks are covered by volcanic rock of the San Juan volcanic field.

The clastic terrane is of major importance for energy resources. The Cretaceous units contain thick coal beds as well as other rock layers that are sources of both conventional and unconventional reservoirs for oil and gas. The stratigraphic units of the clastic terrane are described below, from oldest to youngest. See Figure 7 for the stratigraphic column.

The Upper Pennsylvanian Rico Formation, a mixed unit, is transitional between the carbonate and clastic terranes and contains limestones as well as both marine and continental clastic rocks. Rocks overlying the Rico Formation are the picturesque “redbeds” of the Permian Cutler Formation and the Upper Triassic Dolores Formation. These formations have a combined thickness of nearly 3,000 ft and crop out extensively in the central part of the RFD Area (Figure 5).

The Upper Jurassic Entrada Sandstone, which overlies the Dolores Formation, was deposited in an eolian and coastal dune environment. It consists of clean, permeable, medium-grained sands. The Upper Jurassic Wanakah Formation is composed mostly of eolian and interdunal sandstone and limestones. The Morrison Formation overlies the Wanakah Formation and crops out in the central part of the RFD Area and on its western boundary along tributaries to the Dolores River. The Morrison is as much as 800 ft thick and consists of sandstone with interbedded clays and mudstones, including the fluvial and lacustrine sandstones of the Salt Wash Member overlain by the mostly varicolored claystone and sandstone of the Brushy Basin Member. Away from outcrops, the Morrison is deeply buried beneath younger clastic rocks.

The uppermost units of the clastic terrane, several thousand feet of Upper Cretaceous marine and nonmarine sandstones and shales, contain important energy resources, including coal-bed methane, conventional oil and gas, and carbon dioxide. Because of their significance, they are described separately below.

Cretaceous Rocks of the RFD Area

Over the past century Cretaceous rocks have been assigned various formation names by geologists as an aid in description, mapping, and studies of the stratigraphic deposits. The sedimentary rock units are of both continental and marine origin, and they show that, during Upper Cretaceous time, the western shoreline of an Epicontinental Sea, which trended north-south across North America, advanced toward the southwest and retreated toward the northeast several times across Colorado and adjacent areas in response to varying sediment supply and rate of subsidence of the ocean basin. Because little has changed in our understanding of the geology of this area since the 1994 resource assessment of the San Juan National Forest, this section is taken largely from M'Gonigle and Roberts (*in* Van Loenen and Gibbons 1994).

Figure 9 shows a generalized geometric configuration of the stratigraphic succession and the names applied to the coastal, marine, and continental deposits that accumulated during these marine oscillations. In any one place a vertical section in outcrop or drill hole would show the various stratigraphic units stacked upon each other; only in a regional section, such as shown in Figure 9, can the geometry and interrelationships of the units be discerned. It is apparent from the figure that the formations rise stratigraphically and are younger to the northeast.

FIGURE 9. Stratigraphic section showing the Upper Cretaceous rocks of the San Juan Basin (*from* Molenaar 1988)

The basal Upper Cretaceous unit, the Dakota Sandstone, was laid down across fluvial rocks of the Burro Canyon Formation of possible Lower Cretaceous age during the initial advance of the sea into this area. The Dakota Sandstone, about 200 ft thick in the RFD Area, is fluvial at the base and deltaic to marine shore face in upper parts, and includes sandstone, conglomerate, and subordinate interbedded lenticular claystone, carbonaceous mudstone, and coal.

The Mancos Shale, which conformably overlies the Dakota Sandstone, is about 2,000 ft thick in the RFD Area and consists of dark-gray to black, sparsely fossiliferous marine shale containing local thin limestone beds. The unit contains a regional unconformity, with limestone development a function of distance from shore.

The Mancos Shale intertongues with the Mesaverde Group, members of which are named the Point Lookout Sandstone, Menefee Formation, and the Cliff House Sandstone. The Mesaverde Group thins eastward across the area to where individual members are not resolvable. It is about 1,200 -1,500 ft thick in the area around Mesa Verde National Park, about 325-365 ft thick in eastern exposures in the southern part of the RFD Area, and merges into (marine) shales to the northeast.

The Point Lookout Sandstone has a maximum thickness of about 400 ft in the RFD Area; the lower part is made up of thin sandstone and interbedded shale and the upper part of massive sandstone. It was deposited in a variety of shoreline environments during the regression of the Epicontinental Sea toward the east and is transitional with the underlying Mancos Shale.

The Menefee Formation of the Mesaverde Group formed to the southwest or landward of the Point Lookout and the Cliff House Sandstones. It is a complex assemblage of sandstone, siltstone, shale, and coal measures that formed in fluvial, estuarine, and littoral environments and is characterized by extreme irregularity or lenticularity of individual beds. Coals in the Menefee Formation usually are concentrated near the top and base. In the northern part of Mesa Verde National Park, the Menefee is about 340 ft thick, but it thins to the east; its thickness in the RFD Area generally averages 100 ft or less.

The Cliff House Sandstone is a transgressional shallow marine, fine-to medium-grained sandstone that forms cliffs separated by shaly sandstone and siltstone units; it becomes more shaly eastward in the RFD Area. It was formed during transgression of the Epicontinental Sea, largely in shoreface environments along a barrier-island beachfront. The sandstone interfingers laterally and vertically with overlying Lewis Shale and the underlying Menefee Formation.

The Lewis Shale is a dark-gray to black marine shale that ranges from about 1,800 to 2,400 ft in thickness in the RFD Area. It contains a few interbeds of fine-grained sandstone, limestone, calcareous concretions, and bentonite and, like the Mancos Shale, represents fairly deep-water marine sediments.

The Pictured Cliffs Sandstone is a well-sorted, medium-grained sandstone with shaly beds in the lower part. The thickness of the unit is about 200 ft on the east side of the Animas River; it thins to the east and is absent on the San Juan River northeast of Pagosa Springs. The Pictured Cliffs Sandstone was laid down during the final retreat of the Epicontinental Sea from the area and represents deposits made along a prograding shoreline. Rises or northwest-trending benches of the Pictured Cliffs Sandstone, combined with thickness increases, represent temporary stability of the shorelines when sediment supply balanced marine subsidence. In most places the Fruitland Formation directly overlies the Pictured Cliffs, but in the southeastern part of the basin, the Pictured Cliffs Sandstone is thin or absent and the Fruitland Formation locally overlies the Lewis Shale. This implies either nondeposition of the Pictured Cliffs Sandstone or perhaps uplift and erosion of the Pictured Cliffs Sandstone prior to deposition of the Fruitland Formation (Aubrey 1991).

The Fruitland Formation and Kirtland Shale are continental deposits laid down landward of the Epicontinental Sea as it made its final retreat to the northeast. The sedimentary rock types indicate that the sedimentary environments were similar to those of the Menefee Formation.

The Fruitland Formation in the Durango area is about 300 ft thick and along the Los Pinos River as much as 390 ft thick; farther east the Fruitland Formation and the Kirtland Shale thin rapidly. Aubrey (1991) described a thinning of the two formations from the northwestern to the southeastern part of the San Juan Basin and stated that their local absence in the southeast could be the result of either depositional thinning onto a structurally positive area or pre-Tertiary uplift and erosion. The Fruitland Formation is defined as coal bearing, whereas the Kirtland Shale is not; the Fruitland is the most important coal-bearing formation in the San Juan Basin and contains more than 200 billion short tons of coal (Fassett 1989).

The Fruitland Formation consists of an irregularly bedded sequence of sandstone, shale, and coal beds or, more specifically, interbedded sandstone, siltstone, carbonaceous shale, carbonaceous siltstone, carbonaceous sandstone, coal, and thin pelecypod shell limestone. The thickest coal beds are in the lower part of the formation and form a fairly continuous coal-bearing interval or zone, although the individual coal beds are lenticular and cannot be traced far. The thickest Fruitland coal deposits of the San Juan Basin trend toward the northwest parallel to, but southwest of pronounced stratigraphic rises of the Pictured Cliffs Sandstone. The coal beds and associated strata represent coastal-swamp, lagoon, alluvial, and lacustrine deposits inland from the shoreline.

The Kirtland Shale is about 1,200 ft thick near Durango and thins eastward, as mentioned above. The formation is subdivided into an upper and a lower shale member that are separated by a middle sandstone unit, the Farmington Sandstone Member. The formation is considered to be an alluvial deposit, with siltstone and mudstone beds formed as overbank floodplain deposits and sandstones formed as stream channel deposits. The large quantities of feldspar and ferromagnesian minerals and coarse clastic material in the upper member likely indicate deeper erosion of uplifted source areas, perhaps reflecting the beginning of the Laramide Orogeny.

Tertiary clastic deposits overlie Cretaceous rocks (Figure 7). The Animas Formation is the principal Tertiary sedimentary unit in the RFD Area, although the Nacimiento and San Jose formations also occur not far south of the RFD Area boundary. These Tertiary formations contain large amounts of andesitic and other volcanic material. Source areas for andesitic material in the Animas Formation probably included the La Plata Mountains to the north. Metamorphic and granitic material source areas probably included the San Juan and Needle mountains to the northwest and the Brazos-Sangre de Cristo uplift to the northeast (Aubrey 1991). Baltz (1967), Baltz and others (1966), and Smith and others (1985) discuss the stratigraphy and origin of these Tertiary units at length. As they do not play an important role in the energy resources of the RFD Area, they are not discussed further in this report.

4.0 MAJOR OIL AND GAS PLAYS

The RFD Area contains a number of important and productive oil and gas plays, many of which have been extensively explored since the last assessment of the region in the early 1990s. According to the Colorado Oil and Gas Conservation Commission (COGCC 2005) database, as summarized in Table 1 and expanded for the RFD Area in Appendix E, 1339 wells have been drilled in the RFD Area, with 40 percent (533) drilled after 1984. At the end of 2004, there were 502 producing wells, 339 (68 percent) of which were located in the Ignacio-Blanco Coal-bed Methane (CBM) field of Archuleta and La Plata counties. Of the remainder, 31 percent (156 wells) produced conventional oil and gas from the Paleozoic section in Dolores, Montezuma, and San Miguel counties.

Since 1999, an average of 34 new wells have been added annually, equally split between CBM production and conventional oil and gas. In 2004, 331,000 barrels of oil and 89 BCF (billion cubic feet) of gas were produced in the RFD Area, excluding CO_2 production. Carbon dioxide production from three wells in Montezuma County added another 321 BCF to the total gas produced in the Area.

The following discussion is largely taken from the 1994 resource assessment prepared for the San Juan National Forest by the USGS (Huffman and Molenaar, *in* Van Loenen and Gibbons 1994) and the 1995 USGS National Assessment (Huffman 1995a). New potential plays in the RFD Area that have been upgraded in their resource potential in this RFD report include the Entrada play of the northern San Juan Basin Province, and the structural and fractured shale play and Mississippian play in the southeastern Paradox Basin Province.

As defined here, a play is a set of oil or gas accumulations that are geologically, geographically, and temporally related and that exist by virtue of identical or similar geological conditions. The oil or gas accumulations may be known to exist or be completely hypothetical and may be discovered or undiscovered. Geological characteristics as reservoir lithology, timing and migration, trapping mechanisms and source rock, as well as maturation, are taken into consideration in the definition and evaluation of each play. In order to assess the potential oil and gas resources of the RFD Area, this RFD used play analysis methodology and the same plays that were defined and evaluated for the 1995 and 2000 National Assessment (USGS 2005). Figure 9 shows a typical cross-section of conventional oil and gas plays. Estimates of undiscovered oil and gas resources in the RFD Area are derived from the 1995 and 2000 National Assessment of undiscovered oil and gas resources (USGS 2005).

FIGURE 10. Schematic of continuous and conventional oil and gas plays (*from* USGS in GMUG 2004)

The RFD Area includes parts of two major oil and gas provinces, the San Juan Basin Province (Province 022 of the USGS National Assessment) in the east and the Paradox Basin Province (021) in the west (Figure 4). The RFD Area also includes the southwestern part of the lightly explored, but oil productive, San Juan Sag (Figure 11). The San Juan Basin (Figure 12) is the second-largest natural gas field in the United States. Coal-bed methane development in the San Juan Basin Province accelerated during the mid-1980s and is currently the primary focus of natural gas development in the region. The Paradox Basin Province is an important oil and gas producer, and gas production, in particular, has accelerated in the last decade in the RFD Area.

FIGURE 11. The San Juan Sag of south-central Colorado (*from* Gries 1989)

FIGURE 12. Structural elements of the San Juan Basin Province

Because the National Assessment does not provide specific data for the plays in the RFD Area, the resource quantities given below are for the entire San Juan Basin and Paradox Basin provinces rather than the RFD Area. An attempt to proportionate or delineate the specific resources of the RFD Area is presented where appropriate and possible in this RFD report.

According to the 2000 USGS National Assessment, the most likely estimates of undiscovered oil and gas resources in the San Juan Basin Province are 19 MMBO and 50 TCF of gas. Much of the favorable area will be gas prone because of burial depths, source rock type, proximity to intrusive rock heat sources, or various combinations of these. Undiscovered oil resources in the Paradox Basin are larger, 475 MMBO; gas is estimated at 1.5 TCF (trillion cubic feet). Most of these resources in the Paradox Basin are likely to be distributed in small-to-moderate-size accumulations rather than concentrated in a few large ones.

The coal-bed methane area on the eastern side of the RFD Area, in the San Juan Basin Province, likely contains the vast majority of the undiscovered gas resource. Porous carbonate plays on the western side of the RFD Area, in the Paradox Basin Province, will likely account for additional undiscovered oil. New gas also will come from Paleozoic plays in the eastern Paradox Basin Province; Mississippian and Devonian rocks on the western side of the RFD Area both probably have some potential, but the magnitude is uncertain due to the presence and percentage of CO_2 in the natural gas and the likelihood of increased CO_2 percentages in the vicinity of the Laramide age and younger intrusives. No probability for the occurrence of CO_2 as opposed to natural gas is made in this RFD report.

4.1 SAN JUAN BASIN PROVINCE

Introduction

Oil and gas development is extensive in the San Juan Basin Province, with over 26,000 wells currently in operation by dozens of companies. Within the Colorado part of the San Juan Basin

Province, there are approximately 2,500 wells in operation (SJPL 2004). Within New Mexico, the Resource Management Plan for the Farmington Resource Area projects development of 9,900 new wells over the next 20 years, drilled at a rate of about 500 wells per year (Engler et al. 2001). At the end of 2004, about 330 coal-bed methane (CBM) and five non-CBM conventional oil and gas wells were producing in the San Juan Basin part of the RFD Area (Table 1), along with about six water disposal wells (SJPL 2004). Since 1999, an average of 17 new wells have been drilled each year in the San Juan Basin part of the RFD Area (Table 1).

Plays in the San Juan Basin Province are defined primarily on the basis of stratigraphy because of the strong stratigraphic controls on the occurrence of hydrocarbons throughout the San Juan Basin. In general, the plays correspond to lithostratigraphic units containing good quality reservoir rocks and having access to mature source beds. Around the flanks of the Basin, structure and stratigraphy are the key trapping factors.

4.1.1 Stratigraphic Framework of the San Juan Basin Province

At least 5,000 ft of Cretaceous strata once blanketed the region of southwestern Colorado and adjacent states. As described in the previous section and summarized in Figures 7 and 9. These Cretaceous units are well preserved in the San Juan Basin Province, the northern part of which lies in the RFD Area. The Animas and San Jose formations that later filled the San Juan Basin and partially cover the Cretaceous rocks were formed by the deposition of sediments transported from the uplifted area to the north during and after the structural formation of the Basin.

Many of the structural features of the San Juan Basin Province formed at the end of the Cretaceous and in the early Tertiary, during a series of events collectively termed the Laramide Orogeny. Erosion of rocks in some places and deposition of sediments in others occurred during and since the Laramide events. This, in combination with extensive intrusion and extrusion of Tertiary magmas over older rocks and strata, has had the net effect of considerably reducing the coverage and exposure of the Cretaceous rocks in the RFD Area.

4.1.2 Geologic Structure of the San Juan Basin Province

The San Juan Basin is an asymmetric basin about 200 miles long (north-south) and 130 miles wide (east-west) that is filled with sedimentary rocks (Figure 12). The deepest part of the basin, near the Colorado-New Mexico state line, contains up to 15,000 feet of sedimentary rocks (Huffman 1995a). The Cretaceous section is exposed near the northern margin of the Basin in a series of outcrops that extend 90 miles across southwestern Colorado. As noted in Section 3, a number of tectonic events have taken place in the region since Cretaceous time, both modifying preexisting structures and earlier sedimentary basins (e.g., the Uncompahgre uplift and the Paleozoic Paradox Basin) and creating new ones (e.g., the San Juan Uplift, the San Juan Sag, and the San Juan Basin). The successive overstepping of the Animas, Nacimiento, and Wasatch-San Jose beds on the northern edge of the San Juan Basin near the Colorado-New Mexico border suggests that the San Juan Basin was outlined in late Cretaceous time and mostly formed in Paleocene time (Baltz 1953; Kelley 1955; Fassett and Hinds 1971; Fassett 1985). Figure 12 shows some of the more prominent structural features of the area around the RFD Area.

Major monoclinal folds bound and define many parts of the San Juan Basin. Minor folds occur throughout the Basin and are especially apparent where the regional dip changes, such as near the Hogback monocline and at the periphery of the Basin floor (Woodward et al. 1997). Natural fractures (joints and cleats) are widespread in Cretaceous and Tertiary rocks of the Basin (Laubach and Tremain 1994b) and consist of local fractures of tectonic origin and fractures caused by compaction that occurred as coal formed (Ayers et al. 1994). Ayers and Kaiser (1994) and Woodward and others (1997) describe the structural setting of the San Juan Basin part of the RFD Area in more detail.

Local folds form structural traps for oil, gas, and coal bed methane. Localized structural deformation caused fractures that may offset reservoirs or may become reservoirs themselves. Fractures that formed during folding may enhance reservoir permeability (Gorham et al. 1979; DuChene 1989). These minor folds and faults caused fractures that may enhance the movement of water and gas through reservoir or source lithologies or may offset them against rocks with lower permeability and impede the movement of gas or water. Ayers and Zellers (1994) evaluate the impact of basin structures on the occurrence of coal-bed methane. Structural influences on the major plays are discussed in Section 5.

Laubach and Tremain (1994a) describe fracture patterns in the northwestern part of the San Juan Basin. Along the northwestern margin of the Basin, the west-northwest and northeast trends of fracture zones may coincide with permeability that is greater in the direction of cleat orientation than in other directions. Locally, prominent fractures in the Pictured Cliffs Sandstone extend into overlying Fruitland coal seams, where they are marked by more fractures with better interconnections and small normal faults. Permeability may be enhanced in these areas.

Structural features in the Cretaceous strata that could affect movement of water or gas were considered in the 3M CBM model (Questa 2000) when their existence could be demonstrated by evidence or inferred through multiple reasons. No structural features were added to Questa's model in the RFD Area. Structural features occurring outside the RFD Area, including the Valencia Canyon and 44 Canyon faults southwest of Durango, may compartmentalize coal reservoirs near the northwestern margin of the Basin and impede movement of water and gas (Ayers and Kaiser 1994; Applied Hydrology Associates 2000).

The only basement fault shown in the southernmost RFD Area, which exhibits a surface trace of about 6 miles occurring along a west-northwest trend near Bayfield (Taylor and Huffman 1998), is not expressed in Cretaceous strata. Other regional geology maps do not show any faults in the

RFD Area (Steven et al. 1974; Green 1992; Van Loenen et al. 1997; Day et al. 1999). The locations where drainages cut through the Hogback monocline may represent the surface traces of faults. These locations include the Los Pinos River, Animas River, Florida River, Texas Creek, and Piedra River. However, published geologic maps, such as Fassett and others (1997), do not show any mapped faults.

In the southeastern part of the RFD Area, the northwest-trending Archuleta Anticlinorium separates the San Juan Basin from the San Juan Sag east of Pagosa Springs (Figure 11). Much of this area is covered by the San Juan volcanic field of the San Juan Mountains and includes part of the San Juan Sag play of Gries (1989).

4.1.3 Summary of Plays in the San Juan Basin Province

The detailed resource potential of the San Juan Basin Province in the RFD Area is discussed below by play and summarized in Table 3. The mature source rocks, which delineate the area of higher oil and gas resource potential, are shown on Figure 13.

FIGURE 13. Clastic oil & gas system for the RFD Area

Table 3. Summary of resource potential of the San Juan Basin Province in the RFD Area (Appendix H)

Conventional oil and gas exploration and development in the San Juan Basin part of the RFD Area is largely found in the Ignacio-Blanco field (Figure 2), which produces from the Dakota Sandstone, Fruitland Formation, Pictured Cliffs Sandstone, and the Mesaverde Group. The field was discovered in 1950. The Dakota Sandstone, Mesaverde Group, and Pictured Cliffs Sandstone are the principal producing horizons and typically yield dry gas with small quantities of produced water and associated hydrocarbon liquids (BLM et al. 2000). By 1995, the Dakota Sandstone had produced 279 BCF of gas. Production from the Dakota Sandstone reached its peak in 1996, but this formation may still have potential for limited development. The Mesaverde Group produced 678 BCF of gas and 40,000 barrels of condensate from 1952 to 1995. Wells completed in the Pictured Cliffs Sandstone, which includes the Pictured Cliffs Sandstone and Fruitland Sand, produced 88 BCF through 1995 (BLM et al. 2000). Current production is limited to small amounts of oil (Table 1). As of December 2001, 13 active conventional gas wells existed in this part of the RFD Area in the Ignacio-Blanco field (SJPL 2004).

The majority of the gas produced from the RFD Area, excluding CO_2 production from McElmo Dome in Montezuma County, comes from the Ignacio-Blanco CBM field. In 2004, 339 wells produced 65 BCF of gas from the Fruitland Coal.

4.1.4 Dakota Play

The southeastern part of the RFD Area lies within the northern part of the Dakota oil and gas play of the San Juan Basin and the southern part of the Dakota oil and gas play of the San Juan Sag (Figure 11). This play is in shallow marine sandstone and continental fluvial sandstone units, primarily within the transgressive Upper Cretaceous Dakota Sandstone. In the basinal part of the San Juan Basin it is a gas play, in which the traps are dominantly stratigraphic and the reservoirs are tight; on the flank of the Basin it is an oil and gas play, in which the traps are typically both stratigraphic and structural and the reservoirs are generally conventional. The Basin flank play lies within the southeastern part of the RFD Area.

Reservoirs

Within the RFD Area, the Dakota is 150-200 ft thick. It ranges from surface outcrop at the Basin flank to about 6,000 ft in depth, with reservoir depths commonly between 1,000 and 3,000 ft. In the central part of the San Juan Basin, reservoir quality within the Dakota producing interval is highly variable. Most of the marine sandstones within the Dakota of the central part of the Basin are considered “tight,” having porosities ranging from 5 to 15 percent and permeabilities generally less than 0.1 millidarcies (md). Fracturing, both natural and induced, is essential for effective development. In contrast, a conventional reservoir such as the Gramps field, on the southern flank of the San Juan Sag in the eastern part of the RFD Area (Figure 11), has an average reservoir porosity of 13 percent and permeability of about 100 md. Permeabilities elsewhere may be as high as 400 md. Oil production ranges in depth from 1,000 to 3,000 ft.

Source Rocks

Source beds for Dakota oil and gas are in the marine shales of the overlying and intertonguing Mancos Shale and carbonaceous shale and coal of the Dakota Sandstone, as well as the Menefee Formation (Ross 1980).

Timing and Migration

Depending on location, the Dakota Sandstone and lower Mancos Shale entered the oil window during the Oligocene to Miocene. In the southern part of the RFD Area, migration was still taking place in the late Miocene or even more recently (Huffman 1995a).

Traps

Most of the oil production from the Dakota Sandstone is from stratigraphic or combination traps on the northern flank of the San Juan Basin in the RFD Area. Stratigraphic traps are typically formed by up-dip pinchout of porous sandstone into shale or coal. Structural traps on faulted anticlines likely form some of the larger fields in the play. The seal is commonly provided by either marine shale or paludal (marshy) carbonaceous shale and coal and (or) permeability barriers in sands.

Exploration status and resource potential

Most of the Basin flank oil fields are small, that is, less than one MMBO, but approximately 30 percent of the fields have an estimated ultimate recovery exceeding one MMBO (Van Loenen and Gibbons 1994).

4.1.5 San Juan Sag Play

The San Juan Sag is a foreland basin adjacent to and west of the San Luis highland and northeast of the San Juan Basin (Figure 11). The Sag formed during the late Laramide Orogeny and was modified by rifting in the middle Tertiary (Gries 1989). Thick deposits of Oligocene volcanic rocks of the San Juan volcanic field have concealed the Sag, which was discovered by exploratory drilling in the early 1980s.

The largest field in the San Juan Sag is the Gramps field, which produced just over 7 MMBO (Huffman 1995a) before ceasing production in the late 1990s. About 15 billion cubic feet of associated gas was produced through 1990 (Van Loenen and Gibbons 1994). The Gramps field is on the faulted crest of an asymmetrical anticline and has produced from the Dakota at a depth of about 1,100ft. Dakota oil at the Gramps field is characterized as intermediate paraffinic with an API gravity of 31.4° and a pour point of 60° (Donovan 1978). Noteworthy shows noted in drilling associated with the field occur in the Cretaceous Bridge Creek Limestone Member of the Mancos Shale, the Jurassic Morrison Formation and Entrada Sandstone. Because this field exemplifies a potential resource area that may extend below the volcanic rocks on the eastern side of the RFD Area, it is discussed in more detail below. The Gramps field is now inactive, with its wells abandoned or plugged.

Reservoirs

The main objective of most tests in the San Juan Sag play was the Dakota Sandstone, although the thick eolian Jurassic Junction Creek and Entrada sandstones were secondary objectives (Figure 14). Many of the tests had good oil and gas shows in igneous sills and fractured Cretaceous shales. For a few months, a fractured igneous sill in the Mancos Shale was a marginal producer before it was abandoned.

FIGURE 14. Stratigraphic column for the San Juan Sag region (*from* Gries 1989)

Source Rocks

The best source rocks are undoubtedly in the lower part of the Mancos Shale.

Timing and Migration

Depending on location, the Dakota Sandstone and lower Mancos Shale entered the oil window during the Oligocene to Miocene. In the southern part of the RFD Area, migration was still taking place in the late Miocene or even more recently (Huffman 1995a).

Traps

Most of the oil production from the Dakota Sandstone is from stratigraphic or combination traps. Stratigraphic traps are typically formed by up-dip pinchout of porous sandstone into shale or coal. Structural traps on faulted anticlines form some of the larger fields in the play. The seal is commonly provided by either marine shale or paludal (marshy) carbonaceous shale and coal and (or) permeability barriers in sands or by igneous features such as Tertiary dikes and sills.

Exploration Status and Resource Potential

This industry play was based on traps, primarily in Cretaceous rocks, below the San Juan volcanic cover. Oil seeps and staining in surface igneous rocks and in mining company cores in the Sag area, which have been known for many years, caught the attention of petroleum geologists in the oil-boom years of the early and middle 1980s. Prior to the inception of the industry's San Juan Sag play, Ryder (1985) discussed the petroleum potential of the South San Juan Mountains wilderness area, which covers much of the easternmost RFD Area.

About 12 tests were drilled by industry in this play in the 1980s; the last one was drilled in 1990. All the wells were drilled east of the RFD Area; most of the wells were along the eastern foothills of the San Juan Mountains in the Del Norte area. Hydrocarbon shows encountered in many of the test wells, as well as several surface indications of oil in igneous rocks and the oil found in igneous rocks in some mining company cores, indicated that there are mature hydrocarbon source rocks in the system. Therefore, it seems reasonable to assume that the area has potential for oil and gas accumulations. The large oil and gas production from the Gramps field confirms this assumption.

Although the area of the San Juan Sag and the easternmost part of the RFD Area has good potential for containing hydrocarbon accumulations, the favorable factors are offset by the difficulties in finding the traps. Some of the problems in this high-risk area are:

- High rugged terrain makes seismic surveying very difficult and expensive. Many of the seismic surveys have been conducted with helicopters, and costs are $40,000 to $50,000 per line mile.
- The quality of the seismic data is poor. As the thickness of volcanics increases in the San Juan Mountains, the seismic quality decreases.
- The many igneous sills in the area are difficult or impossible to detect on seismic. The last Amoco well, the Beaver Mountain Unit No. 1, encountered a 600-ft-thick sill that was intruded into the Dakota Sandstone. It had about the same seismic velocity as the Dakota.

- The igneous activity has locally baked the adjacent shales into hornfels. Maturation of the source rocks ranges from the oil-generating range to super mature.
- The area of the San Juan Sag seems to be highly faulted under the volcanic cover, likely related to early Tertiary igneous activity and late Tertiary activity along the Rio Grande rift. There is 3,334 ft of apparent fault relief of between wells 2 miles apart south and southeast of South Fork.

In summary, the San Juan Sag play in the southeastern part of the RFD Area, where covered by volcanics in the rugged San Juan Mountains, has good potential for containing hydrocarbon accumulations. However, finding them would be costly and difficult. The structure, maturity, and proximity of shows and production from the Dakota play make the likelihood of an occurrence similar to Gramps field very high, and there is a possibility of several similar accumulations being present under the volcanic rocks along the eastern side of the RFD Area, particularly in the southern part of the San Juan Sag and those areas of the extreme southern part of the San Juan Sag near Pagosa Springs that are not covered by volcanics. The USGS assigned a most likely value of 10 MMBO and 9 billion cubic feet of associated gas distributed between two or more fields (Van Loenen and Gibbons 1994); these values have been retained in this RFD report. Table 4 summarizes the resource potential of the San Juan Sag play.

Table 4. Summary of Resource Potential of the San Juan Sag Play in the RFD Area (Appendix H)

4.1.6 Mesaverde Oil Play

The Mesaverde oil play is a confirmed oil play around the margins of the central San Juan Basin Province. Except for the Red Mesa field on the Four Corners platform, field sizes are very small. The play usually depends on intertonguing of porous marine sandstone at the base of the Upper Cretaceous Point Lookout Sandstone with the organic-rich upper Mancos Shale, and fluvial, non-marine channel sands that also trap hydrocarbons.

Reservoirs

Porous and permeable marine sandstone beds of the basal Point Lookout Sandstone provide the principal reservoirs. The thickness of this interval and of the beds themselves may be controlled to some extent by underlying structures oriented in a northwesterly direction.

Source Rocks

The upper Mancos Shale intertongues with the basal Point Lookout Sandstone and has been positively correlated with oil produced from this interval (Ross 1980). API gravity of Mesaverde oil ranges from 37º to 50º.

Timing

Around the margin of the San Juan Basin, the Mancos Shale entered the thermal zone of oil generation during the Oligocene.

Traps

Structural or combination traps account for most of oil production from the Mesaverde. Seals are typically provided by marine shale, but paludal sediments or even coal of the Menefee Formation may also act as the seal.

Exploration status and resource potential

The only important Mesaverde oil field, Red Mesa (adjacent to, but outside the RFD Area), was discovered in 1924. Future discoveries are likely to be small. No resource potential is assigned to the thinning Mesaverde play in this RFD.

4.1.7 Fractured Mancos Shale Play

In the 1989 San Juan Basin assessment, the fractured Mancos Shale play, as used here, was included in the Tocito-Gallup play (Powers 1993) because the New Mexico Oil and Gas Commission, for recordkeeping purposes, considers all producing zones from the top of the Bridge Creek Limestone Member of the Mancos Shale (formerly Greenhorn Limestone Member) to the base of the Mesaverde Group as the Gallup interval. With the exception of the several fields producing from fractured Mancos Shale, nearly all production from this thick and rather nebulous interval has been from the Tocito Sandstone Lentil of the Mancos Shale, the Torrivio Member of the Gallup Sandstone, and the fractured El Vado Sandstone Member. These sandstone reservoirs are all in the central and southern parts of the San Juan Basin Province and do not occur in the RFD Area. In the northern part of the Basin, the lithology of this interval, which is about 1,800 ft thick, is dominantly dark-gray marine shale. Hence, in the northern part of the Basin and in the RFD Area, this is the fractured Mancos Shale play (Figure 13). Actually, much of the upper part of the lower half of the interval contains thin-bedded, very fine grained, dolomitic or calcareous sandstone or siltstone, which is the part that comprises the potential fractured reservoir. Huffman (1995a) considers the fractured Mancos Shale play to be a confined, unconventional, continuous-type play.

Several fields, including the East and West Puerto Chiquito and the Boulder Mancos on the east and Verde Gallup on the west side of the San Juan Basin Province of New Mexico, have been developed in fractured Mancos Shale of the El Vado Sandstone Member.

Reservoirs

The reservoirs consist of fractured shale and interbedded coarser clastic intervals at approximately the Tocito Lentil stratigraphic interval.

Source rocks

The Mancos Shale generally contains 0.5 - 3 weight percent organic carbon and produces a sweet, low sulfur, paraffin-base oil that ranges from 38° to 42° (API) gravity in the Verde field (8 MMBO), and from 34° to 40° API gravity in the Puerto Chiquito East (4.5 MMBO), Puerto Chiquito West (9 MMBO), and Boulder (2 MMBO) fields.

Timing

The Mancos Shale of the central part of the San Juan Basin Province reached thermal maturity for oil generation in the late Eocene and for gas in the Oligocene.

Traps

All of the fractured shale fields are on or adjacent to monoclinal or anticlinal structures that form the structural boundary of the central part of the San Juan Basin Province. The same types of structures occupy much of the RFD Area between Durango and Pagosa Springs, and similar conditions are likely to exist in this area. Dips of 10° to 15° do not appear to be too steep; much of the production in the Verde and Boulder fields is from shale dipping at similar angles. Nearby, the Chromo field (Figure 2) indicates that conditions favorable for the occurrence of fractured Mancos oil do in fact extend into the southeastern part of the RFD Area.

Exploration status and resource potential

It is very likely that an oil and gas field similar to the Boulder field (2 MMBO) exists within the RFD Area, and it is possible that a Puerto Chiquito-size field (9 MMBO) is present. Van Loenen and Gibbons (1994) assigned a most likely value of 3 MMBO and 3 billion cubic feet of associated gas to this play based on the presence of favorable structures and source rocks; these values has been retained in this RFD report. There is a higher likelihood that oil and gas would be distributed between two or more smaller fields than in a single large field.

4.1.8 Coal-bed Gas Resources

Coal-bed methane (CBM) is a by-product of the evolution of plants into coal. The influence of heating and pressure when organic debris is buried beneath thousands of feet of sediments causes CBM and coal to form. CBM is contained in and adsorbed to the coal until removal of groundwater reduces the pressure within the coal bed, liberating CBM. Fassett (1989), Ayers and others (1994), Rice (*in* Van Loenen and Gibbons 1994, p. 130-131), and Rice and Finn (1995) present the regional geologic framework and coal-bed gas potential of the Fruitland Formation in the San Juan Basin Province, the largest source of CBM in the RFD Area.

Reservoirs and source rocks

CBM occurs where the coal bed serves as both the source rock and the storage reservoir for methane gas. Methane is the primary component in CBM that is produced from the RFD Area in the San Juan Basin Province; however, water, carbon dioxide (up to 13 percent), wet gasses (up to 23 percent of gas such as ethane, propane, and butane), nitrogen (up to 11 percent), and liquid hydrocarbons are also present in smaller quantities (Rice and Finn 1995; BLM et al. 2000). Coal beds found within the Fruitland Formation are considered the most important reservoirs for development of CBM within the San Juan Basin Province. Fruitland coals are present throughout the subsurface of the Basin to a maximum depth of slightly more than 4,000 feet (Fassett et al. 1997). The Menefee Formation also contains coals that may yield CBM, but the Menefee coals are generally thinner, more discontinuous, and dispersed over a greater stratigraphic interval (Rice and Finn 1995). They are also deeper. Only limited production has been recorded in the Menefee Formation when compared with the Fruitland Formation (BLM et al. 2000).

Character of coal and coal-bed gas

Coal beds are widespread in the lower part of the Fruitland Formation throughout most of the San Juan Basin. The following data are from M'Gonigle and Roberts (in Van Loenen and Gibbons 1994, p. 110 – 129) and Rice and Finn (1995). In the RFD area, the total thickness of Fruitland coal beds individually greater than 1.2 ft thick ranges from about 35 to 50 ft. The coal resources are estimated to be about 6,170 x 106 short tons in the RFD Area. The Fruitland coal beds generally dip steeply to the southwest along the Hogback monocline into the main part of the San Juan Basin (Figure 12). The coalbeds crop out along the northeastern flank of the Basin and occur at depths in excess of 4,000 ft, their deepest present-day depth of burial in the Basin. The rank of the Fruitland coals in the RFD Area increases to the southwest from high volatile A bituminous to medium volatile bituminous [vitrinite reflectance (Ro) values of 0.8 to 1.2 percent] (Rice 1983; Law 1992). The area of highest rank does not coincide with the area of maximum present-day depth of burial. Regional trends suggest that the coal-bed gases in the RFD Area are composed mainly of methane (gas wetness (C2+) values less than 3 percent) with some carbon dioxide (less than 6 percent) (Rice et al. 1989; Scott et al. 1991). The molecular and isotopic composition of the gases indicates that the coal-bed gases are mainly thermogenic with mixing of some relatively recent biogenic methane and carbon dioxide associated with groundwater flow (Scott et al. 1991).

Gas production

Production rates for individual wells are highly variable and range from 50 to 15,000 MCF/day. Vertical open-hole cavity wells commonly produce 10 times more gas than those completed by hydraulic fracturing. However, successful open-hole cavity completions are generally restricted to a northwest-trending area referred to as the “Fairway,” located north of the structural hingeline in the RFD Area. Cavity wells in the Fairway are successful because of artesian overpressuring and high permeability; open-hole cavity completions have not been successful in other CBM basins. Coal-bed gas wells commonly exhibit a distinctive production history because of the relation between gas and water production (Kuuskraa and Brandenberg 1989). In general, large volumes of water and small volumes of gas characterize the early stage of production from a well, the dewatering stage. As dewatering depressurizes the coalbed reservoir, increasing amounts of gas begin to desorb, diffuse through the matrix, and flow through the cleats to the well bore. A "negative decline" curve for water is maintained during the dewatering and stable production stages, whereas the decline stage for gas begins at the end of the stable production stage.

Traps and factors affecting development of coal-bed resources

Three factors present-day depth of burial of coals, water, and topography—influence the development and production of the CBM resources in the RFD Area. Although most of the Fruitland coal beds contain large quantities of commercial gas at depths greater than about 500 ft, commercial production of the gas depends on the development of permeability, which occurs mainly in the cleat (fracture) system. This cleat-associated permeability is strongly influenced by in-situ stress or depth of burial, such that there is a general decrease in permeability with increasing depth of burial (McKee et al. 1988). Current production of Fruitland CBM in the San Juan Basin Province extends to depths of about 3,000 ft. In the southern part of the RFD Area, the effect of an additional 2,000 ft of overburden (total of 5,000 ft) on permeability of the coals and thus economic production of coal-bed gas is unknown.

The Fruitland coals are aquifers in the RFD Area and are in an area of recharge characterized by the influx of high amounts of relatively fresh water, as indicated by low total dissolved solids and low chlorinity (Kaiser et al. 1991a). This recharge is probably the result of high rainfall in the La Plata and San Juan mountains to the north, and tectonically enhanced cleats in relatively continuous coals that crop out in this area. The southward flow of groundwater into the Basin has resulted in artesian overpressuring and production of large amounts of water from the coal beds in the northern part of the Basin (Kaiser et al. 1991b). The disposal of this produced water affects the economical development of the CBM resources and poses an environmental concern. Under the control of Federal, State, and local agencies, most of the produced water in the northern San Juan Basin Province is disposed of in underground injection wells (Zimpler et al. 1988). In addition, the water from individual wells must also be transported to these injection wells by truck or pipeline.

As much as 2,500 ft of relief is present in that part of the RFD Area with potential for CBM. The lower elevations are mainly in the drainage areas of the Los Piños and Piedra rivers where most of the development of CBM has taken place to date. The highest elevations are present in the area of Pargin Mountain about 10 mi east of Bayfield in central part of the area of CBM development. Development of CBM resources, including siting and drilling of wells and construction of roads and pipelines, is commonly restricted in forested areas with steep slopes. In addition, the topographically high areas coincide with areas of maximum burial depths of the Fruitland coal beds. As stated earlier, this increased depth has the effect of reducing both permeability and gas production rates.

Exploration status and discovery potential

The first CBM wells in the San Juan Basin Province were drilled into the Fruitland and Menefee formations in 1948, and production was first recorded in 1951. Until the mid-1980s, inadequate technology for extraction of coal gas and the lower heating value (BTU) made CBM from the Fruitland Formation uneconomical to develop (BLM et al. 2000). Widespread CBM development began in the mid-1980s, after the Crude Oil Windfall Profits Tax provided tax incentives for operators to overcome technical problems associated with production of CBM (BLM et al. 2000).

Approximately 1,000 CBM wells were drilled in the Colorado part of the San Juan Basin Province by 1999, including new wells and conventional gas wells plugged and recompleted in the coal beds of the Fruitland Formation. As of December 2004, about 330 active or approved CBM wells target the Fruitland Formation in the RFD Area or have commingled production from the underlying Pictured Cliffs Sandstone and the Fruitland coals (Table 1).

On the basis of hydrology, pressure regime, reservoir properties, and hydrocarbon composition, three subplays are identified for the Fruitland CBM by the USGS: 1) San Juan-Overpressured Play, 2) San Juan-Underpressured Discharge Play, and 3) San Juan-Underpressured Play (Rice and Finn 1995).

The San Juan-Overpressured Play (National Assessment code 2250) is in the north-central part of the San Juan Basin Province in the RFD Area, where recharge of relatively fresh water takes place. The coals are generally thick (>10 ft) and laterally extensive in northwest-trending bands. The coals are generally of high rank (as much as medium-volatile bituminous), have high gas contents, and are characterized by high formation pressures (greater than 0.5 psi/ft). The coalbed gases are relatively dry (heavier hydrocarbons less than 3 percent) and contain considerable amounts of CO_2 (3-12 percent). Although depths of burial extend to 4,200 ft, the Fruitland Coal in a large part of this play is at depths of less than 3,000 ft. Within this play is the very productive Fairway trend. The average daily gas production for wells in this play during their most productive year ranges from less than 30 MCF/day to more than 3,000 MCF/day, and the highest rates were in the Fairway trend. Because of recharge of fresh water on the north margin, most wells produce water and must be dewatered to initiate desorption and production. Because of the high productive capacity of wells in this play, the prime areas have been explored and developed (Cedar Hills, Ignacio-Blanco, and Basin Fruitland coal fields). The potential for additional reserves from this play is considered to be good; however, the areal extent of this potential is limited because of previous development. The 2002 National Assessment estimates a known resource of 15 TCF of gas for the Fairway CBM and an undiscovered resource of 4 TCF of CBM (USGS 2005).

The San Juan-Underpressured Discharge Play (code 2252) is south of the structural hingeline in the southwestern part of the Basin where the coal beds are underpressured (0.3 to 0.4 psi/ft). The area is characterized by regional groundwater convergence and discharge. The groundwater is a NaCl type and has a higher chloride content than that of the overpressured play. Coals may be as thick as 10 ft and the thickest coals are in northeast trends. Compared to the overpressured play, coal rank is lower (high-volatile B bituminous and lower) and gas contents are lower. The gas is chemically wet (heavier hydrocarbons generally more than 5 percent) and contains less than 1.5 percent CO_2. During early months of production, the coals of high-volatile B bituminous rank produce some waxy oil. Depths of burial are less than 3,000 ft, and production is commonly water free. The average daily production of wells in this play during their most productive year ranges from 30 to 300 MCF/day.

The potential for undiscovered CBM in this play is good to fair. Similar to the overpressured play, extensive drilling and production (Basin Fruitland coal-bed gas field) have taken place in this play, and the remaining potential for reserves is mainly at shallower depths (less than 1,500 ft) in the southwestern part of the play. The 2002 National Assessment estimates a known resource of 155 BCF for the Basin CBM and an undiscovered resource of 19 TCF of gas (USGS 2005).

The San Juan-Underpressured Play (code 2253) is in the eastern part of the Basin where groundwater flow is slow. The produced waters are a NaCl type and similar to seawater. Coal beds are generally thin and gas content is low, particularly in the eastern part. Minor production has been established and rates are low (average annual production in the range of 1-3,000 MCF) with little or no water production. Depths of burial (500-4,000 ft) and coal rank (sub-bituminous to medium-volatile bituminous) are variable and generally increase to the north. The potential for additional reserves from this play is only fair because of underpressuring and low permeability. No specific estimates of the known or undiscovered resource have been made in the National Assessment, and none are given in this RFD.

CBM resource estimates

The part of the RFD Area in the northern part of the San Juan Basin Province (Figure 13) is considered to have major future potential for additional CBM resources in the Upper Cretaceous Fruitland Formation, with the coal-beds serving as both the reservoir and source rock. Although coal beds are present in the Upper Cretaceous Menefee Formation of the Mesaverde Group, they are not evaluated in this RFD because of the thinness of the coal beds and because no commercial production has been established. However, the Menefee coals are considered to be the probable source for some of the gas in adjacent low-permeability sandstone reservoirs of the Mesaverde Group.

Estimates of in-place gas resources in the Fruitland coal beds in the San Juan Basin Province have been made using information on thickness, areal extent, density/rank, and gas content of the coal beds (USGS 2005). Estimates for in-place CBM resources within the San Juan Basin Province include 50 TCF in the Fruitland Formation and 34 TCF in the Menefee Formation (BLM et al. 2000). According to the USGS (2005), the latest (2002) USGS National Assessment yields 24 TCF of known CBM resource in the San Juan Basin Province and another 50 TCF in undiscovered gas (USGS 2005), including 4 TCF in the Fairway area, 20 TCF in the Basin Fruitland, and 660 BCF in the Menefee Formation. Questa Engineering corporation estimates about 1.1 TCF of recoverable gas in the HD Mountains (Questa 2002).

4.1.9 Tight-Gas Resources

The following discussion is largely taken from the previous resource assessment done for the San Juan National Forest by the US Geological Survey (Spencer and Wandrey, *in* Van Loenen and Gibbons 1994). It is included for completeness, as there is very little current production in the RFD Area from this source and a low probability that future development will occur in this reservoir in the RFD area, particularly given the huge CBM resource.

Reservoirs

Tight-gas (very low permeability) reservoirs are present in a small area of the RFD Area in eastern La Plata and western Archuleta counties (Figure 13). The rocks containing tight gas include the Dakota Sandstone, the Juana Lopez Member (Sanostee of industry usage) of the Mancos Shale, the Mesaverde Group, and Pictured Cliffs Sandstone, all of Late Cretaceous age. In the San Juan Basin Province, most designated tight-gas reservoirs are deeper than 5,000 ft, although some wells less than 5,000 ft in Upper Cretaceous Pictured Cliffs Sandstone have been certified as “tight” in the New Mexico part of the Basin.

Resource Potential

According to Dutton and others (1993), only two formations, the Dakota Sandstone and the Mesaverde Group, are believed to have potential for any tight-gas production in the RFD Area. Of these, the Dakota has the better potential. Generally, the conventional (not tight) Dakota Sandstone wells have produced gas in economic quantities. The few producing Mesaverde wells near the RFD Area are poor. Many of the tight-gas designated wells that produce from the Dakota appear to be marginally commercial or uneconomic at gas prices of $2.00 per MCF or less, but may be economic today.

According to Van Loenen and Gibbons (1994), there are approximately 36 well locations in the RFD Area that could produce about 0.5 billion cubic feet (BCF) each, for a most likely recoverable resource of 18 BCF. The most likely probability will result in a recoverable volume of gas from the RFD Area of 6 BCF (95 percent probability) and a least likely (5 percent probability) of 40 BCF. Their estimate is retained in this RFD, with the codicil that production in the next 15-20 years will be limited because of the more productive CBM source in the RFD Area.

4.1.10 Entrada Play

The Entrada play is associated with relict dune topography on top of the eolian Middle Jurassic Entrada Sandstone and is based on the presence of organic-rich limestone source rocks and anhydrite in the overlying Todilto Limestone Member of the Wanakah Formation. North of the present producing area in the southern San Juan Basin Province, in the deeper, northeastern part of the Basin, porosity in the Entrada decreases rapidly (Vincelette and Chittum 1981). Compaction and silica cement make the Entrada very tight below a depth of 9,000 ft.

The southern part of the RFD Area lies across the northernmost part of the Entrada oil play (Figure 13). Although to date the Entrada play has produced only on the Chaco Slope (Figure 12) in the southern part of the San Juan Basin Province, there is also recognized potential for oil and gas production from this play on the northern flank of the Basin where the Jurassic Entrada is directly overlain by the Todilto Limestone and in turn is capped with anhydrite.

Reservoirs

Some of the Entrada relict dunes are as thick as 100 ft but have flanks that dip only 2°. Dune reservoirs are composed of fine-grained, well-sorted sandstone, massive or horizontally bedded in the upper part, and thinly laminated, with steeply dipping cross bedding, in the lower part. The porosity of the buried dunes with their well-sorted and well-rounded clean quartz sand grains makes excellent reservoir rocks. Porosity values are in the high 20 -26 percent range. Permeability ranges from 150 to over 300 millidarcies. The oil is black paraffin based 32° to 36° gravity crude with little or no associated gas. Its chemistry is unique to the organic material in the Todilto limestone, which is the source of all the oil found in the Entrada fields in the Basin. Pour point is approximately 50°. Water saturations are in the 50 percent range. Average net pay in developed fields in the southern San Juan Basin Province is 23 ft.

Source rocks

After the deposition of the Jurassic dune fields, a large fresh to brackish water body called Lake Todilto flooded the low lying dune field in the Four Corners area. The lake was probably connected periodically with a Jurassic seaway that lay to the north. As the water evaporated from the lake, which was rich in fish and algal material, first organic rich carbonate was deposited and then, as the waters became more saline, laminated anhydrite and black limestone stringers and eventually pure anhydrite were deposited over the top of the buried dune field. These later evaporite beds both covered and draped over the underlying dunes. Limestone in the Todilto Limestone Member is the source of Entrada oil according to Ross (1980). There is a reported correlation between the presence of organic material in the Todilto Limestone and the presence of the overlying Todilto anhydrite (Vincelette and Chittum 1981). This association limits the source rock potential of the Todilto to the deeper parts of the depositional basin in the eastern San Juan

Basin Province. Elsewhere in the basin, the limestone was oxygenated during deposition and much of the organic material destroyed.

Timing and migration

When the San Juan Basin was formed by downwarping during the Laramide Orogeny, the organic-rich Todilto limestone began to generate oil in the deeper part of the Basin. This generation accelerated and continued into the lower Tertiary as the central Basin was buried by the lower Tertiary clastic sediments. Migration of the generated oil took place as the hydrocarbons moved into the porosity of the underlying Entrada dunes that were sealed by the overlying limestone and anhydrite. In the eastern part of the basin the Todilto entered the oil generation window during the Oligocene (Huffman 1995a). Migration into Entrada reservoirs either locally or up dip to the south probably occurred almost immediately; however, in some fields, remigration of the original accumulations has occurred subsequent to original emplacement.

Traps

All but one of the eight Entrada fields on the southern flank of the San Juan Basin Province are combined stratigraphic and hydrodynamic traps where the Todilto-sourced oil is trapped in the crestal areas of Entrada paleotopography and displaced to a greater or lesser extent by waters in the Entrada that are moving down the hydrodynamic dip. This paleotopography is generally believed to be large dunes that were flooded and partially preserved under the Todilto limestone and anhydrite that was deposited over and around the dune fields in the Jurassic. This residual topography set up the stratigraphic trapping potential for the Entrada. All traps are sealed by the Todilto limestone and anhydrite. Local faulting and drape over deep-seated faults has enhanced, modified, or destroyed the potential closures of the Entrada sand ridges. Hydrodynamic tilting of oil-water contacts and (or) "base of movable oil" interfaces has had a destructive influence on the oil accumulations because the direction of tilt typically has an up-dip component. All fields developed to date have been at depths of 5,000-6,000 ft. Because of the increase in cementation with depth, the maximum depth at which suitable reservoir quality has been found is approximately 9,000 ft.

Exploration status and resource potential

The areal extent of the Entrada play is limited on the northern flank of the San Juan Basin Province in the RFD Area to those areas where both the source and seal are present over the Entrada (Figure 13). In addition the steeper dips here may be detrimental to hydrodynamic and stratigraphic trapping in the Entrada fossil dunes that are found in the southern Basin. Nevertheless, the potential for structural traps in faulted noses and other structures, and stratigraphic trapping by facies changes in the dune to sabka transitions that may be found in the northern subsurface Entrada, has given rise to recent exploration targets in the northern San Juan Basin Province.

The majority of the Entrada fields have been found by seismic (Vincelette and Chittum 1981). The Todilto anhydrite is a good reflector due to the velocity contrast between it and the underlying Entrada sand. This sand and evaporite package is usually easily followed on the seismic records. In those areas where dunes are located, the thinning of the overlying Todilto anhydrite dims the reflection of the Todilto and the thickening of the sand is commonly apparent. In addition there is commonly a “doublet” and a sag in the reflections beneath the dune, which is caused by the slower sand velocity.

The fields in the southern San Juan Basin Province are generally small in area, with one to six wells per field. Fields range in ultimate production from less than 100,000 barrels to in excess of 2.5 million barrels. There is a strong water drive. The oil-water contacts are usually tilted basinward due to the hydrodynamic effect of the water moving in the Entrada from areas of high to low energy. These same characteristics are expected to be present in fields, if any, on the northern flank of the Basin within the RFD Area. We estimate no more than one field will be found in the immediate future with a 1 million barrel potential within the RFD Area.

4.1.11 Other Possible Plays

Tertiary rocks above the Cretaceous in the San Juan Basin that lie within the RFD Area have only limited potential for gas or oil. To the south in New Mexico, the Ojo Alamo Sandstone in the lower Tertiary has produced some limited gas.

There is also the possibility of deeper Pennsylvanian oil or gas production, particularly in the northwestern part of the San Juan Basin Province that underlies the RFD Area. Additional production from fields like the Alkali Gulch Field and the Barker Dome Field may exist. However, the rich source rocks in the Paradox black shales pinch out to the southeast; thus source rocks are less abundant in the northwestern San Juan Basin than they are to the northwest in the deeper Paradox Basin.

Mississippian and Devonian rocks in the RFD Area are relatively unexplored. Although oil and gas have been found in these beds in the Four Corners area, they underlie the RFD Area mostly in the Paradox Basin Province. In the San Juan Basin Province, all of the lower Paleozoic rocks are thin to non-existent. Only the Mississippian with its upper karsted surface may have potential in the parts of the RFD Area that are in the northwestern San Juan Basin Province. Rocks below the Mississippian, if present, do not have any currently recognizable potential.

4.1.12 Oil and Gas Fields of the San Juan Basin Province in the RFD Area

Table 5 lists the important oil and gas fields of the San Juan Basin Province in the RFD Area. Figure 13 summarizes the major plays in the RFD Area.

TABLE 5
MAJOR OIL AND GAS FIELDS IN THE SAN JUAN BASIN PROVINCE IN THE RFD AREA

Name	Type	Producing Reservoirs
Ignacio-Blanco	Gas	Mesaverde Group (Point Lookout), Dakota, Fruitland Coal
Chromo	Oil	Fractured Mancos (limited production)
Menefee Mtn.	Oil	Dakota; tests in Desert Creek, Ismay (limited production)
Gramps	Oil	Dakota and fractured Mancos (currently abandoned)
Navajo	Oil	Mesaverde Group, Mancos, Gallup

4.2 PARADOX BASIN PROVINCE

The Paradox Basin Province is in southeastern and south-central Utah and southwestern Colorado and encompasses much of the area from latitude 37º to 40º N and from longitude 108º to 114º W (Figure 4). It includes almost all of the Paradox Basin, the Uncompahgre and San Juan uplifts, the San Rafael, Circle Cliffs, and Monument uplifts, the Kaiparowits and Henry Mountains basins, and the Wasatch and Pausaugunt plateaus (Kelley 1955). The Province is approximately 280 mi long and 200 mi wide and covers an area of about 33,000 sq mi. The maximum thickness of Phanerozoic sedimentary rocks ranges from 5,000-8,000 ft in the central part of the Province to more than 15,000 ft in the Paradox Basin, Kaiparowits Basin, and Wasatch Plateau.

Within the Colorado part of the Paradox Basin Province, there are approximately 160 wells in operation (Table 1). In 2004, these wells produced about 330,000 barrels of oil and 24 billion cubic feet of conventional gas. Since 1999, an average of 17 new wells have been drilled and completed each year in the Paradox Basin part of the RFD Area (Table 1). The 1995 National Oil and Gas Assessment (USGS 2005) estimated reserves of 242 MMBO and over 2 TCF of conventional gas for the entire Province; the undiscovered resources totaled 476 MMBO and about 1.5 TCF of gas (USGS 2005).

Most of the production in the Province has been from porous carbonate buildups, mainly algal mounds (Porous Carbonate Buildup Play, USGS code 2102), around the southwestern shelf margin of the Paradox evaporite basin. The giant Aneth field, with more than 1 billion barrels of oil in place, accounts for about two-thirds of the proven resources in the Province, and other fields such as the Ismay in this primarily stratigraphic play account for much of the rest. Most of the other plays have a strong structural component, particularly the Buried Fault Blocks, Older Paleozoic (2101), Fractured Interbed (2103), and Salt Anticline Flank (2105) plays. The Permian-

Pennsylvanian Marginal Clastics Play (2104) is a combination of both structure and stratigraphy. The Fractured Interbed Play (2103) is an unconventional, continuous play.

The westernmost part of the RFD Area lies within the southeastern part of the Paradox Basin Province (Figure 6). The Paradox Basin was formed in Middle Pennsylvanian time as a result of faulting along the pre-existing, northwest-trending Uncompahgre lineament, with uplift to the northeast and corresponding basin downwarping across the faults to the southwest. Salt anticlines developed in the deeper part of the Basin, which has the thickest section of evaporates, as salt moved upward in response to sediment loading from the north (Scott 2003). The basin contains the thickest sediments along the northeastern margin, where it is bounded by the Uncompahgre Uplift (Figures 4, 6).

4.2.1 Stratigraphic framework

Rocks in the basin range in age from Precambrian through Cenozoic (Figure 15). The primary oil and gas producing formation is the Middle Pennsylvanian Paradox Formation, which consists of cyclic carbonates, clastics, and evaporates deposited in a marine environment (Scott 2003). The oldest formation with oil and gas production is the upper Mississippian Leadville Limestone. Overlying Pennsylvanian rocks include the Molas Formation and the Hermosa Group, which includes the Paradox and Honaker Trail Formations. The Paradox Formation includes most of the evaporites, and the majority of the production is from the interbedded carbonates. The overlying Honaker Trail consists of marine carbonates, shales, siltstones, and sandstones. The Permian Cutler Formation consists of fluvial sandstones and shales. The Cutler Formation is the youngest interval of potential gas production within the RFD Area.

FIGURE 15. Stratigraphic Correlation Chart for the Paradox Basin Province in the RFD Area (Huffman 1995b)

4.2.2 Geologic Structure

The structures of Paradox Basin are primarily controlled by northeast- and northwest-trending lineaments (Figure 6). The basin originated from faulting along the pre-existing northwest-trending Uncompahgre lineament, and the uplift resulted in basin downwarping to the southwest across the fault (Scott 2003). The RFD Area is located within a sub-basin of the larger Paradox Basin. Salt anticlines developed in parts of the Basin, which now appear as erosional valleys because of the dissolution of the exposed salt.

4.2.3 Summary of Source Rocks, Reservoir Rocks, Traps and Seals

The Lower Paleozoic play within the Paradox Basin Province is within buried fault blocks, consisting of the McCracken Sandstone and a dolomitized limestone reservoir in the Leadville Limestone. The source rocks are also the limestone and Pennsylvanian black shales faulted against the reservoirs. The gas is trapped and sealed by Paradox evaporates and faults. The second play is along salt anticline flanks, and includes the Permian Cutler Formation and the Pennsylvanian Honaker Trail Formation of the Hermosa Group. Reservoirs are developed in arkosic sandstones of the Cutler and limestones with minor sandstones in the Honaker Trail that accumulated as thick sediments in synclines along the margins of salt-cored anticlines. The trapping mechanism is a pinchout and up-dip termination against salt diapirs. The third play is fractured interbeds within the Paradox Formation, situated within the deep trough of the Paradox Basin and includes the Paradox fold and fault belt. The organic-rich source rock and reservoir rock consists of fine-grained silty dolomite and dolomitic or calcareous black shale, trapped and sealed in fractures, with salt and shale interbeds. A fourth play includes the carbonate mounds buildups within the Paradox Formation. Dolomitic shales are the source rocks for hydrocarbons within the carbonate mounds (Scott 2003). Three other potential plays, the Permian-Pennsylvanian marginal clastics gas play, the structural and fractured shale play, and a Mississippian play are discussed below.

4.2.4 Plays – Paradox Basin

The USGS 1995 National Oil and Gas Assessment project (Huffman 1995b), identified five major plays in the Paradox Basin Province that overlap with parts of the RFD Area:

- Buried fault blocks, older Paleozoic (2101) – northwestern corner of RFD Area
- Salt anticline flanks (2105) –follows same boundary as buried fault blocks play
- Fractured interbeds (2103) -follows same boundary as buried fault blocks play
- Porous carbonate buildup (2102) -west of Lizard Head Wilderness
- Permian-Pennsylvanian marginal clastics (2104) – northwest part of the RFD Area adjacent to and east of the Paradox Basin boundary.

The critical resource plays are shown in Figure 16; all are discussed below for completeness, although some of the plays are of low potential in the RFD Area. The text below is taken largely from Huffman (1995b). Resource potential data is summarized in Table 6.

FIGURE 16. Carbonate terrane oil and gas system for the RFD Area

Table 6. Summary of Resource Potential in the Paradox Basin Province in the RFD Area (Appendix H)

4.2.5 Buried Fault Blocks, Older Paleozoic Play

This play is based on the occurrence of oil accumulations in fault blocks involving pre-Pennsylvanian rocks, mainly in the salt anticline area of the Paradox Basin Province. Most of the structures are associated with the salt anticlines and were growing at the same time as salt was moving.

Reservoirs

Reservoirs are in porous dolomite or dolomitic limestone beds of the Mississippian Leadville Limestone and the Upper Devonian McCracken Sandstone Member of the Elbert Formation. Reservoirs are as thick as 200 ft, and porosity ranges from 5 to as high as 25 percent in local cases. Permeability is generally low but is as much as several hundred millidarcies in places.

Source rocks

Probable source rocks are the organic-rich black dolomitic shales of the Pennsylvanian Paradox Formation. Migration into Leadville or McCracken reservoirs occurred where fault blocks are in structural and (or) depositional contact with the black shale, which is commonly highly fractured.

Timing and migration

Some hydrocarbon generation may have begun as early as Permian time and has continued to the present in some cases. Migration into pre-salt reservoirs was probably contemporaneous with the growth of salt structures. Severe fracturing of interbedded organic-rich shale during salt movement enhanced migration pathways.

Traps

Known traps are on uplifted fault blocks adjacent to salt anticlines or swells. Seals are Paradox Formation evaporite beds that overlie or are in fault contact with Mississippian or Devonian reservoirs. Drilling depths range from 7,000-8,000 ft at the Lisbon field to greater than 10,000 ft in other areas.

Exploration status and resource potential

Six oil and gas accumulations produce from pre-salt structural blocks; the largest of these is the Lisbon field, which contains approximately 43 MBO and 250 BCF of gas. The other fields are noncommercial or marginally commercial. None are important to the RFD Area. The play is only moderately explored with respect to smaller structures. Future potential is low to moderate, and based on previous production history, undiscovered fields are estimated to be small to medium in size and have minimal oil columns.

4.2.6 Salt Anticline Flank Play

This play is characterized by association of gas- and oil-productive Permian-Pennsylvanian reservoirs along the flanks of northwest-trending salt anticlines in the axial part of the Paradox salt basin. Salt anticlines consist of long northwest-trending diapirs or pillows of Paradox Formation salt over which younger rocks are arched in anticlinal form. The central, or salt-bearing, cores of the anticlines range in thickness from 2,500 ft to more than 14,000 ft; the anticlines are flanked by deep synclines (sites of salt withdrawal) that are filled with 10,000 ft or more of chiefly arkosic clastic rocks of the Permian Cutler Formation and a mixed sequence of clastics and carbonate rocks of the Pennsylvanian Hermosa Group.

Reservoirs

The main reservoirs in the play are pelletal and oolitic limestone and sandstone in the upper part of the Hermosa Group and arkosic sandstone in the Cutler Formation. Sandstone reservoirs are as thick as 200 ft. No data are available on reservoir quality, but it is estimated that permeabilities may be as high as 1,000 millidarcies locally. Vertical communication between these reservoirs is common because of: 1) well-developed fracture systems resulting from strong subsidence in the flank syncline, and 2) related salt movement and flowage into the adjacent salt anticlines.

Source rocks

Several potential sources for hydrocarbons are present in the play. Organic-rich black dolomitic shale of the Hermosa Group is commonly in contact with reservoir rocks along the margins of salt structures and may also be sufficiently connected by fracture or fault systems to allow vertical migration under the synclines. Some coaly carbonaceous shale is locally present at the Cutler-Hermosa contact and may be the source for some of the gas accumulations.

Timing and migration

No data are available on maturity of these source rocks. Source rocks buried to depths of from 4,000 to more than 10,000 ft in the synclines are probably mature to post mature. Hydrocarbon generation in the deeper parts of the Basin probably began by Permian time. Migration was coincident with salt movement and anticlinal growth.

Traps

Stratigraphic and stratigraphic-structural traps are present in conjunction with the reservoirs as the result of both thinning and permeability pinch outs and are sealed along the steeply dipping flanks of the salt anticlines. Some traps may be the result of up-dip termination against salt diapirs. Drilling depths range from 5,000 to more than 15,000 ft.

Exploration status and resource potential

The play is lightly explored; four gas fields of undetermined size have been discovered, only one of which, Andy’s Mesa in the RFD Area, has had any substantial production. The other three fields are small, one-well fields. According to Huffman (1995b), future potential for oil is low but fair to good for gas. However, recent production activity in the Andy’s Mesa area suggests good oil and gas potential.

4.2.7 Fractured Interbed Play (aka Structural and Fractured Shale Play)

The presence of conventional structural traps whose reservoirs are aided by fracturing in and around the salt anticlines of the southeastern Paradox Basin Province is a possibility. With the advent of horizontal drilling and the ability to open up large lateral areas of relatively tight but highly fractured rock in the past decade, and the rapidly expanding associated technology that this type of drilling has produced, new exploration ideas are being spawned. This is particularly true where rich source rocks are present. The multiple, black, organic rich shales in the Paradox Formation in the Paradox Basin Province are an integral part of the thick cyclic deposits of halite, anhydrite, gypsum, limestone, black shale, and shaly dolomite packages in the hypersaline facies of the Basin. There have been as many as 40 of these cycles identified in the Basin. The black shales in these cycles are extremely rich in organic content and commonly contain in excess of 13 percent total organic carbon. These shales are the source for most of the oil and gas found in the Paradox Basin Province.

This unconventional continuous-type oil and gas play is oil prone throughout most of the Paradox Basin Province, but is more gas prone to the east close to the ancestral Uncompahgre uplift; the reasons for this change in character are increased depth of burial and a larger percentage of terrestrial herbaceous organics to the east.

Reservoirs

The play depends on extensive fracturing in the organic-rich dolomitic shale and mudstone in the interbeds between evaporites of the Pennsylvanian Paradox Formation or carbonate and clastic rocks of the related cycles on the shelf of the Paradox evaporite basin. These shales and mudstones may be as thick as 130 ft, but are more commonly less than 20 ft thick.

Source rocks

The organic-rich black dolomitic shales and mudstones are the source rocks for the vast majority of the oil and gas in the Paradox Basin Province. Total organic carbon commonly ranges from 1 to 5 percent but may be as high as 20 percent. Oil produced by these source rocks typically has 40º- 43º API gravity and low sulfur content.

Timing and migration

The thermal history of these rich source rocks is determined mostly by depth of burial and to a lesser degree by the added effect of Oligocene volcanic activity. Pennsylvanian, Permian, Late Cretaceous, and early Tertiary sediments thicken greatly to the east so that the Pennsylvanian section entered the thermal zone of oil and gas generation at different times depending on location. Close to the Uncompahgre uplift, Pennsylvanian rocks may have generated oil as early as the Permian; elsewhere these rocks may have entered the oil generation zone in the Late Cretaceous and the dry gas zone as late as the Oligocene.

Traps

Fracturing of the shale on structures is a necessary attribute of this play, but the actual trapping and sealing mechanisms may be stratigraphic as well as structural because the fractures die out into unfractured shale and vertically in the overlying and underlying salt beds. Only certain intervals within the total shale thickness may be of sufficient richness or sufficiently fractured for noteworthy oil production. Depths to potential targets range from more than 15,000 ft near the eastern Basin margin to less than 5,000 ft on the Four Corners platform.

Exploration status and resource potential

Until recently, the only noteworthy production from this play was from the Cane Creek Shale in the Lone Canyon field discovered in 1962. Recently, nearby Bartlett Flat field has been developed by directional drilling in the Cane Creek Shale at a depth of approximately 9,000 ft. Neither field is in the RFD Area. The Cane Creek, Chimney Rock, Gothic, and Hovenweep shales have the most potential due to both organic content and thickness.

Past horizontal drilling into the black fractured shales in the Utah part of the Paradox Basin Province, in the Moab-Big Flats areas, has demonstrated industry's ability to open up long lateral areas of these shales. Initial oil production from some of these wells has been in excess of 2000 barrels a day. Future exploitation of the new drilling and completion technologies will probably expand and encourage exploration into the Colorado part of the Paradox Basin Province. This play could have a major impact on future exploitation of the western part of the RFD Area. No ultimate production is assigned to this play at this time. However it is not inconceivable that more than 10 MB of oil could eventually be produced from these black shales and from the enclosing fractured carbonates in the RFD Area.

4.2.8 Porous Carbonate Buildup Play

This is primarily an oil play in the Paradox Basin Province and is characterized by oil and gas accumulations in mounds of algal (*Ivanovia*) limestone associated with organic-rich black dolomitic shale and mudstone rimming the evaporite sequences of the Paradox Formation of the Hermosa Group. Most of the developed fields within the play produce from stratigraphic or combination traps. The largest oil field in the province, Aneth, is developed in this play. Many smaller "satellite" mounds in the vicinity of the Aneth field also produce oil from the play, as do other fields with more of a structural component.

Reservoirs

Almost all hydrocarbon production has been from vuggy limestone and dolomite reservoirs in five informal zones of the Hermosa Group, in ascending order, the Alkali Gulch, Barker Creek, Akah, Desert Creek, and Ismay. The largest producers are the upper two zones, and they are the producing intervals at Aneth. Net pay thickness generally ranges from 10 to 50 ft but may be as great as 100 ft; porosities are 5-20 percent.

Source rocks

Source beds for Pennsylvanian oil and gas are the interbedded organic-rich dolomitic shale and mudstone and laterally equivalent carbonate rock within the Paradox Formation. They commonly range from 1 to 5 percent in total organic compounds. Oil is typically 40º- 43º API gravity. Correlation of black dolomitic shale units of the Paradox Formation with prodelta facies in clastic cycles, which are present in the marginal clastics and fan delta complex on the northeastern edge of the Paradox evaporite basin, helps to account for the high percentage of kerogen from terrestrial plant material in the source rocks.

Timing and migration

Along the northeastern margin of the Paradox Basin Province, most of the Pennsylvanian sediments entered the thermal zone of oil generation during the Late Cretaceous to Paleocene, and the zone of gas generation during the Eocene to Oligocene. It is probable that Pennsylvanian source rocks entered the oil generation zone during the Oligocene throughout most of the Four Corners platform and Blanding Basin area, including the Aneth area. Up-dip migration and local migration from laterally equivalent carbonate rocks and shale in areas of favorable reservoir beds predominate; remigration possibly occurred in areas of faulting and fracturing.

Traps

Stratigraphic traps are dominant among Pennsylvanian fields of the Paradox Basin Province, although fault-bounded structures of Pennsylvanian age may have played a critical role in the deposition of bioclastic limestone reservoir rocks. Seals are provided by a variety of mechanisms, including porosity differences in the reservoir rock, overlying evaporites, and interbedded shale. Most production ranges in depth from 4,000 to 6,000 ft.

Exploration status and resource potential

Field sizes in the play vary considerably; most oil discoveries are in the 100 to 1 MB size range but also include the giant 1 billion barrel Aneth field. The greater Aneth field, comprising four production units, occupies an area of approximately 47,000 acres and was discovered in 1956. Recently, high-resolution seismic surveys have been successful in targeting many similar, but smaller mounds in the vicinity of the Aneth field. Most are charged with oil, and field sizes are in the 1 to 3 MB range.

The nearest production from this play in the RFD Area is at the Dove Creek (1 BCF of gas) and Papoose Canyon (6 MB of oil, 41 BCF of gas) fields. The Cache field (4 MB of oil) on the Colorado-Utah border is an example of the size and type of field expected in the RFD Area. Favorable conditions probably exist in the RFD Area, but the source rocks become less extensive and more poorly developed and more gas prone to the northeast. If the belt of mounds in the upper part of the Paradox Formation does continue into the RFD Area, the fields will probably be small, 1 MB of oil or less, and with a high gas to oil ratio, becoming entirely gas toward the eastern side of the play. Our assessment indicates most likely values of 3 MB of oil and 12 BCF of both associated and non-associated gas.

4.2.9 Permian-Pennsylvanian Marginal Clastics Gas Play

Along the east flank of the Paradox Basin Province in the northwestern part of the RFD Area, the Hermosa Formation of Pennsylvanian age contains an easterly derived clastic facies known as the Silverton fan delta (Spoelhoef 1976). These clastics were deposited as coalesced outwash fans that intertongue with the cyclic marine deposits of the Pennsylvanian Hermosa Group. The delta is made up of numerous depositional cycles, each of which includes a prodelta facies of dark marine shale. The prodelta units are believed to be correlative with the black organic-rich shales of the carbonate-evaporite cycles in the Paradox Basin Province to the west. Isopach maps of individual black shale units indicate that many of them thicken appreciably in the vicinity of the Silverton fan-delta complex (Peterson 1989).

Reservoirs

Limited subsurface data is available on the potential sandstone reservoirs of this play. However, some of these rocks crop out in the San Juan Mountains south of Silverton, where the delta-front sandstones have been described as well sorted, fine to medium grained, and arkosic (Spoelhoef 1976). The arkosic and calcareous nature of much of the clastic section may be detrimental to consistently good porosity and permeability, but the variable energy regime of the deltaic depositional environment should enhance reservoir characteristics in many sandstone units. Although similar deposits occur in the eastern part of the RFD Area, they appear to be more arkosic and thus poorer reservoirs (Peterson 1989).

Gas shows have been encountered in porous and permeable sandstone intervals within the generally arkosic Permian Cutler Formation in the vicinity of the Ancestral Uncompahgre uplift. Such potential reservoir rock is present where feldspar and clay were winnowed out by wave action or fluvial stream flow. For most of the area, the lower part of the Pennsylvanian interval is more likely to contain these beds than the upper part because of the lower original feldspar content of the lower part. In the upper part of the Pennsylvanian interval, the southeastern Paradox Basin Province is more likely to contain such beds because of the presence of a large fan delta complex that provided the necessary depositional environments to clean the sandstone.

Source rocks

This play is dependent on the presence of Desmoinesian organic-rich dolomitic shale and mudstone in contact or close proximity to reservoir lithologies. Dark-gray or black marine shales of potential source rock quality intertongue with the marine and delta-front sandstone facies along the western margin of the play area. These rocks are organic rich in the central Paradox Basin Province and probably become more humic in character in the deltaic complex, where land-derived organic matter is more prevalent. The presence of large igneous intrusions (Rico, San

Miguel, and La Plata mountains) suggests that greater maturation levels also may be expected in parts of the area. The probability of Type III kerogen plus higher heat flow indicates that the Silverton delta area will be gas prone.

Traps

Traps should be a combination of structural and stratigraphic on folded and faulted structures of variable size. Trap types are expected to be dominantly combinations of up-dip pinch outs of permeable sandstone lenses localized on folded and faulted structures. The presence of distributary, delta fringe, and longshore sand bodies within the deltaic complex offer potential stratigraphic trap possibilities. Seals are provided by shale beds as well as by reduced up-dip permeability.

Exploration status and resource potential

This play is speculative, and drilling density in the area is low. At least one well on the northwestern margin of the play had noteworthy gas shows in sandstones of the Hermosa Formation, which are probably part of the Silverton fan-delta complex. Many of the potential reservoir rocks crop out up-dip from the play area, increasing the probability of trap leakage and flushing of reservoirs by groundwater recharge, thus reducing the favorability of this play.

This play will remain highly speculative until more data is available, but there is at least some potential for small accumulations of non-associated gas. The most likely estimate of 2 billion cubic feet of gas assigned to this play reflects a low confidence level but also a conviction that it should not be overlooked entirely.

4.2.10 Mississippian Play

On the west side of the RFD Area, Mississippian rocks are present beneath the Pennsylvanian section in the southeast parts of the Paradox Basin Province. The Mississippian carbonates in the central part of the RFD Area, where present, are generally prone to freshwater flushing and poor reservoir development compared to these same rocks to the west. There is also an increased likelihood of a higher CO_2 content in the gas and (or) CO_2 production east from the Colorado-Utah state line. Consequently only the northwestern part of the RFD Area is expected to have potential for oil and hydrocarbon gas similar to fields like the Mississippian Lisbon Field in southwestern Utah. Although the Mississippian is still lightly explored, the carbonates in the northwestern part of the RFD Area are prospective, will probably be structurally controlled, and may have a high percentage of CO_2. No assignment of ultimate reserves is given to these rocks at this time.

4.2.11 Oil and Gas Fields of the Paradox Basin in the RFD Area

Table 6 summarizes the resource development potential of the Basin in the RFD Area. Table 7 lists the currently producing oil and gas fields of the Paradox Basin Province that are located in the RFD Area. Figure 16 summarizes the location of the critical plays in the Paradox Basin Province of the RFD Area.

TABLE 7
CURRENTLY PRODUCING (2005) OIL AND GAS FIELDS OF THE PARADOX BASIN PROVINCE IN THE RFD AREA

Name	**Type**	**Producing Reservoirs**
Andy's Mesa	Gas/oil	Cutler, Cutler Arkose, Honaker Trail, Ismay
Cache	Oil	Ismay
Cahone	Oil/gas	Honaker Trail
Cocklebur Draw	Gas	Hermosa, Paradox
Double Eagle	Gas	Honaker Trail, Cutler
Flodine Park	Oil/gas	Ismay
Hamilton Creek	Gas/oil	Hermosa, Cutler, Honaker Trail
Hamm Canyon	Gas	Hermosa
Island Butte	Oil	Desert Creek
Lisbon Southeast	Gas/oil	Leadville
McClean	Oil/gas	Desert Creek
Papoose Canyon	Oil/gas	Desert Creek, Ismay
Roadrunner	Oil/gas	Ismay
SE Andy's Mesa	Gas/oil	Cutler, Cutler Arkose, Honaker Trail, Ismay
Sleeping Ute	Oil/gas	Ismay
Stone Pony	Gas/oil	Ismay
Towaoc	Oil/gas	Ismay

5.0 OIL & GAS OCCURRENCE POTENTIAL IN THE RFD AREA

This section summarizes the occurrence potential of oil and gas in the RFD Area based on the geology (Section 3) and major plays (Section 4) in the Area. The criteria used for designation of potential are from BLM Handbook H-1624-1, revised December 19, 1994 and are listed in Appendix E. Designated wilderness areas were not evaluated and classified for their oil and gas potential based on the legal constraint of no leasing. Figure 17 summarizes the oil and gas potential. Industry interviews (Appendix D) have been used to support this analysis.

FIGURE 17. Favorable resource occurrence in the RFD Area

Appendix E. Classification of oil and gas potential (*from* BLM 1990*)*

5.1 SAN JUAN BASIN PROVINCE OIL AND GAS POTENTIAL

5.1.1 High Potential

Lands with high potential in Cretaceous rocks are present in the RFD Area in the extreme northern part of the San Juan Basin Province. Productive oil and gas fields such as the Ignacio-Blanco and Fruitland–Picture Cliffs, and production from the Dakota, "tight" Dakota, and Mesa Verde plays are in and (or) immediately adjacent to the RFD Area. Their productivity and future potential is due to the combination of excellent source rocks in the organic-rich Mancos shale and Fruitland coals and their stratigraphic position, interfingered with both nonmarine and marine sandstones that are in and immediately up dip of the mature oil and gas generating window.

This combination of source, maturity and good reservoir rocks makes the potential for future oil and gas discoveries and development high in the areas of the RFD Area that fall within the San Juan Basin Province where the Dakota and younger rocks are present.

In addition to these more conventional reservoirs, the oil and gas potential of fractured Mancos is considered to be high, particularly in the sandier and more dolomitic El Vado member of the Mancos Shale.

5.1.2 Medium Potential

Within the northern San Juan Basin area, the lands that overlie the Entrada Sandstone are prospective. This is particularly true in the vicinity of the southwestern flank of the Archuleta Anticlinorium on the northeastern flank of the San Juan Basin Province. In this area the excellent sand reservoir of the Entrada Sandstone is overlain by the black, organic rich source rocks of the Todilto Limestone, which is in turn overlain by the excellent sealing anhydrites of the Todilto Formation (Wanaka). This package of source rock overlying excellent reservoir rock sealed by the Todilto anhydrite and limestone is immediately up dip of the "cooking pot" of the deeper San Juan Basin and is in an excellent position for up-dip migration and trapping in stratigraphic or structural traps in the Entrada. Most of the Entrada fields in the southern part of the San Juan Basin Province are, in whole or part, hydrodynamic traps. Hydrodynamics may play an important role in trapping in the northern part of the San Juan Basin as well.

Because it is likely that the rich Paradox black shales pinch out to the southeast of the Paradox Basin Province, only medium potential is assigned to the Pennsylvanian rocks in the San Juan Basin Province part of the RFD Area.

5.1.3 Low Potential

Tertiary rocks have only low potential in the RFD Area. Because of limited source rocks and lack of exploration interest in this area, Mississippian and Devonian rocks in the RFD Area are of low potential at present as well, although escalating oil prices may drive exploration interest higher with time.

5.1.4 No Currently Recognizable Potential

In the San Juan Basin part of the RFD Area, the rocks below the Mississippian, if present, do not have any currently recognizable potential, although escalating oil prices may drive exploration interest higher with time.

5.2 SAN JUAN SAG AREA OIL AND GAS POTENTIAL

5.2.1 High Potential

Cretaceous rocks in the southern and southwestern part of the San Juan Sag generally dip northeasterly away from the Archuleta Anticlinorium that separates the San Juan Sag from the San Juan Basin. The Cretaceous rocks in the Sag are essentially identical to those found in the northeast San Juan Basin Province; however they were deposited slightly more “seaward.” In addition these rocks have generally been eroded more deeply, are more highly faulted and are covered to the north with a thick cover of Tertiary volcanic rocks of the San Juan volcanic field.

Virtually everywhere within the San Juan Sag, Cretaceous rocks are mature to super mature due to depth of burial and the higher heat flow associated with the San Juan volcanic field, which is adjacent to the area. The good source rock character of the Mancos Shale has the same high potential for oil and gas generation that it has to the south in the San Juan Basin Province, and considerable oil and gas has likely been generated from the Cretaceous section. Like the Gramps Field in the eastern part of the RFD Area, the primary reservoirs are the Dakota and possible fractured shale of the Mancos. The Mesaverde is also a potential objective in the northeastern part of the RFD Area in the San Juan Sag area.

In summary, the Dakota and fractured Mancos shale potential is considered to be high in this part of the RFD Area where Cretaceous outcrops and subcrops are not covered by thick volcanic flows.

5.2.2 Medium Potential

The Entrada Sandstone has medium potential in the San Juan Sag part of the RFD Area. This is particularly true along the northeastern flank of the Archuleta Anticlinorium. In this area the Entrada is likely overlain by the black, fetid, organic rich source rock of the Todilto Limestone, which is in turn overlain by the sealing anhydrite of the Todilto (Wanaka).

5.2.3 Low Potential

Very little is known about the Pennsylvanian section in the San Juan Sag area. However it has been mentioned by several operators as a possible objective, if present, beneath the Mesozoic rocks in the Sag. It is therefore given a low potential.

5.2.4 No Current Recognizable Potential

Although Mississippian and (or) Devonian and older Paleozoic rocks may exist under this part of the San Juan Sag, they are virtually unexplored and no recognizable potential is given to this stratigraphic package.

5.3 PARADOX BASIN PROVINCE OIL AND GAS POTENTIAL

5.3.1 High Potential

Actively producing fields in the Andy’s Mesa, Cache, Cocklebur Draw, Flodine Park, Hamilton Creek, Hamm Canyon, Island Butte, McClean, Papoose Canyon, Roadrunner, Sleeping Ute, and Towaoc fields have high potential for continued expansion of production of gas and some oil in the Paleozoic section of the Paradox Basin Province of the RFD Area. The Carbonate Buildup play and Structural and Fractured Shale play both have good to excellent potential for oil and associated gas development in the Area.

5.3.2 Medium Potential

Only the northwestern part of the RFD Area is expected to have potential for oil and hydrocarbon gas similar to fields like the Mississippian Lisbon Field in southwestern Utah. Although the Mississippian is still lightly explored, the carbonates in the northwestern part of the RFD Area are prospective, will probably be structurally controlled, and may have a high percentage of CO_2. No assignment of ultimate reserves is given to these rocks at this time, but medium resource potential exists.

5.3.3 Low Potential

Generally, this includes the remaining lands within the Area outside the medium potential area that are underlain by a sedimentary section at least 1000 feet thick, but may not have source and reservoir rocks, or traps. Most of this area has not been leased for oil and gas, and has not been drilled. The scattered exposures of Cretaceous and other sedimentary rocks within and outside the play and Paradox Basin Province boundaries are also considered to have low potential based on the projected thickness of the sedimentary section. The Marginal Clastics (Silverton Delta) play remains speculative, but there is some potential for small accumulations of conventional gas.

5.3.4 No Currently Recognizable Potential

Generally, this area includes both lands located outside the Paradox Basin Province boundary and those that are not underlain by at least 1000 feet of sedimentary rocks. Based on the geologic map (Figure 5), some sedimentary exposures are found outside the Basin, but presumably consist of a thinner section. The plutonic rocks within the Paradox Basin Province have no currently recognizable potential.

6.0 SCENARIO FOR FUTURE OIL & GAS EXPLORATION AND DEVELOPMENT ACTIVITY

Based on the analysis of the geology (Section 3) and plays (Section 4) in the RFD Area, and their resource potential (Section 5), the parts of the RFD Area that have high and moderate potential for oil and gas occurrence and development are: 1) the clastic terrane in the San Juan Basin Province, largely from source and reservoir rocks in the Cretaceous section; 2) the Cretaceous and Jurassic section in the San Juan Sag; and 3) the carbonate terrane in the Paradox Basin Province, largely from source and reservoir rocks in the Pennsylvanian, with lesser contributions from the Permian and Mississippian section (Figure 17). Currently 491,710 acres of public land (21 percent of USFS and BLM land in the RFD Area) are leased for oil and gas development.

6.1 BACKGROUND

The RFD Area consists of 2,362,408 acres of San Juan National Forest and adjacent BLM lands, as well as private property (1,025,121 acres), tribal lands mainly in the HD Mountains and Chimney Rock areas (1,377 acres), Colorado Division of Wildlife (39,758 acres), and state, county and city lands (41,652 acres). As discussed in the previous Sections (3-5), it lies on the periphery of two major oil and gas provinces, the San Juan Basin Province and the Paradox Basin Province, as well as parts of the lightly explored San Juan Sag. The 2000 EPCA oil and gas inventory analysis prepared by the U.S. Geological Survey (EPCA 2003; USGS 2005) indicates that both provinces contain substantial known and undiscovered oil and gas resources. These resources include areas along the eastern edge of the Paradox Basin Province, which underlies the western RFD Area, and beneath the northern margin of the San Juan Basin Province, which makes up the southern part of the RFD Area (Figure 17). The EPCA study results for these two basins, in their entirety, and the southern part of the San Juan Sag, conclude the following (USGS 2005):

- Most of the undiscovered natural gas (95%) is widely dispersed in continuous deposits rather than distinct structural traps
- This area has the greatest proportion of proved natural gas reserves (28%) relative to undiscovered resources of the five major EPCA study areas in the conterminous United States
- The two provinces are estimated to contain 200 MMB of oil (52% of the undiscovered technically recoverable oil) and 28.9 TCF of natural gas (79% of the reserves and undiscovered technically recoverable natural gas) that is available for leasing.

Although most of these resources lie outside the RFD Area, the play analysis in this RFD report suggests that it is likely that at least 10 percent of the oil and 20 percent of the natural gas in the two provinces are within the RFD Area.

Both provinces have recently been the locus of increased exploration, leasing, and drilling activity. According to a recent RFD for the San Juan Basin (Engler et al. 2001), which overlaps the southern part of the RFD Area, the San Juan Basin is one of the most strategic gas producing basins in the United States, yielding over 1 TCF of gas and 3 MMBO in 1999. The San Juan Basin RFD predicts approximately 10,000 new wells will be drilled during the next 20 years.

The Draft Environmental Impact Statement for the Northern San Juan Basin Coal Bed Methane Project in La Plata and Archuleta counties (SJPL 2004) was written in response to a proposal by six companies to drill approximately 300 new coal-bed methane (CBM) wells in the RFD Area in the next five years. The companies' proposal includes disposing of produced water using deep underground injection and directional drilling where necessary to avoid steep slopes in parts of the HD Mountains. The overall life of this CBM project, including construction, production, and reclamation, would be approximately 40 years.

The Canyon of the Ancients National Monument lies on the eastern edge of the Paradox Basin Province and adjacent to the southwestern part of the RFD Area. Numerous oil and gas fields are located within the Monument. The largest carbon dioxide (CO_2) gas field in the United States is found beneath large parts of the Monument. This field has been producing CO_2 for enhanced oil recovery in the Texas oil fields since the early 1980s. A recent draft RFD for the Monument (BLM 2004) estimates that over the next 20 years another 150 wells will be drilled in the Monument. Sixty-nine of the proposed new wells will be for CO_2, with the remaining 81wells for conventional oil and gas.

The RFD for the Grand Mesa, Uncompaghre, Gunnison National Forests (GMUG) area (GMUG 2004), which lies north of the RFD Area and includes part of the Paradox Basin Province, has been lightly explored and developed, with only 106 wells drilled in the last 55 years. Only 15 wells were capable of production in 2004. The GMUG forecasts 30 wells drilled over the next 15 years, plus 15 wells that are already in the approval and permitting process, for a total of 45 wells to 2021. This projection is currently the subject of objection by industry as falling short of their projections.

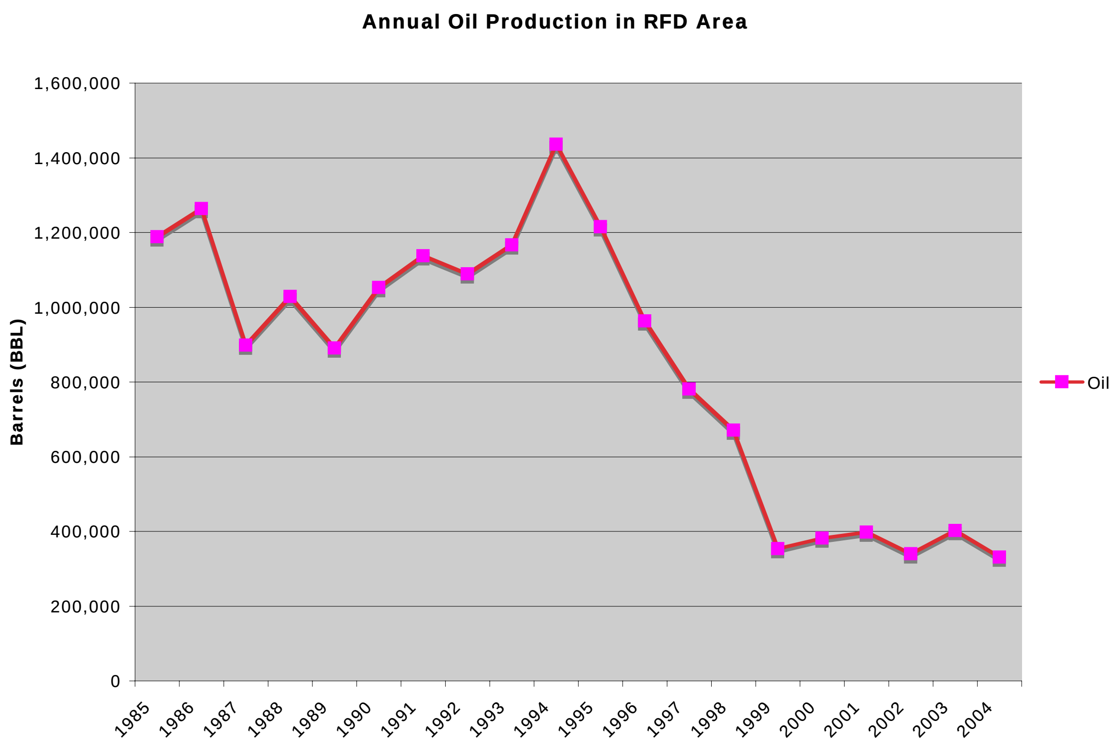
The Jicarilla Ranger District of the Carson National Forest (Carson 2003), which is adjacent to the southeastern part of the RFD Area in New Mexico, includes about 150,000 acres of National Forest land leased for mineral development, and is actively being developed for natural gas production. The District was included in the San Juan Basin RFD (Engler et al. 2001). This study concluded that some 700 wells would be developed in the District over the next 20 years (to 2020), or seven percent of gas production on federal minerals ownership in the San Juan Basin Province.

In the RFD Area, 1339 wells have been drilled (Appendix F), with an average of 34 new wells annually since 1999 (Table 1). Figure 18 shows the distribution of the wells active in 2004, during which 331,000 barrels of oil and 89 billion cubic feet of gas were produced in the Area. This RFD has identified that some 10 TCF of gas and at least 20 MMBO are potentially developable in the Area through 2020 (Section 5).

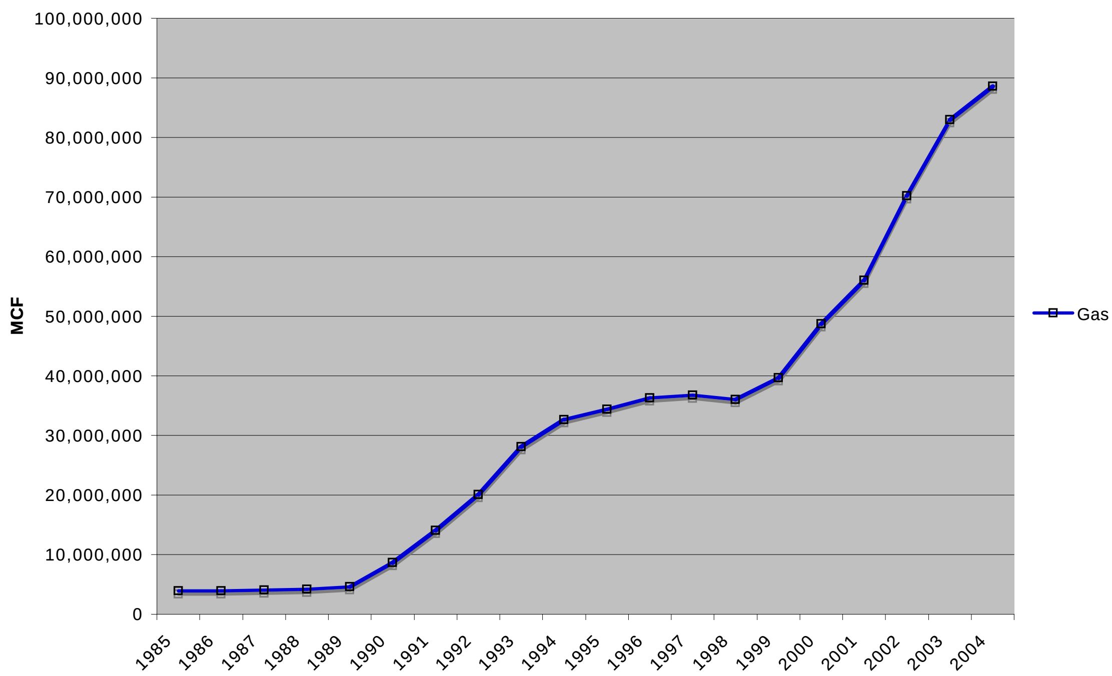
FIGURE 18. 2004 well locations and oil & gas fields

Appendix F. Production Data Compiled from COGCC Well Data (CD-ROM)

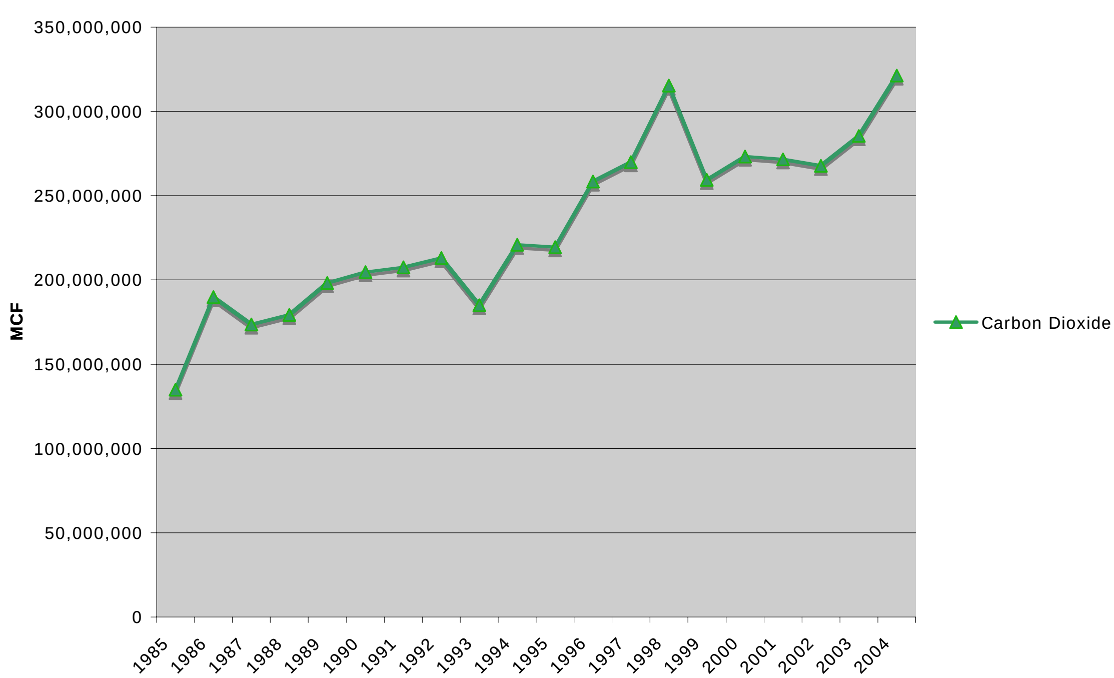
Using data compiled from the COGCC well database, Appendix F, the figures below illustrate the last 20 years (1985 to 2004) of development in the RFD Area (data from COGCC 2005). Currently (2005) there are 42 producing wells in Archuleta County, 17 in Dolores County, ~300 in La Plata County, 49 in Montezuma County, and 68 in San Miguel County in the RFD Area (COGCC 2005).



Annual Non-CO_2 Gas Production in RFD Area



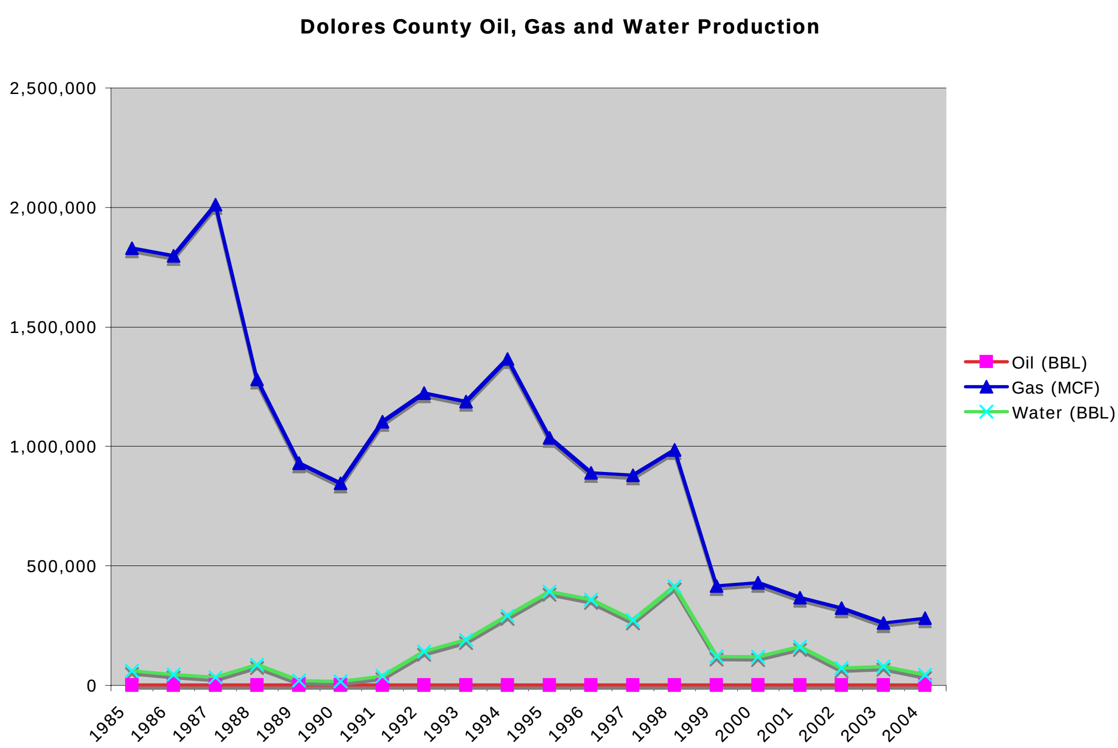
Annual CO_2 Production (3 wells) in RFD Area



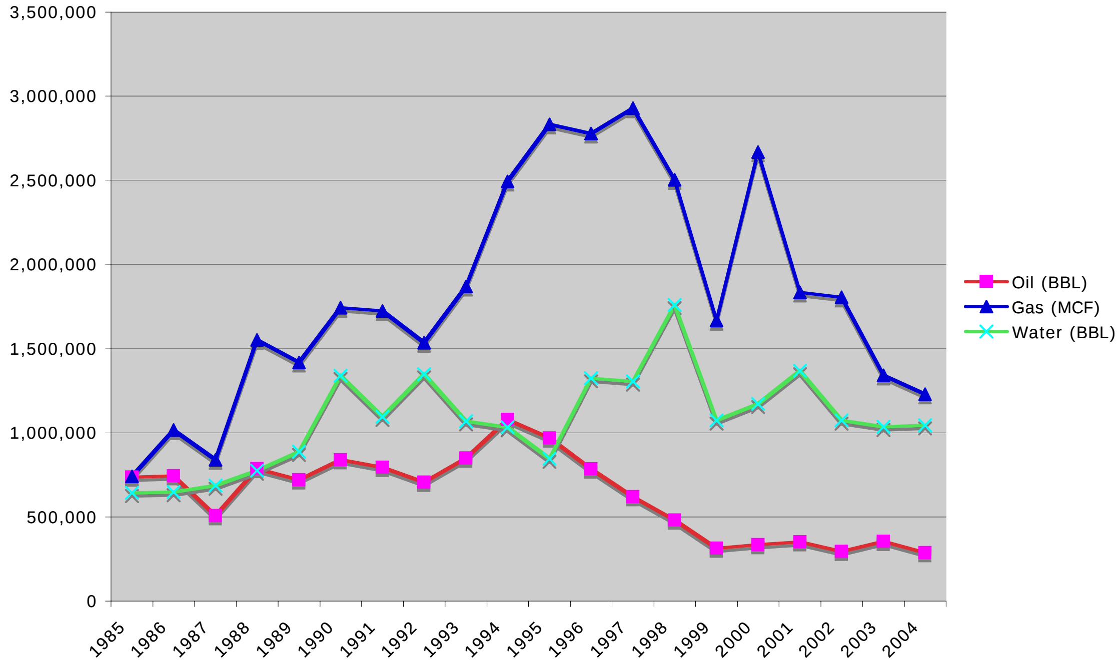
6.2 RECENT EXPLORATION AND DEVELOPMENT TRENDS

As part of this RFD, many of the oil and gas operators in the RFD Area were interviewed (Appendix C). Summaries of the interviews are found in Appendix D. The operators anticipate growth in their activities over the next 15 years and some of them will use enhanced technology (i.e., directional drilling, and secondary and tertiary recovery) as part of their future development activities. New lease activity in the CBM areas of the San Juan Basin Province and in the conventional oil and gas fields of the Paradox Basin Province (Figure 3) clearly points toward the increasing interest in CBM and conventional oil and gas. Pending lease applications also indicate new exploration interest in the San Juan Sag. See Appendix F for the source of the charts below.

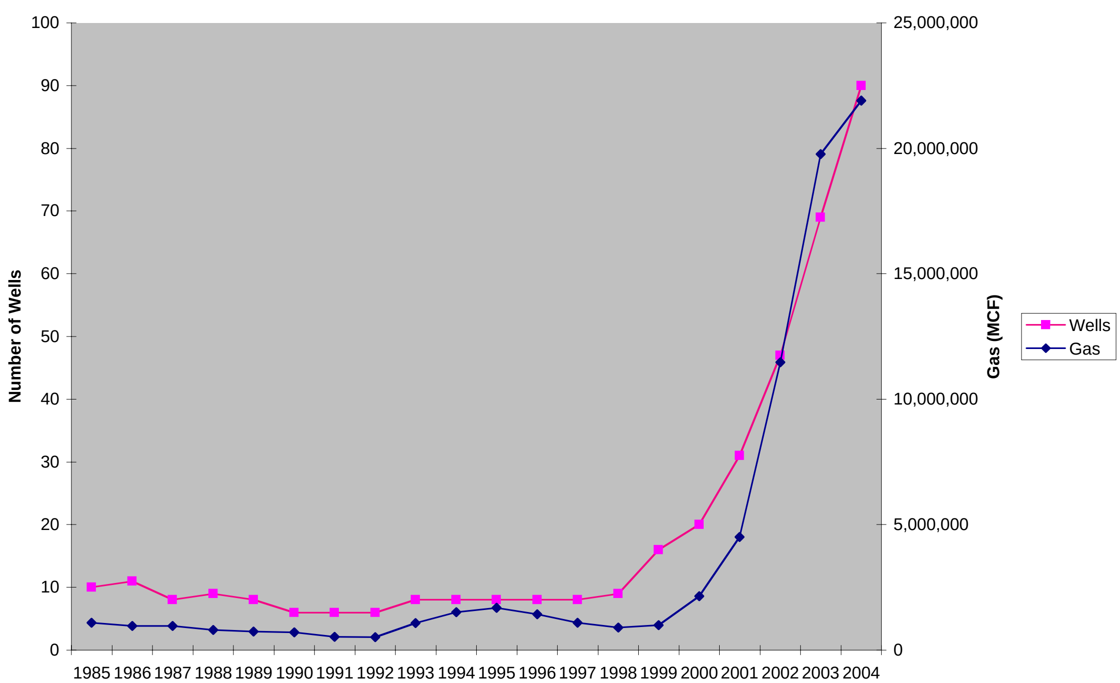
Current oil and gas production in the RFD Area is split into two major types: conventional oil and gas in the Paradox Basin Province, and CBM in the San Juan Basin Province. Oil production in the Area is largely from the Paradox Formation, with about 70 wells currently producing about 330,000 BBL annually, averaging about 5000 BBL per well. Conventional natural gas in the Paradox Basin Province is derived primarily from the Permian and Pennsylvanian section, with about 90 wells producing 22 BCF, averaging about 250 MMCF of gas per well. Oil and gas production has stabilized in Montezuma and Dolores counties, having decreased considerably from the mid-1990s; oil and particularly gas production has increased substantially in San Miguel County over the past decade (see figures below).

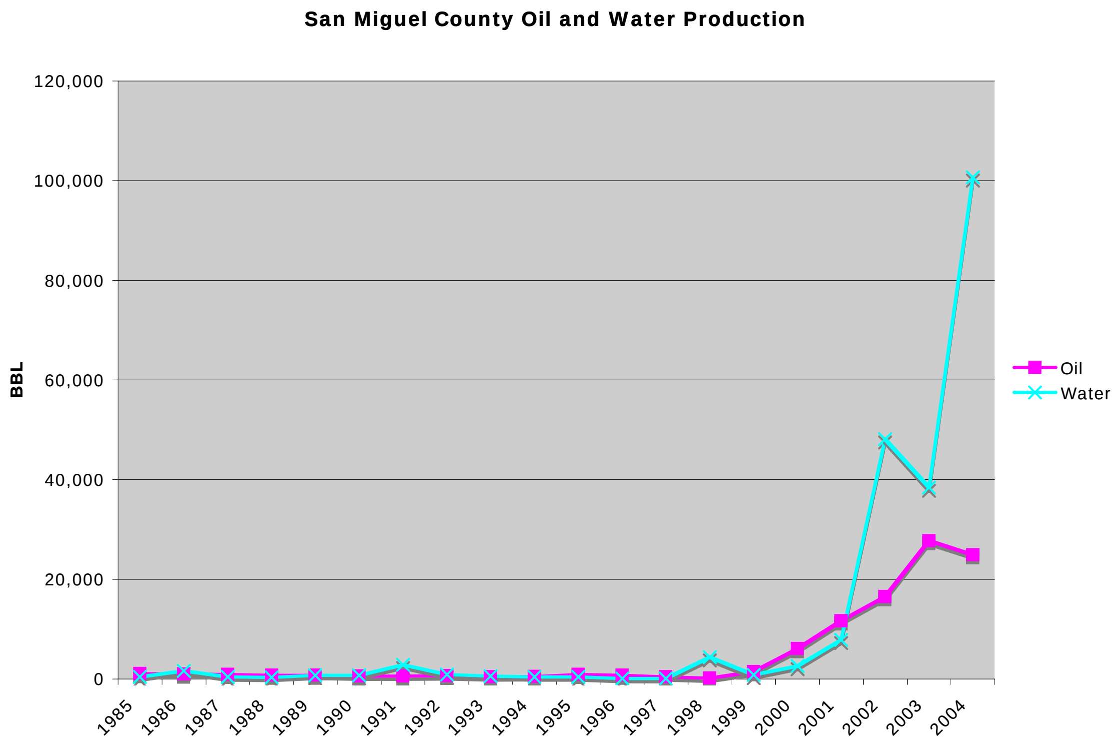


Montezuma County Oil, Water, and Non-CO_2 Gas



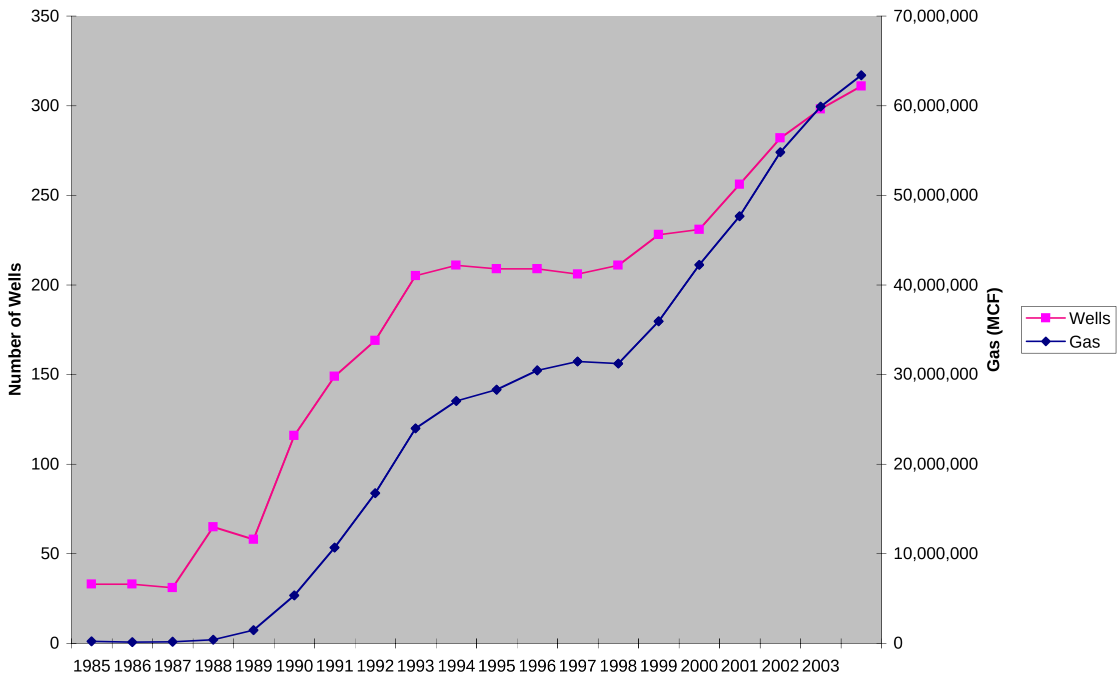
San Miguel County Gas Production



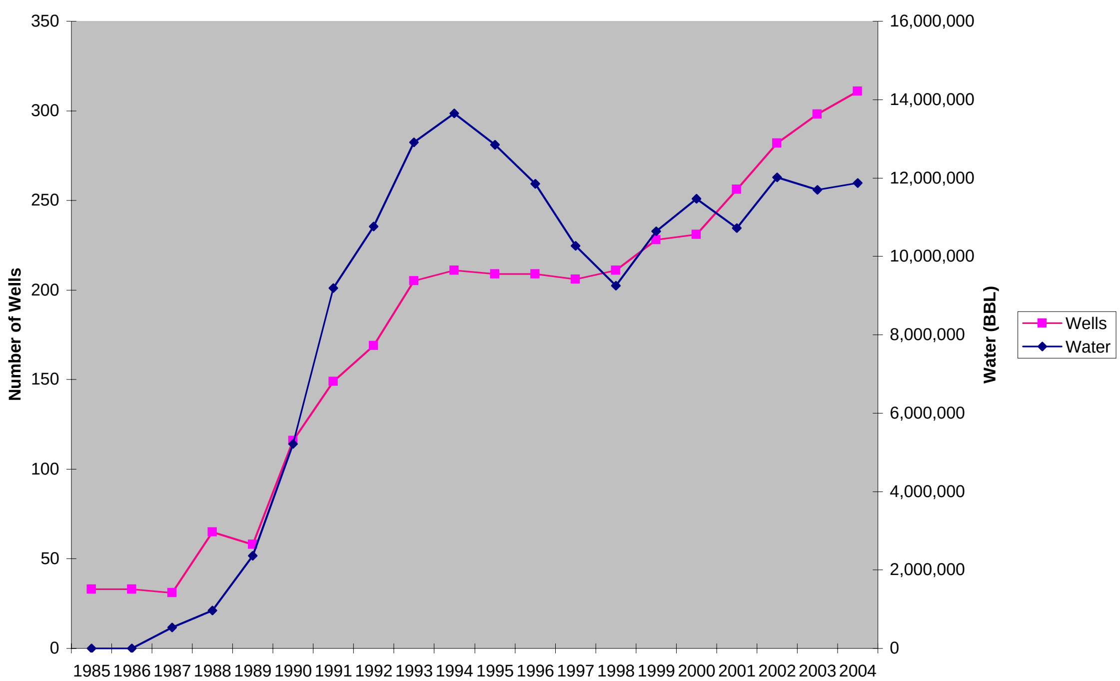


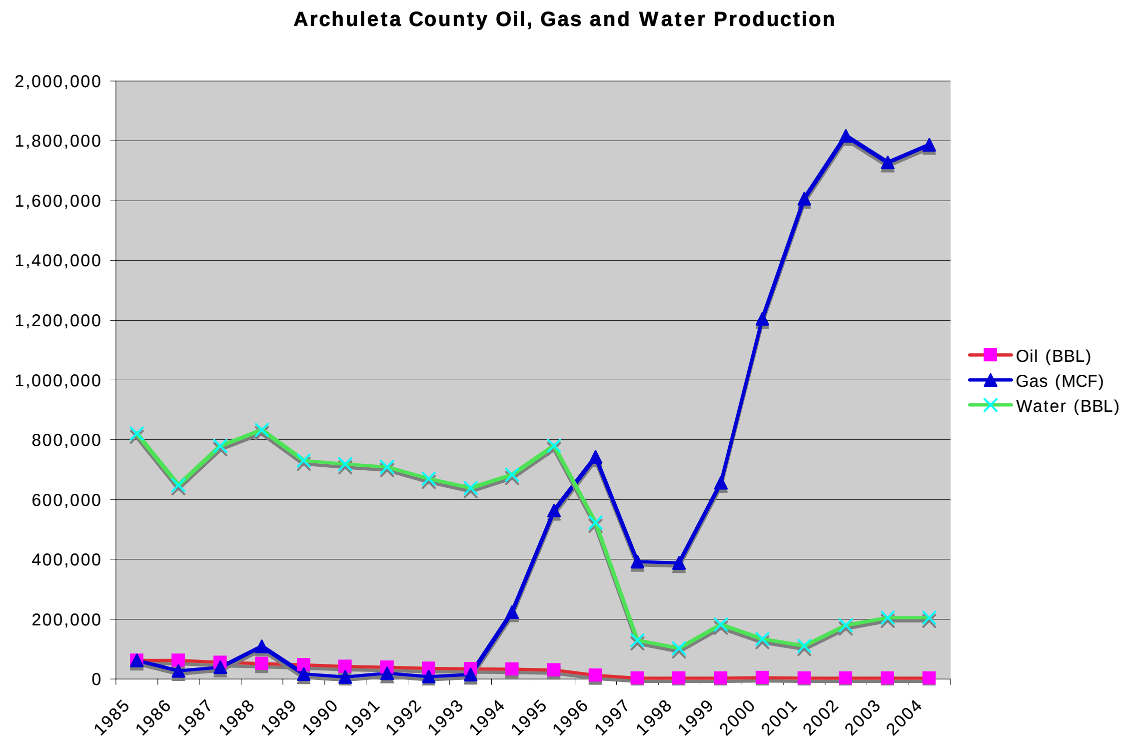
CBM in the San Juan Basin Province of the RFD Area is produced from approximately 330 wells and totals 65 BCF, averaging 200 MMCF per well. Production has increased steadily over the past decade, as illustrated in the figures below. Substantial water is removed in the extraction of CBM; amounts have stabilized around 1500 acre-feet annually, but additional new wells will likely increase this amount. The figures below summarize the oil, gas, and water production from La Plata and Archuleta counties.

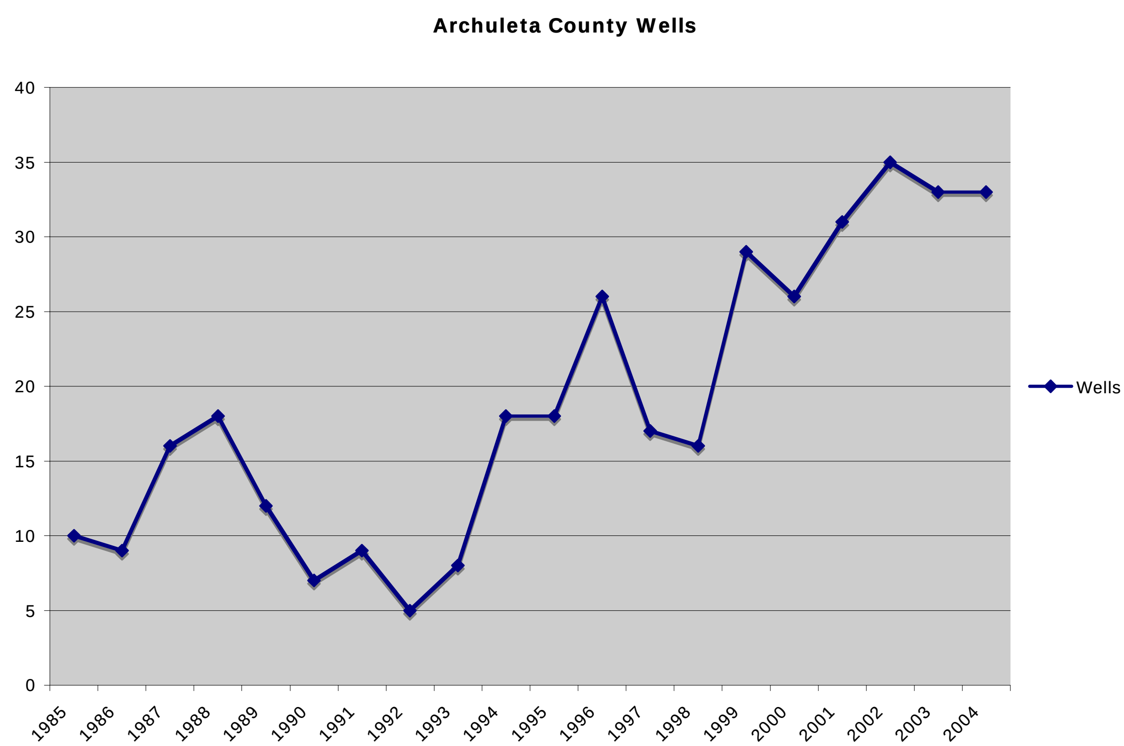
La Plata County CBM Production



La Plata County CBM Water Production




Archuleta County Oil, Gas and Water Production
2,000,000
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
Oil (BBL)
Gas (MCF)
Water (BBL)


Archuleta County Wells
40
35
30
25
20
15
10
5
0
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
Wells

6.2.1 Unit Agreement Summaries

The definition of a Unit is the joining of all or substantially all interests in a reservoir or field, rather than a single tract, to provide for efficient development and operation of a common reservoir without regard to separate property interests. Leases may be unitized when the geologic conditions do not permit the drilling of wells on conventional locations, e.g., one well in every ¼ section with 160-acre spacing. Table 8A lists the Units in the RFD Area. Unit Agreements are relatively common in the Paradox Basin Province in the RFD Area. They are less common in the San Juan Basin Province.

TABLE 8A
OIL AND GAS UNIT AGREEMENTS IN THE RFD AREA

Unit Name	Field	Lead Operator	2005 Production
Andy’s Mesa	Andy’s Mesa	EnCana Oil & Gas (US)	Gas/minor oil
Bull Creek	Ignacio-Blanco	Elm Ridge Exploration	Gas (CBM)
Cache	Cache	Smith Energy	Oil/gas
Cannonball	NA	EOG Resources	NA
The Canyon	NA	Questar Expl. & Prod.	NA
Cocklebur Draw	Cocklebur Draw	Merrion Oil & Gas	Gas
Cutthroat	McClean	Questar Expl. & Prod.	Oil/gas
Double Eagle	Double Eagle	Cabot Oil & Gas	Gas/minor oil
Egnar	Lisbon Southeast	EnCana Oil & Gas (US)	Gas/minor oil
Fasset Gulch	NA	Petrock	NA
Hamilton Creek	Hamilton Creek	EnCana Oil & Gas (US)	Gas/minor oil
Hamm Canyon	Hamm Canyon	EnCana Oil & Gas (US)	Gas
Island Butte	Island Butte	Kinder-Morgan	Oil
Mary Akin	NA	Black Resources	NA
McElmo Dome	McElmo Dome	Kinder-Morgan	Oil/CO2
McIntyre Canyon	Lisbon SE	EnCana Oil & Gas (US)	Gas/minor oil
Megas	NA	BP America	NA
Mockingbird	NA	Kinder-Morgan	NA
Papoose Canyon	Papoose Canyon	Kinder-Morgan	Oil
Pargin Mountain	Ignacio-Blanco	BP America	Gas (CBM)
SE Andy’s Mesa	Andy’s Mesa	EnCana Oil & Gas (US)	NA
SE Hamilton Creek	Hamilton Creek	EnCana Oil & Gas (US)	NA
Sabertooth	NA	Cabot Oil & Gas	NA
Tiffany	Ignacio-Blanco	BP America	Gas (CBM)
The Tower	NA	Questar Expl. & Prod.	NA

Source: BLM, SJPL Center

Table 8B lists the major operators in currently producing fields in the RFD Area that do not have Unit Agreements listed in Table 8A.

TABLE 8B
PRODUCING FIELDS IN RFD AREA IN 2005 WITHOUT IDENTIFIED UNIT AGREEMENTS

Field Name	Type	Lead Operator(s)
Flodine Park	Oil/gas	Bayless
Ignacio-Blanco	Gas (CBM)	BP America, Elm Ridge, Enegen Resources
Navajo	Oil	Alamosa Drilling
Roadrunner	Oil/gas	Rim Production
Sleeping Ute	Oil/gas	PetroCorp
Stone Pony	Gas/oil	Questar Exploration & Production
Towaoc	Oil/gas	PetroCorp., Rim Production

6.2.2 Infrastructure

In addressing infrastructure issues in the RFD Area, particularly the pipeline and power infrastructure, it is important to first review the current situation for the entire San Juan Basin Province, where current production is in the 3.5 – 3.7 BCF/day range (1.3 TCF annually) (US EIA 2005). In a study conducted by Pace Global Energy Services for the State of New Mexico Minerals and Energy Department (PACE 2004), the future of the San Juan Basin's resource potential is discussed; there are many scenarios and arguments showing production increases and declines. Recent history indicates that the San Juan Basin Province may have already peaked and has begun a long-term decline; other data suggests production is still on a slight incline. Pace Global forecasts flat production for at least the next five years (PACE 2004). It is likely safe to assume overall flat production from the San Juan Basin Province in New Mexico for the next five to 10 years, followed by a slow decline (estimates are 1 – 1.5 percent per year).

With respect to the RFD Area (Figure 19 and Table 9), the critical issue is how gas moves into the San Juan Basin pipeline system through the Blanco Hub. Consideration is primarily given to trunk pipelines, larger capacity lines used to transport gas or oil to market. Credible data is not available to address local gathering infrastructure. Currently the Paradox, Piceance, and Uinta basins all flow south to the Blanco Hub. There is insufficient capacity in these pipelines to accommodate the future development proposed in this RFD through 2020. For example, the Trans-Colorado pipeline (Figure 19), a major conduit for gas from the Paradox Basin part of the RFD Area, is at or near capacity. As more gathering capacity is built to feed the Blanco system, capacity constraints are likely for transmission out of the Blanco Hub. Currently, transmission capacity is very tight at the Blanco Hub, and if additional Paradox, Piceance and Uinta gas flows into the system, transmission capacity constraints could become real. The State of New Mexico is the responsible entity for dealing with this issue. Note that currently La Plata County represents over 50 percent of Colorado's gas production and makes up approximately 32 percent of the total San Juan Basin gas production.

FIGURE 19. Pipelines in the RFD Area

TABLE 9
MAJOR PIPELINES IN THE RFD AREA

Name	Owner	Use	Size (inches)
Basin	*	Gas	*
Mid-America	Enterprises Production	Gas	*
Public Service of Colorado	*	Gas	*
Rocky Mountain	*	Gas	4, 10
Trans-Colorado	Kinder-Morgan	Gas	22
Trans-Texas	Kinder-Morgan	CO_2	*
Williams	Williams Field Services	Gas	*

*Information unavailable at time of document publication

Introduction of liquefied natural gas (LNG) into the California markets could have an important effect on gas delivery in the San Juan Basin, as Southern California is the primary market for gas from the Blanco Hub. When LNG enters the California market in the next few years (industry estimates are 2007 – 2009), the daily volumes displaced by LNG would be lost by the San Juan Basin; i.e., when California starts using 10 percent LNG, the Blanco Hub will be sending 10 percent less to California. Pace Global predicts in their aggressive model that California may be using up to 35 percent LNG by 2015 (PACE 2004). In order to maintain sales, San Juan Basin gas would have to flow east to the Texas Panhandle or other eastern markets, with the overall effect that there will be pipeline constraints at the Blanco Hub, as there may be insufficient capacity there to deliver gas to the east. If there is insufficient capacity for eastern delivery, this may also affect the ability of gas upstream from the RFD Area to be delivered to the marketplace, as downstream users have priority.

In the HD Mountain area, a critical part of the future development of CBM, the only pipeline that is available to take gas is the Public Service of Colorado line, which is a high-pressure (900 psi) consumer line. CBM from the HD mountain area may contribute considerably more production than is currently estimated, particularly with the pending 80-acre down spacing. Elm Ridge Resources, a CBM producer in the HD Mountain area, is already attempting to run another line south to flow gas to the Blanco Hub.

In summary, although the pipeline infrastructure in the RFD Area is basically in place, capacity for future gas development may be limited, particularly in the Paradox Basin Province part of the RFD Area. In addition, moving gas out of the San Juan Basin may limit future development in the

RFD Area if new pipelines are not built to transport gas from the San Juan Basin to eastern markets.

With respect to electrical power infrastructure, most operators in the RFD Area use electricity only when it is readily available. If a well happens to be located adjacent to existing power transmission lines, then a possible connection might be made. However, the majority of the engines used on location (i.e. pump jack motors, compressor engines, and so forth) are natural gas fired. With the limited number of wells over such a large area as the RFD Area, it is unlikely that any company or combined companies will require large-scale electrical power usage that is not already available on the existing power grids.

Oil in the RFD Area is transported by tanker truck. Although the cost of transportation may be affected by rising fuel costs, the highway infrastructure is adequate to allow truck transport to proceed at the predicted higher production rates.

6.2.3 Pending Leases

Existing lease nominations in the eastern Paradox Basin Province of the RFD Area total 86 leases on 103,448 acres (Figure 3). An unknown number of unprocessed lease parcel requests have been submitted to SJPLC. This suggests a minimum potential for 140 new wells based on an average well spacing in the ununitized fields of the RFD Area of 1.15 wells per section. A proposal to drill 300 new wells over the next five years in the HD Mountain area is under review as part of the Northern Basin Environmental Impact Statement (SJPL 2004). Unitization in the RFD Area could result in an increase in well density and related increase in disturbance.

6.2.4 Impacts of Future Technology

A number of conventional and experimental development technologies are being used or evaluated in and adjacent to the RFD Area. These include stimulation technology, directional and horizontal drilling, multiple zone completion and other techniques. Some of the more important are discussed below; this discussion is largely taken from Engler and others (2001), who conducted a detailed analysis of the potential of future technology in the San Juan Basin Province.

Conventional well drilling is still common in the RFD Area, where vertical wellbores are the preferred drilling and completion method for oil and gas wells. There is lower cost and risk by drilling vertically. Reserves often can be captured adequately with vertical wellbores. When pumping is required to produce the oil, maintenance costs are lower in vertical wellbores. However, directional drilling and stimulation technology are being applied more frequently in the Area, particularly in the Paradox Basin Province, and these techniques are likely to continue to be used at an increasing rate. Some of the future development of new or mature plays in the Paradox Basin also may require application of some of the technologies discussed below.

Stimulation technology

Hydraulic fracturing techniques have evolved over the years with better fluids, proppants, and design. Advances in hydraulic fracturing of low permeability formations will have, perhaps, the greatest potential impact on the future development of the RFD Area. Hydraulic fracturing techniques are actively employed in the RFD Area and will likely be used more frequently as development proceeds. Although these techniques have been widely applied in the San Juan Basin Province since the 1950s, there remain many aspects upon which improvement is needed. Currently identified issues that require further improvement are (*ibid*):

- All stimulations tend to cause some degree of formation damage such that the efficacy of the stimulation is less than ideal.
- There is a regional shortage of better-engineered liquefied CO_2 delivery systems. This limits the application of, and increases the cost of less damaging liquid CO_2 fracturing.
- Cost reduction of all stimulations is a priority among all operators. The goal is to increase fracture efficiency while reducing cost per application in future well completions.
- Research is required to achieve more effective hydraulic fracturing of naturally underpressured or semi-depleted formations.
- There is currently a need to improve multi-zone or multi-formation stimulations within a single well bore.

These or other advancements could have significant impact on the efficiency of existing and future wells in the RFD Area.

Directional and horizontal drilling

Directional (purposely deviated) drilling allows producers to drill more than one well from a well location and to disturb less surface area. It also makes drilling more feasible in areas with multiple-use restrictions. The cost of drilling a directional well is commonly considerably more expensive and presents additional technical and financial risks. Therefore this technology has only recently been suitable and economically viable in the RFD Area.

The objectives of directional and horizontal drilling are typically related either to avoiding surface occupation or to increasing production efficiency, both of which are relevant to the RFD Area, particularly in the Paradox Basin Province. These two objectives are not always compatible. Avoidance of surface occupancy is typically due to topographic or environmental concerns. In terms of economic efficiency, such wells are less efficient due to increased cost (approximately 20%) and higher operating expenses with no change in producible reserves.

Under certain reservoir conditions, directional and horizontal drilling can be applied to improving recovery efficiency. Well bores oriented to maximize intersection of fractures, in particular, may better access fractured reservoirs. Directional drilling for improving efficiency is currently an option in the San Juan Basin Province (ibid), typically applied as an experimental technique. Known disadvantages of this type of directional drilling as applied to the San Juan Basin are significantly increased cost and production problems for wells that yield liquids.

Directional drilling can be applied to all producing formations in the Paradox Basin Province of the RFD Area, as the separation between the surface locations and the bottom hole locations are typically greater than 2000 feet. The more shallow the target formation, the less directional distance can be obtained. In the adjacent Canyon of the Ancients RFD area, at least four wells have been directionally drilled into the Desert Creek field, typically to avoid surface use conflicts (BLM 2004). EnCana Oil & Gas (US) is actively applying directional drilling in the Andy's Mesa, Cocklebur Draw, Hamilton Creek field, and Hamm Canyon fields of the RFD Area. Drilling costs for directional wellbores are higher and there is a slightly higher potential for problems to occur during drilling. Pumps located in the curved well bore experience more friction and have higher maintenance costs.

Single-lateral directional well drilling has been an experimental technique in the San Juan Basin in the past but has recently gained momentum as improvements are developed (Engler et al. 2001). Past efforts generally failed to achieve favorable economics when cost versus results were evaluated.

Horizontal drilling is possible but not currently applied in the San Juan Basin Province due to poor cost to benefit ratio (*ibid*). If horizontal drilling should prove economically and technically feasible in the future, the next advancement in horizontal well technology could be drilling multi-laterals or hydraulic fracturing horizontal wells. Multilaterals could be one, two or branched laterals in a single formation or single laterals in different formations. Hydraulic fracturing could be a single fracture axial with the horizontal well or multiple fractures perpendicular to the horizontal well. These techniques are currently complex and costly.

In the Paradox Basin Province, success with horizontal drilling in mature fields may increase drilling or redrilling activity because of the extra reserves captured with this new technology (BLM 2004). In some cases this technology could utilize existing vertical wellbores (recompletions), because the operators have a clearer picture of localized geology in the producing fields. By redrilling wells with a horizontal leg, the operator can accelerate and capture more reserves than a vertical well. In the case of new development, such as the Fractured Shale play, fewer wells would be required with horizontal wellbores. As a horizontal wellbore intersects a thousand or more feet of the producing formation verses vertical penetration, more oil or gas can be accessed and produced.

The success of horizontal drilling is dependent on the geology of the reservoir. It has not been tested in the existing oil and gas reservoirs in the Paradox Basin Province in the RFD Area. Horizontal wellbores are not as conducive for pumping. Operators will have to weigh these risks prior to opting for expensive horizontal completions verses traditional vertical completions.

Multiple zone completions/commingling

Recent advances in technology have enabled multiple zone completions in single well bores (Engler et al. 2001). Multi-zone completions include: 1) individual zone treatments with significant time lag between stimulation of each zone, 2) staged, limited-interval fracture treatments accomplished in a short period of time, and 3) limited entry where one large treatment is applied to multiple zones. Multiple zone completions are likely to be employed in the RFD Area as development proceeds.

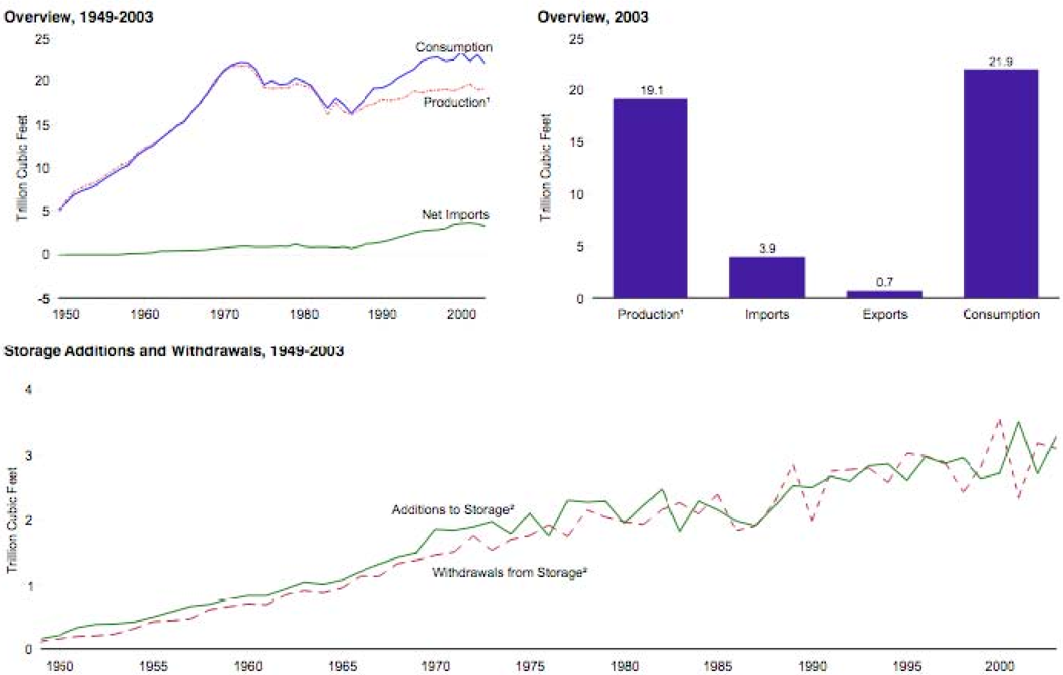
Although multi-zone completions reduce the number of well bores, problems have been identified with each type. For example, individual zone treatments require multiple trips to a well increasing well costs; they also cause loss of production due to extended shut-in periods. Staged fracture treatments have a significant residence time of fluid in the formations and thus can cause formation damage. Also, a limitation exists on the number of stages that can be pumped. Limited entry fracturing fails when formations of different reservoir characteristics are treated as a single zone. Future advances in fracture technology will focus in overcoming these limitations and should provide significant opportunities for commingling more zones in fewer well bores (*ibid*).

6.3 TRENDS

6.3.1 Natural Gas Price and Demand Trends

The figure below from the US Energy Information Administration (EIA) summarizes national natural gas trends (US EIA 2005). According to the EIA, total domestic natural gas consumption is projected to increase from 22 TCF in 2003 to 31 TCF in 2025. This represents a 41 percent increase in gas consumption over 22 years, or about two percent per year.

Figure 6.1 Natural Gas Overview



[1] Dry gas.
[2] For all years, includes underground storage; for 1980-2002, also includes liquefied natural gas stored in above-ground tanks.

Note: Because vertical scales differ, graphs should not be compared.
Source: Table 6.1.

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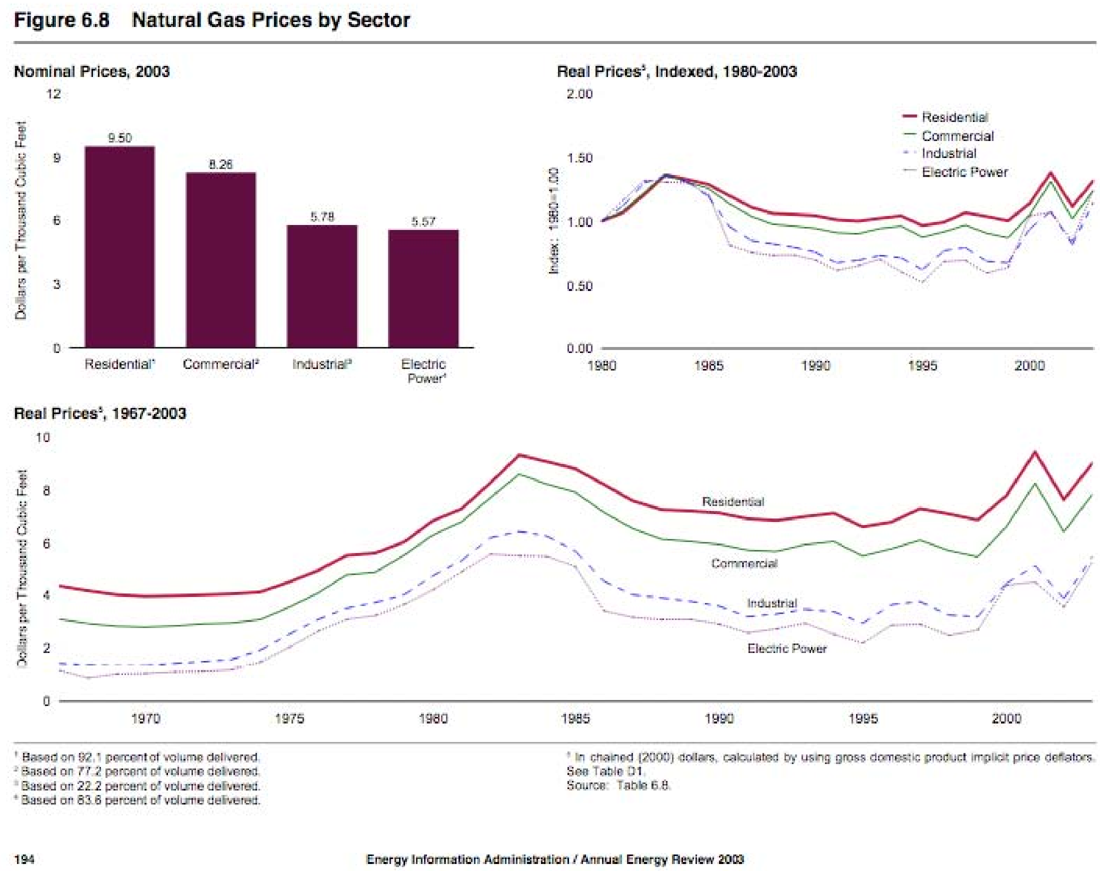
The largest increase in the Lower 48 onshore natural gas production is projected to come from the Rocky Mountain Region (which includes the RFD Area), primarily from unconventional (e.g., coal-bed methane) gas deposits (US EIA 2005). Production is projected to increase from 3.7 TCF in 2003 to 5.6 TCF in 2025. In 2003, Rocky Mountain production was 27 percent of the total Lower 48 onshore production and is projected to increase to 38 percent in 2025.

The natural gas resource base is sufficient in the early years of the forecast to support the increase in drilling activity. In later years, rising costs of gas well development reduce drilling activity, and resource depletion reduces reserve additions. As a result, total reserves are projected to decline. Projected gas price will be moderated slightly by increased gas imports from Canada and Alaska as well as increasing use of Liquefied Natural Gas (LNG) imports.

EIA projects an increased gas price of an average of about two percent per year not adjusted for inflation. Colorado's wellhead gas price trends follow closely with the national trend. However, gas prices can be strongly influenced by the international marketplace as well as by regional energy demands such as those of California, and increasing domestic consumption due to changes in population growth patterns.

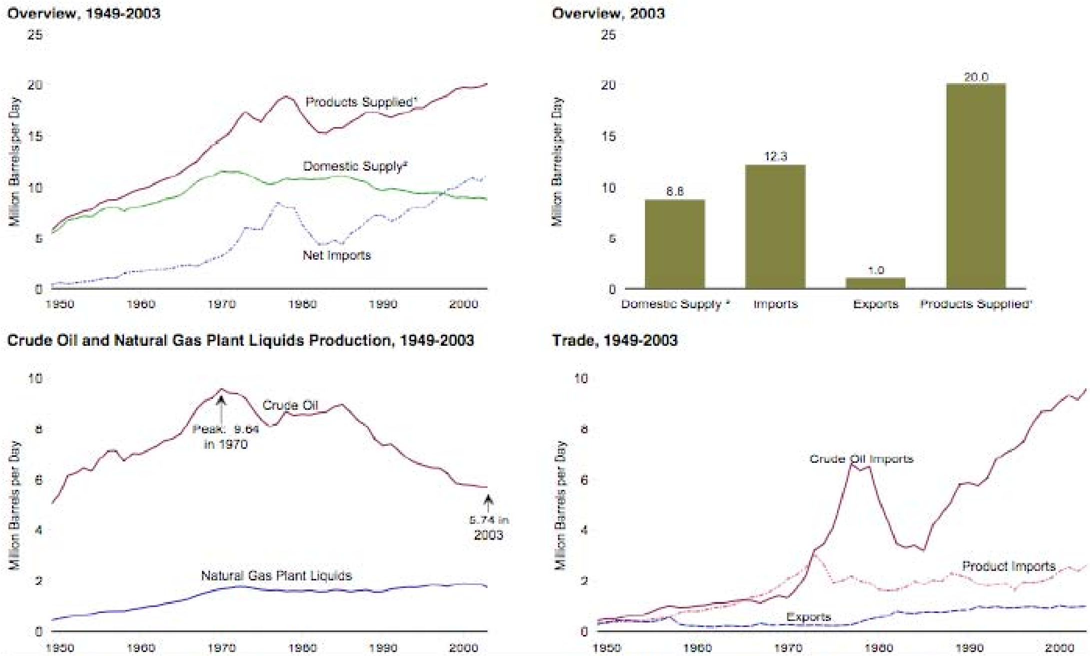


However, recent changes in international and national demand and consumption, which have led to spot prices for natural gas exceeding $15/MCF, as well as prognostications that predict prices for natural gas will remain high over the short and at least medium term, suggest that gas prices may equilibrate at levels well above those shown above.

6.3.2 Oil Price and Demand Trends

The figure below summarizes national petroleum trends (US EIA 2005). According to the EIA, total Lower 48 crude oil production is projected to increase from 4.7 MMBO per day in 2003 to 5.4 MMBO per day in 2009, and then decline to 4.1 MMBO in 2025.

Figure 5.1 Petroleum Overview



[1] Approximate representation of petroleum consumption.
[2] Crude oil and natural gas plant liquids production; refinery processing gains; and field production of other hydrocarbons, hydrogen, oxygenates (ethers and alcohols), gasoline blending components, and finished petroleum products.

Note: Because vertical scales differ, graphs should not be compared.
Sources: Tables 5.1 and 5.3.

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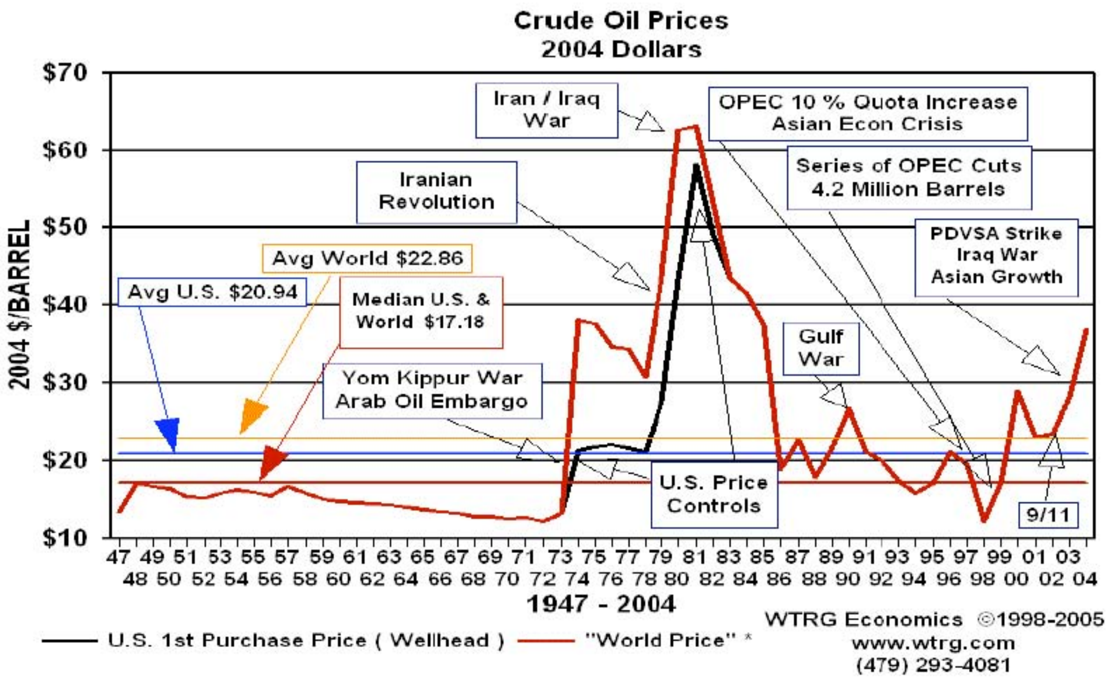
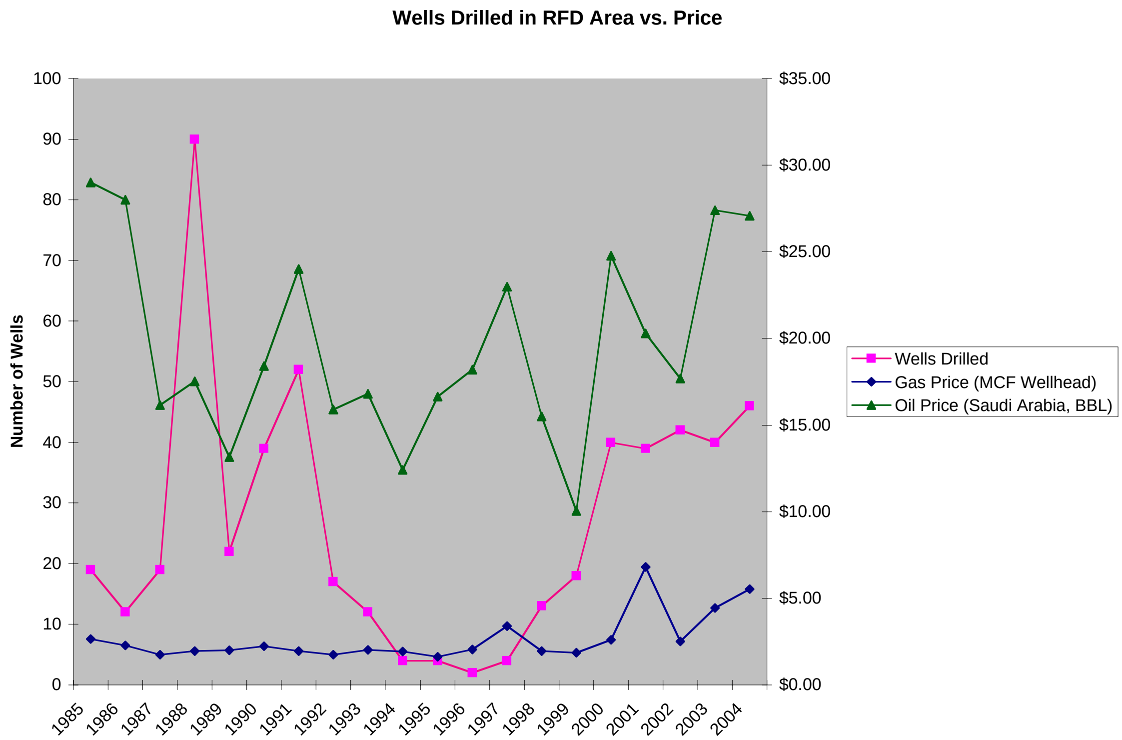
The historical oil price and demand is summarized in the figure below. Currently the price of oil is at highs of above $60/BBL. Most analysts concur that it has little likelihood of a major retreat in the short and at least medium term.



6.3.3 Drilling and Completion Trends

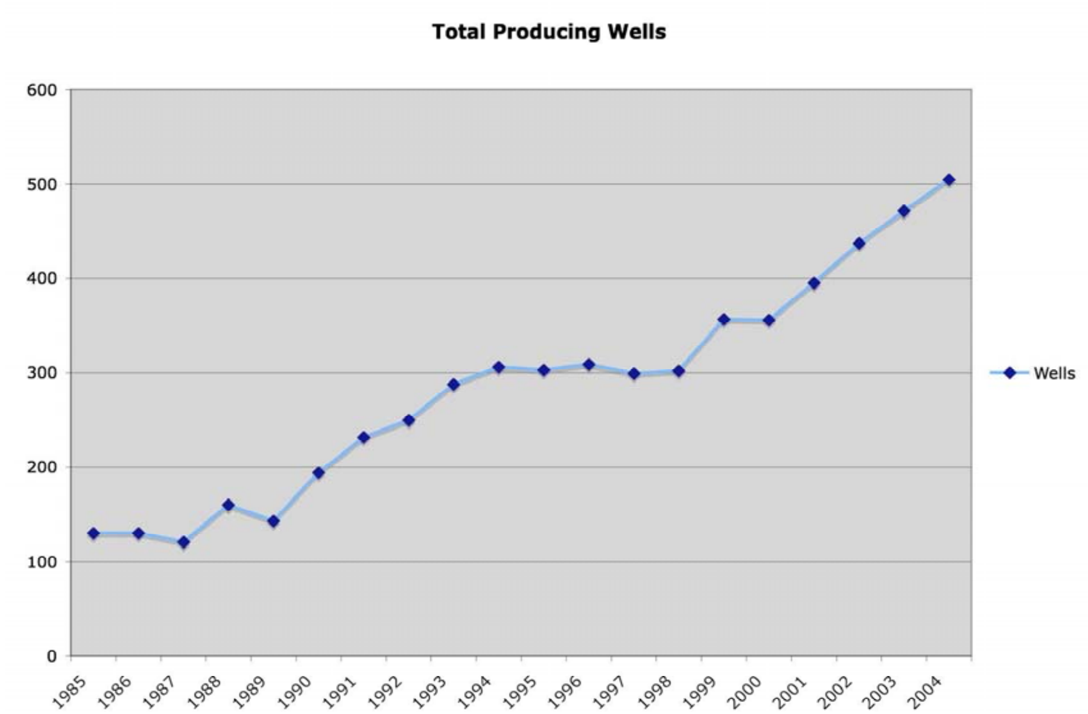
Drilling activity has been noteworthy in the RFD Area over the past twenty years, with 534 new wells drilled since 1984 (Table 1). Development activity has accelerated in the last five years, with an average of about 40 wells per year being drilled and completed. Note that current (October 2005) oil and gas prices are appreciably above 2004 values (US EIA 2005), with gas currently in the $13.50-$14.00/MCF range (as compared to $5.50 in 2004) and oil at about $62/barrel (as compared to $27.00 in 2004), with limited likelihood of a substantial retreat in price in the near term due to changes in international demand and supply.

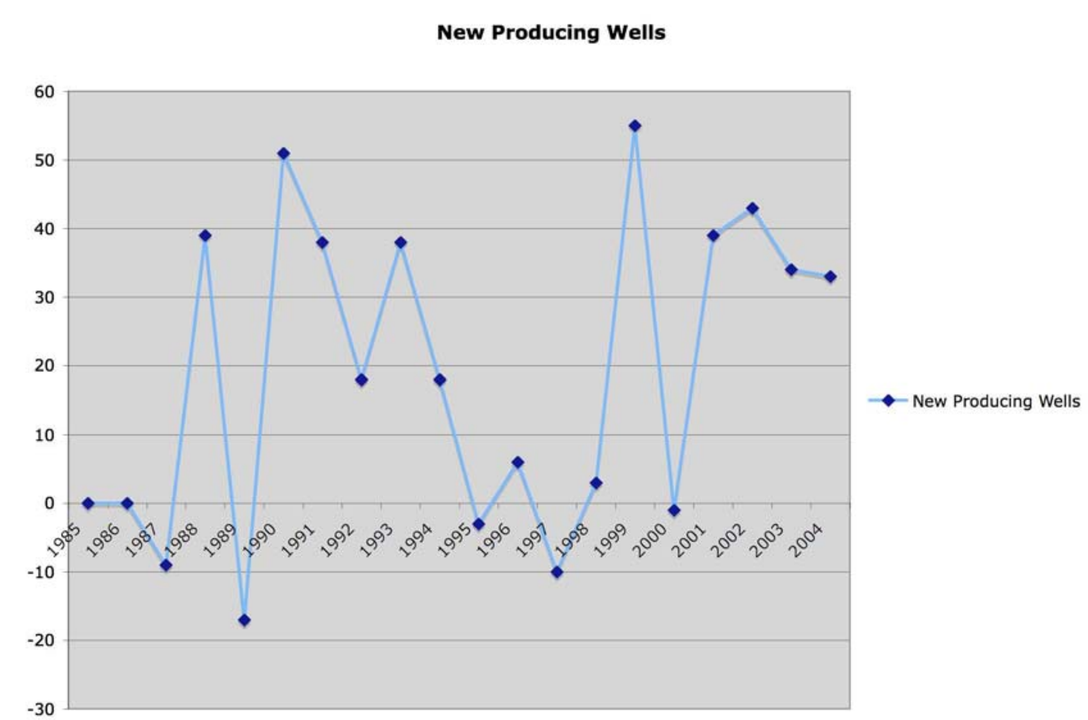
The figure below summarizes the drilling activity and compares it to the price of oil and gas (US EIA 2005) over the past 20 years. Over the last five years there is a clear relationship between steadily rising price and increasing well development activity in the RFD Area. The current (2005) prices and drilling trends point to considerable new development interest in the RFD Area, as does the new drilling and leasing activity in the RFD Area during 2004-2005.



6.4 FORECAST BASED ON HISTORICAL DRILLING ACTIVITY

As noted in the previous section, production from developed wells has also increased steadily, and the number of producing wells currently shows a constant annual increase of about 10 percent over the last six years, as indicated in the figures below. Based on current trends, drilling activity in the RFD Area is likely to continue at a minimum of 35 new wells per year. Given the oil and gas price trends discussed above, it is likely that this drilling activity may increase to more than 60 wells per year.


Total Producing Wells
600
500
400
300
200
100
0
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Wells


New Producing Wells
60
50
40
30
20
10
0
-10
-20
-30
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
New Producing Wells

7.0 REASONABLE FORESEEABLE DEVELOPMENT IN THE RFD AREA

Historical development and price trends, USGS and EPCA resource estimates, current drilling and development activity, existing leases, pending wells, pending leases, and pipeline and power infrastructure were considered in formulating this RFD report. The projection of drilling activity, both wildcat and development, is based primarily on the escalation of oil and gas prices that corresponds closely to the historical drilling activity and will mostly be confined to the high and medium resource potential areas (Figure 20). The low potential areas may have little or no activity, and the no potential areas are forecast for no activity. Proposed wells, such as those in the HD Mountain area, were also considered.

FIGURE 20. RFD Resource Potential

Increasing oil and natural gas prices, rising domestic consumption, and rig availability favor continued exploration for oil and gas nationally. More specifically to the RFD Area, 300 pending wells in the CBM area and 86 pending leases on 103,448 acres in the Mancos-Dolores area suggest noteworthy industry interest in additional development of the RFD Area.

For the purposes of this RFD, it is assumed that undrilled wells with currently approved permits, application for permit to drill (APD), are covered under the existing plan and previous RFD forecast. These wells are not covered in this new RFD forecast. From the historical drilling trends discussed in Section 6.3, one can forecast at least 525 new wells (35 per year) in the RFD Area over the next 5-15 years. Based on existing lease nominations and average well spacing, 140 wells can be anticipated in the western part of the RFD Area and at least 300 wells are planned for the eastern (CBM) area (SJPL 2004). These already proposed wells and (or) leases yield an average of about 30 wells per year.

7.1 ASSUMPTIONS

The following assumptions were made in making the RFD projections for the Area:

- Well-spacing regulations will be similar to current requirements
- Access to new well sites through the appropriate leasing and permitting activities will continue
- Current oil and gas prices will not escalate beyond an assumed two percent annually
- Existing technology will be used to develop the wells
- Well production efficiency will remain at current levels
- Existing infrastructure can be modified to handle future growth
- No disturbance reclamation credit is given for well abandonment.

Each of these assumptions is discussed below.

7.1.1 Well Spacing

In the RFD Area within the San Juan Basin Province, the current spacing is 320 acres with one well per 160 acres infill allowed as a matter of course. A major producer, British Petroleum (BP America) has sought to change that rule to allow drilling on 80-acre spacing immediately south of the RFD Area in the Southern Ute Reservation; this has been recently approved by the COGCC. Currently, BP America is producing 650 million cubic feet (MMCF)/day from their leases in southern Colorado from the Fruitland Coal Formation. Gas wells have been producing in the 640 - 670 MMCF/day range for the last three years. With the 80-acre downspacing, BP and other producers could drill an additional 450 Fruitland Coal wells in the San Juan Basin portion of the RFD Area. BP America believes that the additional production from these wells could push their daily production up to 700 MMCF/day. BP has also stated that they plan to drill directionally from existing locations, but as they approach the Fruitland outcrop zone, which is close to or in the RFD Area, directional drilling may not be possible because of the shallow depth to coals and limited new surface locations may be needed.

In the New Mexico part of the San Juan Basin Province, well spacing is as follows: Dakota, 160 acres with 80 acre infill; Mesaverde, 80 acres; Pictured Cliffs, 160 acres; Fruitland CBM, 320 acres with 160 acre infill with administrative approval.

In the adjacent Carson National Forest, Jicarilla District, plays have variable spacing: Pictured Cliffs gas is spaced at 160 acres per well; Mesaverde gas wells are spaced at 320 acres, with optional infill allowed at 80 acres per well; Dakota gas wells are spaced at 320 acres with 160 acre infill allowed and potential 80 acre development possible; and Fruitland CBM wells are spaced at 320 acres with 160 acre infill allowed.

In the Paradox Basin Province of the RFD Area, Unit Agreements make well spacing variable. Forty-acre spacing is allowed, but typical spacing over the region is about one well per section, with 320-acre spacing common. Well sites are selected based on geologic conditions. Unitization of leases provides the needed flexibility to properly explore, develop, and manage the reservoirs.

7.1.2 Access

It is assumed that the new Plan for the SJPL will allow access at the same level as is provided in the current SJNF (SJNF 1983, 1992) and BLM (BLM 1991) plans. Current federal policy directed toward easing access restrictions suggests that this assumption may be conservative.

7.1.3 Price Escalation

A two-percent annual increase is a conservative assumption based on current trends, but follows the longer-term projections made by the EIA (US EIA 2005).

7.1.4 Technology

It is conservative to assume that existing technology will be the rule in the next 15 years. The previously infrequent use of new technology was based on substantially lower oil and gas prices than exist today. Current price trends make new technology more feasible, particularly where site or reservoir constraints are important. It is likely that new technology will be used more frequently in the RFD period.

7.1.5 Well Efficiency

A conservative assumption is made that production efficiency will remain at constant levels. If new technology is cost effective and is applied to development, then efficiency may increase, potentially leading to additional production from existing wells and possible reductions in the number of wells drilled.

7.1.6 Infrastructure

As discussed in the previous section, power and road capacity are adequate to handle the additional production proposed in the RFD without construction of new power lines or roads. Pipeline construction will likely be required to transport gas from the Paradox Basin Province of the RFD Area, and possibly from the CBM area as well. Disturbance calculations are made below for expansion of the Trans-Colorado gas pipeline and potentially other pipelines.

7.1.7 Disturbance Credit

This assumption is self-explanatory. It potentially leads to an overestimate of the amount of disturbed land in the Area due to oil and gas development.

7.2 PRIMARY FACTORS FOR FUTURE RESOURCE DEVELOPMENT

The primary factors for prediction of future oil and gas development in the RFD Area are:

- Resource capacity in the plays
- Industry interest
- Competitive prices.

Each of these factors is discussed below. It is on the basis of these primary factors that the RFD projections that follow are made.

7.2.1 Resource Capacity of the Plays in the RFD Area

As discussed in Sections 5 and 6, the plays in the RFD Area have substantial future potential for development, with both the San Juan Basin Province CBM and the Paradox Basin Province conventional oil and gas showing many areas of high and moderate development potential (Figure 20), and predicted reserves that exceed the projected resource development in the RFD. It is therefore concluded that the plays can provide the resource predicted.

7.2.2 Industry Interest

Based on interviews with industry (Appendix D) and the proposed lease and development activity by industry in the CBM area (SJPL 2004) and Paradox Basin Province lease nomination areas, there is a clear interest in developing the resources of the RFD Area over the next 15 years. Extensive new drilling in the last two years by EnCana Oil & Gas (US) in the Paradox Basin Province of the RFD Area suggests that the current five-year average trend of ~17 wells per year in the Province is low.

7.2.3 Price Trends

As discussed in Section 6, prices for oil and gas are near their historic highs with little indication that they will fall substantially in the next few years. Moreover, increasing energy needs in the United States and internationally have changed the market for oil and gas in major ways. As drilling activity tends to follow rising prices in the RFD Area and elsewhere, and because the San Juan Basin and Paradox Basin Provinces are projected to play an important role in Rocky Mountain oil and gas development (US EIA 2005; USGS 2005), this RFD concludes that price will play an important role in increasing development activity in the RFD Area.

7.3 RFD PROJECTIONS

Based on the Resource Occurrence Potential discussed in section 5, industry interviews and leasing trends, and the price and development trends identified above, the following RFD projections are made:

- Coal-bed methane development in the San Juan Basin Province of the RFD Area will grow at an average of 60 wells per year at current spacing, for a period of approximately 5 years. This total of 300 CBM wells is taken from the Industry Proposed Action analyzed in the Northern Basin DEIS (SJPL 2004). No additional wells would be drilled within the 15 year projection period at current spacing.

  If, however, 80 acre spacing is applied north of the Ute line, an additional 450 CBM wells could be drilled within the Fruitland Formation, located in the San Juan Basin Province of the RFD Area. The drilling of an additional 90 wells per year would occur from 2009 through 2014 allowing time for regulatory changes to be adopted. Drilling approximately 450 CBM wells north of the Ute Line in addition to the 300 CBM wells at current spacing would allow a total of 750 CBM wells to be drilled within the San Juan Basin Province of the RFD Area. This will result in an average annual production increase of 10 billion cubic feet (BCF) of gas and a total annual production of 220 BCF by 2021. The total production of CBM during the next 15 years is projected to be 2.5 TCF of gas.

- Additional exploration for conventional oil and gas in the San Juan Basin Province in the RFD Area will result in an average of two exploratory wells per year over the next 15 years. Although no specific production is predicted for these wells, development is likely to focus in the Fractured Mancos, Dakota and Mesaverde plays.

- The San Juan Sag will see exploration and development activity at an average of two wells per year, ultimately yielding total production of 10 MMBO and 9 BCF of gas by 2021.
- The Paradox Basin Province plays in the RFD Area will grow at an average of 25 wells per year, for a period of 15 years including 140 new wells in the Mancos-Dolores lease nomination area, resulting in an annual production increase of 25,000 BBL of oil and 2.5 BCF of conventional gas. This will result in a total annual production of 730,000 BBL of oil and 65 BCF by 2021. The total production during the next 15 years in the Paradox Basin Province of the RFD Area is projected to be 8.7 MMBO and 740 BCF of conventional gas.

In summary, this RFD projection predicts drilling of approximately 89 wells per year throughout the RFD Area for the first three years and 179 wells per year for the following two years, 2009 and 2010. The next three years, 2011 through 2013 would include the drilling of 119 wells per year and continue at the rate of 29 wells per year being drilled for the subsequent seven years, 2014 through 2020 for a total of 1185 new wells over the projected 15 year period. These 1185 wells could ultimately produce at least 19 MMBO and 3.25 TCF of gas, which is well below the total discovered and undiscovered resource predicted by the USGS (2005), assuming that about 10 percent of the resources for the San Juan Basin and Paradox Basin Provinces can be allocated to the RFD Area.

7.3.1 Well Disturbance Calculations

Using the well projections above and following agency guidelines (*from* SJPLC), including containment of feeder pipelines to existing roadways, the following disturbance factors are assumed:

First 5-years (excluding 80 acre spacing) – 445 wells total

- Road Disturbance: 0.5 mile (2,640') distance * 40' clearing width = 105,600 sq ft (2.42 acres) per new well site
- Pad Disturbance: 1.5 acres (65,340 sq ft) per new well site
- Number of wells (excluding 80 acre spacing) = 445 (or 89 wells per year)

Disturbance calculations yield the following results:

- The total disturbance per well = Road disturbance (2.42 ac.) + Pad disturbance (1.5 ac.) = 3.92 acres.

- The total disturbance per year for new wells = Total disturbance per well (3.92 ac.) * Total number of wells per year (89) = 350 acres/year.

This first five year construction disturbance total is allocated as follows:

- Northern San Juan Basin CBM, 60 wells/yr = 235acres/yr.
- Northern San Juan Basin convention gas, 2 wells/yr = 8 acres/yr.
- Paradox basin (including NF), 25 wells/yr. = 98 acres/yr.
- San Juan Sag, 2 wells/yr. = 8 acres/yr.

Subsequent 10 years 2011 - 2021 (excluding 80 acre spacing) – 290 wells total

- Road Disturbance: 0.5 mile (2,640') distance * 40' clearing width = 105,600 sq ft (2.42 acres) per new well site
- Pad Disturbance: 1.5 acres (65,340 sq ft) per new well site
- Number of wells (excluding 80 acre spacing) = 290 (or 29 wells per year)_

Disturbance calculations yield the following results:

- The total disturbance per well = Road disturbance (2.42 ac.) + Pad disturbance (1.5 ac.) = 3.92 acres.
- The total disturbance per year for new wells = Total disturbance per well (3.92 ac.) * Total number of wells per year (29) = 114 acres/year.

This subsequent 10-year disturbance total is allocated as follows:

- Northern San Juan Basin CBM, 0 wells/yr = 0 acres/yr.
- Northern San Juan Basin convention gas, 2 wells/yr = 8 acres/yr.
- Paradox basin (including NF), 25 wells/yr. = 98 acres/yr.
- San Juan Sag, 2 wells/yr. = 8 acres/yr.

Total projected disturbance for first 5 years at current spacing is 1,744.4 acres and the disturbance projected for the subsequent 10 years is 1,136.8 acres. A total disturbance area of 2,881.2 acres is projected for the RFD Area over the next 15 years at current spacing.

80-Acre infill development – 450 wells total

A five year build out is assumed beginning in 2009 (or 90 wells/yr.)

Well disturbance assumption:

- Well pad disturbance: 1.5 acres/pad per new well site
- Well pad expansion (where infill well is collocated with existing well): 0.33 acres
- New road: (0.25 mile (1,320') distance * 40' clearing width) = 52,800 sq. ft (1.2 acres) where new well pads are constructed, otherwise zero acres
- Private and state mineral estate wells: one new well pad per section, all other well pads collocated.
- Federal mineral estate: All new wells collocated at existing pads and new well pads prohibited.

Drilling rate: 90 wells per year * 5 years beginning in 2009.

Well disturbance calculation:

Private and State mineral estate:	60 new well pads * 1.5 acres/pad =	90 acres
	190 expanded well pads * 0.33 acres/pad =	63 acres
	60 new road segments * 0.25 mi./pad =	72 acres
	All new pipeline collocated with roads =	0 acres
	New compressors located on existing sites =	4 acres
	Total	230 acres
BLM including split estate:	0 new well pads =	0 acres
	90 expanded well pads * 0.33 acres/pad =	30 acres
Nat. For. Including split estate:	0 new well pads * 1.5 acres/pad =	0 acres
	110 expanded well pads * 0.33 acres/pad =	36 acres
	0 new road segments * 0.25 mi./pad =	0 acres
	All new pipeline collocated with roads =	0 acres
	New compressors located on existing sites =	4 acres
	Total	40 acres

Total land disturbance, all jurisdictions resulting from 80 acre infill development = 300 acres or 60 acres/yr. for five years in the northern San Juan Basin CBM play.

Total disturbance for all projected wells in the San Juan Basin RFD Area including 80 acre infill spacing = 80 acre infill disturbance (300 acres) + Disturbance at current approved spacing (2,881 acres) = 3181 acres disturbance.

7.3.2 Infrastructure Disturbance Evaluation

Power and road capacity are sufficient to handle future development in the RFD Area. Pipeline capacity for the Paradox Basin Province in the RFD Area is insufficient. It is predicted that that a parallel 22-inch pipe to the existing Trans-Colorado gas pipeline will be required, and that a new 50-ft right of way will be necessary to construct the pipeline. The table below shows this disturbance; it also projects disturbance if all mapped pipelines require expansion.

All Mapped Pipelines	**Trans-Colorado Pipeline Only**
159 Miles Total Pipeline	Approximately 70 Miles within RFD Area
839,520ft X 50ft/row = 41,976,000 sq ft.	369,600 ft X 50 ft/row = 18,480,000 sq ft
= 936.63 Acres Total Disturbance	= 424 Acres Total Disturbance

7.3.3 Disturbance in the San Juan Basin Province of the RFD Area

It is estimated that there will be a total of 780 wells drilled in the San Juan Basin Province of the RFD Area over the next 15 years including the 80 acre infill spacing discussed in section7.1.1. Based on the disturbance data in Section 7.3.1, this results in a total of 1294 acres of disturbance from wells drilled at current spacing plus 300 acres of disturbance from wells drilled at 80 acre spacing resulting in 1594 acres of total disturbance. It is likely that 90 percent of the development will occur in the high resource potential areas (Figure 20), with the remainder in the high-moderate resource potential areas.

7.3.4 Disturbance in the Paradox Basin Province of the RFD Area

It is estimated that there will be approximately 25 wells per year drilled in this area. Based on the disturbance data in Section 7.3.1, this results in ~98 acres per year of disturbance, and a total disturbance of 1,470 acres. It is likely that 80 percent of the development (~80 acres/year) will occur in the high resource potential area (Figure 20), with the remainder in the moderate resource potential area, where development will focus on areas with existing leases or in lease nomination areas.

7.3.5 Disturbance in the San Juan Sag of the RFD Area

It is estimated that there will be two wells per year drilled in the San Juan Sag area which will result in a yearly disturbance of 8 acres per year and a total disturbance of 118 acres over the next 15 years.

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APPENDIX A
GLOSSARY

Acre-feet – The volume of water that will cover one acre to a depth of one foot; 43,560 cubic feet or 325, 875 gallons of water.

Alluvium – Unconsolidated sedimentary material that is deposited by a stream.

Aquifer – A body of rock in the subsurface of the earth that is sufficiently permeable to conduct groundwater and to yield water to wells and springs.

Carbon Dioxide (CO_2) – A corrosive gas that occurs naturally in a natural gas reservoir, or is injected into the reservoir to enhance reservoir recovery.

Cleat – A fracture or joint formed in coal beds. Cleats are normally found at right angles to bedding surfaces and are commonly present in two distinct sets at right angles to one another. The most prominent set is called the face cleat and the secondary set is called the butt cleat. Face cleats are more continuous than butt cleats. The density and degree of openness of the cleats in coal beds are the controlling factors in determining the flow of coal-bed gas out of the coal bed into a well bore.

Coal bed – A seam or stratum of coal that is parallel to rock stratification.

Coal-bed methane – Gas that is produced by the desorbtion of methane from coal beds; abbreviated as CBM.

CFR – Code of Federal Regulations; compilation of federal regulations that are adopted by federal agencies through a rule-making process.

Compressor – Equipment that is used to increase the pressure on the produced natural gas to move it into transmission lines or into storage; compressor is typically run by electricity or gas-driven.

Continuous gas accumulations: Petroleum accumulations that are regional in extent, commonly having low matrix permeabilities; have no obvious seals, traps, or hydrocarbon-water contacts; are abnormally pressured; are in close proximity to source rocks; and have low recovery factors. Also called unconventional accumulations.

Conventional accumulations: Discrete petroleum accumulation that has a well-defined hydrocarbon-water contact, commonly having high matrix permeabilities, obvious seals and traps, and high recovery factors.

Desorption – The process that restores an adsorbed substance to its original state; e.g., releasing gas from solid coal. In coal beds, desorption causes the flow of coal-bed methane from micropores in the coal to cleats and ultimately to the well bore.

Disturbance – An event that changes the local environment by removing organisms or opening up an area, facilitating biological colonization by new, often different organisms.

Disturbed areas – Area where natural vegetation and soils have been removed or disrupted.

Exploration – The search for economic deposits of minerals, ore, and other materials through practices of geology, geochemistry, geophysics, drilling, and (or) mapping.

Fault – A planar or gently curved fracture in bedrock along which there has been vertical and (or) horizontal movement.

Faulting – Relative displacement of adjacent bedrock that takes place along a fracture.

Floodplain – That part of a river valley that is adjacent to the river channel and that is built of recently deposited sediments; it is covered with water when the river overflows its normal channel at flood stages.

Fluvial – Comprehensive term that refers to river processes.

Fracturing – A method of stimulating well production by increasing the permeability of the producing formation by inducing fractures into the formation. Fracture fluids, which include propping agents, such as sand, gels or glass beads, are pumped into the formation under extremely high hydraulic pressure. The propping agents facilitate the formation of fracture channels to release hydrocarbons and water into a well.

Groundwater – The mass of water in the ground below the level in which total saturation of the pore space in the subsurface rocks takes place.

Hydrogen Sulfide (H_2S) – A flammable, poisonous, corrosive gas with an odor of rotten eggs that can naturally occur in the gaseous phase in hydrocarbon reservoirs.

Hydrology – The science that deals with the properties, distribution, and circulation of groundwater and surface water.

Infrastructure – The basic framework or underlying foundation of a community, including road networks, electric and gas distribution systems, water and sanitation services, and other facilities.

Igneous rock – A rock formed by the solidification of magma (liquid rock).

Injection well – Any well used to inject material into the subsurface of the earth; typically used for the disposal of air, water, gas or other substances into an underground stratum.

Joint – A planar fracture in a rock across which there is no relative displacement of the two sides.

Lease – Any contract, profit-share arrangement, joint venture or other agreement issued or approved by the United States under a mineral leasing law that authorizes exploration for, extraction of, or removal of oil and (or) natural gas.

Metamorphic rock – A rock whose original mineralogy, texture, or composition has been changed due to the effects of pressure, temperature, or the gain or loss of chemical components.

Methane (CH_4) – The simplest hydrocarbon; most natural gas is mainly or mostly methane.

Natural gas – Those hydrocarbons, other than oil and other than liquids separated from natural gas, that occur naturally in the gaseous phase in the reservoir and are produced and recovered at the wellhead in gaseous form. Natural gas includes coal-bed methane gas.

Natural Environmental Policy Act (NEPA) – The national charter for the protection of the environment, promulgated in 1969. NEPA establishes policy, sets goals, and provides means for carrying out the policy. Regulations at 40 CFR 1500 – 1508 implement the Act.

Permeability – The capacity of a soil, stratum, or aquifer to transmit water or gas.

Permeable – The property or capacity of a porous rock, sediment, or soil to transmit a liquid or gas through pores and cracks.

Play - A set of known or postulated oil and gas accumulations that share similar geologic, geographic, and temporal properties, such as source rock, migration pathway, timing, trapping mechanism, and hydrocarbon type.

Porosity – The percentage of the total volume of a rock that is pore space (voids or openings in rocks and soils).

Produced water – Water in a geological formation that is pumped during the development of an oil or gas well.

Proppant – Agents, such as sand, gels or glass beads that are pumped into a rock formation under extremely high hydraulic pressure to facilitate the formation of fracture channels to release hydrocarbons and water into a well.

Recharge – Replenishment of water in an aquifer through surface infiltration or along fracture lines.

Reclamation – The process of restoring disturbed areas using any of several methods, including recontouring, spreading topsoil or growth media, seeding and planting, and other activities.

Recontouring – Restoration of the natural topographic contours by reclamation measures; commonly applies to reclamation of roadways.

Reserves – Identified resources of hydrocarbon- and mineral-bearing rock from which the hydrocarbons and minerals can be extracted profitably with existing technology and under present economic conditions.

Reservoir rock - A connected layer of porous rock, such as sandstone or carbonates, that contains varying amounts of oil, gas, and (or) water, based on variations in permeability, porosity, and water saturation.

Resources – Reserves plus all other hydrocarbon and mineral deposits that may eventually become available, either know deposits that are not recoverable at present, or unknown deposits that may be inferred to exist but have not yet been discovered.

Right-of-Way (ROW) – An accurately located strip of land with defined width, point of beginning, and point of ending. The ROW defines the area within which the user has authority to conduct operations approved or granted by the landowner in an authorizing document, such as a permit, easement, lease, license, or other document.

Sediment – Materials deposited at the earth's surface by physical agents such as water, wind, and ice, chemical agents such as precipitation from oceans, lakes, and rivers, or biological agents such as living or dead organisms.

Sedimentary rock – Rock formed from fragments of pre-existing rocks (e.g., sandstone) or by precipitation from solution (e.g., limestone).

Soil – Loose, unconsolidated surface material consisting of topsoil and subsoil.

Source rock: Rocks, such as coal, carbonaceous shale, or shale, that provide the source for oil and gas generation and subsequent migration into reservoir rocks.

Strandlines: Former shorelines that became elevated above the sea level. In the San Juan Basin, this refers to the seaward limit of regressive cycles in the Mesaverde Group (sandstones).

Strata – An identifiable layer of bedrock or sediment; does not imply a particular thickness of rock or sediment.

Target formation – The geological association of rocks that contain the exploitable mineral or hydrocarbon reserves.

Thermal maturity values - Value that determined in source rocks by the percentage vitrinite reflectance in oil (%Ro). The vitrinite reflectance is a measure of the reflectivity of polished vitrinite (coal) particles under oil. This provides a measure of the thermal methane generation of the source rocks. Immature source rocks have lower values (less gas generated), whereas mature source rocks have higher values, indicating that source rocks have been heated sufficiently to generate larger quantities of methane.

Total dissolved solids (TDS) – Total mass per unit volume of dissolved material, organic or inorganic, contained in a sample of water.

Transitional gas accumulations – Petroleum accumulations in the transition zone adjacent to the area of continuous gas accumulation; gas saturations are less complete based on less mature source rocks; thus, a higher percentage of water-saturated reservoirs.

Volcanic rock – Rocks formed from volcanoes, any opening through the earth's crust that has allowed magma (liquid rock) to reach the surface.

Water quality – The set of chemical, physical, or biological characteristics that describe the condition of a river, stream, lake or groundwater aquifer.

Wellhead – The equipment used to maintain surface control of a well; composed of casing head, tubing head, and a series of valves and fittings.

Well pad – A level area constructed for the purpose of drilling a well.

APPENDIX B
ACRONYMS, ABBREVIATIONS, AND CONVERSIONS

APD	Application for Permit to Drill
API	American Petroleum Institute
B	1,000,000,000 (billion)
BBL	Barrels (also Bbl)
BCF	Billion cubic feet of gas
BLM	US Department of Interior, Bureau of Land Management
BO	Barrels of oil
BTU	British thermal unit [1 therm = 100,000 Btu = 29. 3 KWH; 10 therms = 1 MCF]
CBM	Coal Bed Methane
COGCC	Colorado Oil and Gas Conservation Commission
CF	Cubic Feet
DEIS	Draft Environmental Impact Statement
EIA	Energy Information Administration
EPCA	Energy Policy and Conservation Act
FEIS	Final Environmental Impact Statement
FS	US Department of Agriculture, Forest Service
G	Gas
GIS	Geographic Information System
KWH	Kilowatt Hours
M	1,000 (thousand)
MCF	Thousand cubic feet of gas [1 MCF ~ 1MM Btu]
MMCF	Million cubic feet of gas
MM	1,000,000 (million)
MMBO	Million barrels of oil
O	Oi1
RFD	Reasonable Foreseeable Development
SJNF	San Juan National Forest
SJPL	San Juan Public Lands
SJPLC	San Juan Public Lands Center
T	1,000,000,000 (trillion)
TCF	Trillion cubic feet of gas
USFS	US Department of Agriculture, Forest Service
USGS	United States Geologic Survey
W	Water

APPENDIX C
RFD INDUSTRY CONTACTS

Company	Telephone	Individual	Department	Action	Address	Interview
BP America (Houston)	(281) 366-2000 (281) 366-0394	Jeanine Piskurich Jeff Schwartz	Land Management Regulations man	Message Left 4/27, 4/29, Jeanine Piskurich Land management 5/16 BAB will send DVD 5/16, sent 5/17, message 5/26, 5/27, 5/31, message Schwartz 5/31 (if you do not know the name BP will not direct you)	P.O. 3092 Houston, TX 77253	6/7 w/Jeff Schwarz (BHB)
Tom Brown				Bought by EnCana		
EnCana	(303) 260-5000 (720) 876-5068 (720) 876-5053	Ruth Ann Morris Mike Kennedy Doug Van Steelandt (Waneel Secretary)	Land Management Exploration Manager	Message Left 4/27, 4/28 Orma Comstock (720) 876-3729 returned the call and indicated she would have the correct person call me, Left message 5/6, Ruth Ann Morris (720)876-5060 5/16 (505)883-6790 message 5/16, spoke w/Ruth Ann 5/16, Message with Mike Kennedy, Wanelle called and said forwarded to Van Steelandt, spoke to Van Steelandt BAB will send DVD 5/16, sent package 5/17	Republic Plaza 370 17th Suite 1700 Denver, 80202	5/24 W/Van Steelandt (BHB)
Burlington	(505) 326-9700	Linda Dean	Manager of Land Dept	Spoke with and delivered DVD, BAB did interview 5/18, wants GIS data		5/18 (BAB)
Cabot O&G	(303) 226-9400	John Muire Dan Row	Land Management	Spoke with, send DVD, sent 4/28, Left message 5/6, Message 5/16, spoke w/ Muire he is forwarding to Dan Roe 5/16, spoke to Row 5/26 call back talk to Muire on Tuesday, 5/31 message,	600 17th Street Suite 900 North, Denver Co 80202,	
CDX Gas	(505) 326-3003 (303) 577-0300	Rich Corcoran Gary Mabie	Land Manager Exploration Manager	Message Left 4/27, 4/29, Left DVD 4/27, 5/18 message with Gary Mabie		6/7 w/Gary Baby & Tom Dimlow (BAB)
Davis Oil Co	(303) 623-1000 918-8905	Russel Spencer	Land Management	Spoke with, send DVD, sent 5/28, Will meet W/Mark Goldberg 5/6, BAB met on 5/6	555 17th Street Suite 1400, Denver, 80202,	5/9 (BAB)

Company	Telephone	Individual	Department	Action	Address	Interview
Devon Energy Corp	(405) 235-3611 (405) 206-8244 (405) 552-4618	Charles Speer Jeff Hall	Land Manager Exploration Manager	Spoke with, send DVD, sent 4/28, Message 5/16, spoke with needs map 5/17, BAB sent map 5/18, message 5/26, message Speer 5/31, Message Hall 5/31,	20 North Broadway Oklahoma City, Oklahoma 73102-8260	
Elm Ridge Resources	(972) 889-2100 #100	Jamie Clark	VP	Message Left 4/27, 29, 5/2 spoke with send out DVD. Called Clark 5/19 message	12225 Greenville Ave., Dallas, Texas 75243	5/17 (BAB)
Energen	(205) 326-2700 (505) 326-6134 (505) 325-6800	Robert Plumb Gary Brink	District Land Manager So. CO.	Message Left 4/27, 29, spoke with Robert 5/2, DVD Sent 5/2, Message 5/16, will meet at 9:00 on 5/25	605 Richard Arrington Blvd. North, Birmingham, Alabama 35203, 2198 Bloomfield hwy	5/27 (BHB)
Petrox	(970) 878-5594	Mike Clark	Land Manager	Spoke with, send DVD, sent 5/28, 5/16 Will meet on 5/23	39868 Hwy 13, Meeker, Colorado 81641 / 1.5 miles west Meeker .75 miles east on 13 on right bus school sign straight on road red roofed white house	5/23 w/Clark (BHB)
Samson	(720) 904 1391 #234 Stowe #249 (720)239-4373	Kerry Heerssen Kevin Stowe	Land Management	Spoke with, send DVD, sent 4/28, Spoke with Kevin Stowe VP 5/2 #249, left message 5/6.message Kevin Stowe 5/16, message 5/26, 5/31	370 17th Street Suite 3000 Denver 80202	
Williams	(800) 945-5426 (918) 573-6171 (918) 573-6169	Brant Hale Berney Hanson	Land Management	Message Left 4/27, 29 DVD sent, message Hanson and Hale 5/16, spoke 5/17 has not looked at DVD need to call back later, Message 5/26, 5/31	1 Williams Center, MD26-4, Tulsa, OK 74172	
D.J. Simmons		John Byrum	President	Spoke with Jeff and left DVD, BAB interviewed 5/18		5/17 (BAB)

Company	Telephone	Individual	Department	Action	Address	Interview
Merrion O&G		Mike Merrion George Sharp	VP	Spoke with Mike and their landlady, left DVD, talked to Sharp will meet 5/26		5/26 (BHB)
XTO	(970) 247-7708 (970) 759-2376	Chuck Freier Lyndon Harrison	Area Production Super, Production Forman	Spoke with and delivered DVD, Spoke 5/31 Lyndon doesn't know where the info is now will call back tomorrow		
Round 2 (Pagosa apps to drill)						
Claude Houchin	(316)684-8614			Message 5/31		6/4 w/Claude Houchin (BAB)
Joe McMahon Jr.	(720)528-8880			Package 2 sent 5/31	4545 South Monaco #144, Denver, CO 80237	6/6 w/Joe McMahon (BAB)
William E. Hughes					P.O. Box 1177, Santa Fe, NM 87501	No Contact
William M. Breisford	(210)647-3521			Package 2 sent 5/31	4530 Hidden Creek, San Antonio, TX 78238	6/3 w/William Breisford (BAB)
Douglas E. Nelson				Package 2 sent 5/31	1600 Broadway #1950, Denver, CO 80202	No Contact
Bison Energy	(303)470-8067	James Crawford		Package 2 sent 5/31	2271 Mountain Sage Terrace, Highlands Ranch, CO. 80126	6/6 w/Travis Brown (BAB)
Neuhaus Properties	(956)686-2491	Wade Knolkamper	Consulting Geologist	Package 2 sent 5/31	656 North CR#1080, Kingsville, TX 78363	6/6 w/Wade Knolkamper (BAB)

NOTES: Interviewers: BAB = Bruce A. Black BHB = Bruce H. Black

APPENDIX D
SUMMARY OF INDUSTRY INTERVIEWS

Company	Plays	RFD Map OK?	Technology	15-yr Growth?	Concerns
Bison Energy	San Juan Sag and Archuleta Anticline--Pennsylvanian	Yes	No	Yes	Leasing and Nominating delays and restrictions
BP America (Houston)	San Juan Basin--Coals and lower horizons	Yes	Yes--Directional and Horizontal drilling	Yes--Horizontal and Directional drilling	Leasing and Nomination delays and restrictions
Burlington	San Juan Basin--Cretaceous; Paradox--Paleozoics	Yes	No	Yes	Continued use of existing leases and lease nominations
CDX Gas	San Juan Basin--Coals, Fractured Mancos, San Juan Sag and Paradox future exploration.	Yes	No	Yes	Leasing and Nominating delays and restrictions. Restrictions to infrastructure
Claude Houchin	San Juan Sag, San Juan Basin				Leasing and Nominating delays and restrictions
D.J. Simmons	Paleozoic--Red Mesa [33N,12W] Paradox--Papoose field	Yes	No	Yes	Continued use of existing leases and lease nominations
Davis Oil	Paradox--Paleozoic	Yes	No	Yes	Continued use of existing leases and lease nominations
Elm Ridge Resources	San Juan Basin--Coals, southern end San Juan Sag	Yes	No	Yes	Spacing rules, continued leasing, continued access
EnCana Oil & Gas (US)	Paradox--Paleozoic; San Juan Basin, San Juan Sag	Yes - add Dakota production in the Paradox	Yes--Directional and Horizontal drilling, improved drilling techniques to speed drilling, improved hydraulic stimulation techniques, He & CO2 tertiary recovery	Yes	Assembling large enough blocks to justify exploration. Open ended timing on regulatory actions and leasing. Lack of continuity between agency divisions.
Energen	San Juan Basin--Coals Archuleta Anticline--	Yes	Yes--Pull down rigs, advanced seismic techniques, advanced	Yes	

Company	Plays	RFD Map OK?	Technology	15-yr Growth?	Concerns
	Dakota		stimulation techniques.		
Joe McMahon Jr.	Pending				Leasing and Nominating delays and restrictions.
Merrion O&G	San Juan Basin, Paradox Basin (existing production only)	Yes	Yes--Directional drilling	Yes	
Neuhaus Properties	San Juan Sag--Cretaceous	Yes	No		
Petrox	San Juan Basin--Coals, possible deeper plays	Yes	Yes-- Tertiary nitrogen recovery of gasses	Yes	Continued use of existing leases and lease nominations, restrictions on access and infrastructure. Extreme delays in nominating and leasing.
XTO	San Juan Basin--Coals	Yes	No	Yes	Leasing and Nominating delays and restrictions.

APPENDIX E
CLASSIFICATION OF OIL AND GAS POTENTIAL
(*from* BLM Handbook H-1624-1, May 7, 1990, Revised December 19, 1994)

HIGH POTENTIAL

Play has demonstrated existence of source rock, thermal maturation, reservoir strata possessing permeability and porosity, and traps. Demonstrated existence is defined by physical evidence or documentation in the literature.

MEDIUM POTENTIAL

Play has geophysical or geological indications that the following may be present: source rock, thermal maturation, reservoir strata possessing permeability and porosity, and traps. Geologic indication is defined by geological inference based on indirect evidence.

LOW POTENTIAL

Play has specific geophysical or geological indications that one or more of the following may not be present: source rock, thermal maturation, reservoir strata possessing permeability and porosity, and (or) traps.

NO CURRENTLY RECOGNIZABLE POTENTIAL

Play has demonstrated absence of source rock, thermal maturation, reservoir rack, and traps. Demonstrated absence is defined by physical evidence or documentation in the literature.

Note:
Inclusion of an area in a USGS oil and gas play defined in the National Assessment should be considered in determining potential for oil and gas resources. However, because the USGS assesses speculative plays, play definition alone should not be the only criterion for determining potential.

APPENDIX G
FIGURES

APPENDIX H
TABLES

1. **RFD Well Summary**
2. **Geothermal wells and springs in the RFD Area** (embedded)
3. **Resource potential for San Juan Basin Province in RFD Area**
4. **Resource potential for San Juan Sag in RFD Area**
5. **Producing oil & gas fields of the San Juan Basin Province in the RFD Area** (embedded)
6. **Resource potential for Paradox Basin Province in RFD Area**
7. **Producing oil & gas fields of the Paradox Basin Province in the RFD Area** (embedded)
8. **A. Oil and gas Unit Agreements in the RFD Area** (embedded)
   B. Producing fields in the RFD Area without identified Unit Agreements (embedded)
9. **Major pipelines in the RFD Area** (embedded)

TABLE 1
RFD WELL SUMMARY

Province	County	Field(s)	Play(s)	Total Wells	New Wells Drilled 1985-2004	Producing Wells2004	Annual New Wells 2000-2004	2004 Production* Oil (KBBL)	Gas (BCF)
San Juan Basin									
	Archuleta**			362	56		0		
		Ignacio-Blanco	Fruitland Coal			28			1.8
		Navajo	Gallup/Mancos			5		2.3	
	La Plata			431	344	311	17		
		Ignacio-Blanco	Fruitland Coal						63.4
Paradox Basin									
	Dolores			54	4		0		
		Papoose Cyn.	Desert Creek/Ismay			16		17	0.3
		Stone Pony	Desert Creek			1		0.5	
	Montezuma			322	27		0		
		Menefee Mtn.	Dakota			1		0.5	
		Remainder	Ismay/Desert Creek			50		285.5	1.2
	San Miguel			170	102				
		Andy's Mesa	Cutler/Honaker Trail			73	16	20.2	18.6
		Hamilton Creek	Cutler/Honaker Trail			12	1	3.1	2.8
		Others	Paleozoic			5		1.6	0.5
			Totals	1339	533	502	34	331	89

Notes: * Excludes CO_2 production (321 BCF from 3 wells, McElmo Dome field)
**Includes 7 geothermal wells in Pagosa Springs

Source: Colorado Oil & Gas Conservation Commission database 2005

TABLE 3
RESOURCE POTENTIAL FOR SAN JUAN BASIN PROVINCE IN RFD AREA

Play	Field(s)	Resource Potential	Total Oil (MMBBL)	Total Gas (BCF)	Status
CBM*	Ignacio-Blanco	High	<1.0	10,000	Proven
Dakota	Ignacio-Blanco	High	1	1	Possible
Entrada	Ignacio-Blanco	Medium			Hypothetical
	Chromo	Medium			Hypothetical
	Navajo	Medium			Hypothetical
Fractured Mancos	Chromo	Medium	0.1		Possible
Mesaverde	Ignacio-Blanco	High	<0.1	<0.1	Possible
	Navajo	High			Possible
Mississippian	San Juan Basin	Low			Hypothetical
Pennsylvanian	San Juan Basin	Medium			Hypothetical
	San Juan Sag	Low			Hypothetical
Tertiary	San Juan Basin	Low			Possible
Tight-gas	Ignaco-Blanco	High	NA	6	Possible
	Navajo	High			Possible

* Includes Pictured Cliffs and Basin CBM

TABLE 4
RESOURCE POTENTIAL FOR SAN JUAN SAG IN RFD AREA

Play	Field(s)	Resource Potential	Total Oi (MMBBL)	Total Gas (BCF)	Status
Dakota	San Juan Sag	High	10	9	Proven
Entrada	San Juan Sag	Medium	1	NA	Possible
Fractured Mancos	San Juan Sag	High	1	2	Proven
Mancos					
Mesaverde	San Juan Sag	Medium	1	1	Possible
Mississippian	San Juan Sag	None			Hypothetical
Pennsylvanian	San Juan Sag	Low			Hypothetical

TABLE 6
RESOURCE POTENTIAL FOR PARADOX BASIN PROVINCE IN RFD AREA

Play	Major Field(s)	Resource Potential	Total Oil (MMBO)	Total Gas (BCF)	Status
Mississippian		Medium			Proven
	Lisbon Southeast				
Paradox		High			
	Andy's Mesa				Proven
	Cache				Proven
	Flodine Park				Proven
	Island Butte				Proven
	McClean				Proven
	Papoose Canyon				Proven
	Roadrunner				Proven
	Sleeping Ute				Proven
	Stone Pony				Proven
	Towaoc				Proven
Pennsylvanian		High			
	Andy's Mesa				Proven
	Cocklebur Draw				Proven
	Double Eagle				Proven
	Hamilton Creek				Proven
	Hamm Canyon				Proven
Permian		High			
	Andy's Mesa				Proven
	Double Eagle				Proven
	Hamilton Creek				Proven
	Total *		103	923	

National Assessment resource values cannot be resolved at 'Field' level; estimates
are given for total production based on 10% of discovered and undiscovered oil resources and 25% of the discovered and undiscovered gas resources for the Paradox Basin Province (EPCA 2000 and USGS 2004 update in USGS 2005).