Oil and Gas Development in Southwestern Wyoming—Energy Data and Services for the Wyoming Landscape Conservation Initiative (WLCI)

By Laura R.H. Biewick

Abstract

The purpose of this report is to explore current oil and gas energy development in the area encompassing the Wyoming Landscape Conservation Initiative. The Wyoming Landscape Conservation Initiative is a long-term science-based effort to ensure southwestern Wyoming's wildlife and habitat remain viable in areas facing development pressure. Wyoming encompasses some of the highest quality wildlife habitats in the Intermountain West. At the same time, this region is an important source of natural gas. Using Geographic Information System technology, energy data pertinent to the conservation decisionmaking process have been assembled to show historical oil and gas exploration and production in southwestern Wyoming. In addition to historical data, estimates of undiscovered oil and gas are included from the 2002 U.S. Geological Survey National Assessment of Oil and Gas in the Southwestern Wyoming Province. This report is meant to facilitate the integration of existing data with new knowledge and technologies to analyze energy resources development and to assist in habitat conservation planning. The well and assessment data can be accessed and shared among many different clients including, but not limited to, an online web-service for scientists and resource managers engaged in the Initiative.

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Acknowledgments

I thank the U.S. Geological Survey (USGS) Southwestern Wyoming Province Assessment Team for the comprehensive geologic analysis that went into assessing undiscovered oil and gas resources of this area. I relied on geologic information provided in U.S. Geological Survey Southwestern Wyoming Province Assessment Team, 2005 to analyze oil and gas exploration and production activity. I also thank Robert Meyer, Wyoming Oil and Gas Conservation Commission (WOGCC), for performing database retrievals that were needed over and above what is available by default at the WOGCC website. Steve Casenave (ATA contractor for the USGS) assisted by assembling the video clip of historical drilling activity, and I thank him for his technical skills. Thanks also go to Greg Gunther (USGS) for managing the Energy Resources Science Center map serving hardware and software that allows us to publish interactive internet GIS services. Also appreciated is Greg's development of the Energy Resources Science Center WLCI website and the map viewer for ArcGIS Server (ESRI, 2008b). This manuscript benefited from the thoughtful reviews of Tom Finn (USGS) and Robert Waltermire (USGS); their efforts in this regard are much appreciated. Lisa Binder (USGS) is gratefully acknowledged for editorial review, and Tracy Pinto and Loretta Ulibarri (USGS) for final document design.

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Introduction—Video of Exploration and Production Through Time

In order to provide a historical perspective of petroleum exploration activity in the Wyoming Landscape Conservation Initiative (WLCI), the USGS Central Energy Resources Team has developed a video clip. This video shows exploration and production in 5-year increments from 1901, when the first gas well was drilled in southwestern Wyoming, to the spring of 2008. Well data used in this report was retrieved from the Wyoming Oil and Gas Conservation Commission (WOGCC) in the spring of 2008. Field names of some of the large oil and gas fields show up during the time interval that the field was discovered. Figure 1 shows oil and gas wells from the WOGCC, overlying imagery from ArcGIS Online (ESRI, 2008a) and shaded relief from the geography network (ESRI, 2000a). All map figures use the imagery from ArcGIS Online and shaded relief from the geography network. To start the oil and gas exploration and production video, click on the image, below.

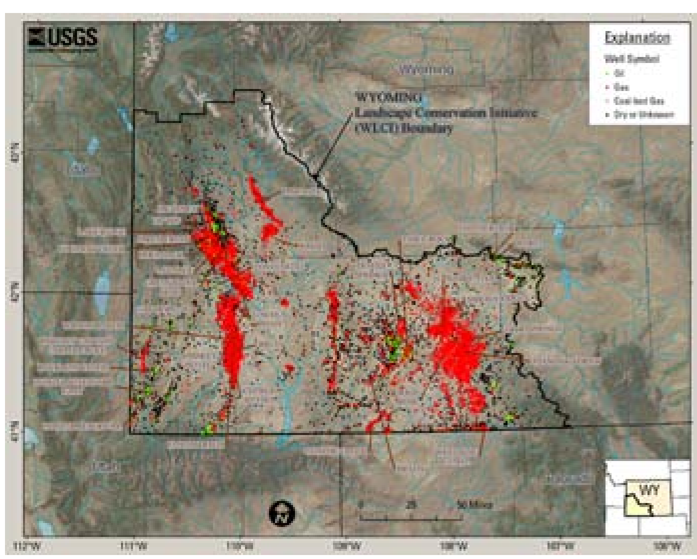

Figure 1. Map of historical oil and gas exploration and production in the WLCI. Field names are included for the

top gas producing fields.

The video is also included as a PowerPoint slideshow ZIP file (69.5 MB). Press the escape key (ESC) to end the slideshow.

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Units of Measure

MMBO, million barrels of crude oil
BCFG, billion cubic feet of natural gas
TCFG, trillion cubic feet of natural gas
MMBNGL, million barrels of natural gas liquids

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Undiscovered Oil and Gas Resources in the Southwestern Wyoming Province

Kirschbaum and others, 2002, used a geology-based assessment methodology to estimate a mean of 84.6 trillion cubic feet of undiscovered natural gas, a mean of 131 million barrels of undiscovered oil, and a mean of 2.6 billion barrels of undiscovered natural gas liquids in nine Total Petroleum Systems (TPS) in the Southwestern Wyoming Province. Nearly all (97 percent, or 82.1 TCFG) of the undiscovered gas resource is from continuous-type reservoirs and distributed in six TPSs:

1. Mowry Composite TPS (8.5 TCFG)
2. Hilliard–Baxter–Mancos TPS (11.7 TCFG)
3. Mesaverde TPS (25.8 TCFG)
4. Mesaverde–Lance–Ft. Union Composite TPS (13.7 TCFG)
5. Lewis TPS (13.5 TCFG)
6. Lance–Ft. Union Composite TPS (8.7 TCFG)

The remainder of the undiscovered gas is associated/dissolved gas in oil accumulations (0.13 TCFG) or is in conventional nonassociated gas accumulations (2.3 TCFG, Kirschbaum and others, 2002). Because the majority of the gas resources are distributed in seven assessment units (AUs) within the six TPSs listed above, this report focuses on these seven AUs:

1. Almond Continuous Gas AU of the Mesaverde TPS
2. Rock Springs–Ericson Continuous Gas AU of the Mesaverde TPS
3. Mesaverde–Lance–Fort Union Continuous Gas AU of the Mesaverde–Lance–Ft. Union Composite TPS
4. Lewis Continuous Gas AU of the Lewis TPS
5. Hilliard–Baxter–Mancos AU of the Hilliard–Baxter–Mancos TPS
6. Mowry Continuous Gas AU of the Mowry Composite TPS
7. Lance–Fort Union Continuous Gas AU of the Lance–Fort Union Composite TPS

The 2002 USGS assessment of undiscovered resources focused on the Southwestern Wyoming Province of Wyoming, Colorado, and Utah (fig. 2). This report is focused on the area defined by the WLCI boundary. In 2003, another assessment was completed west of the Southwestern Wyoming Province, in the Wyoming Thrust Belt Province. The estimates of undiscovered gas resources in the Wyoming Thrust Belt Province are minor compared to the gas resources in the seven AUs, and for that reason, are not included in this report. Assessment values discussed in this report are within the WLCI of southwestern Wyoming but also include portions of northwestern Colorado and a small portion of northeastern Utah. For instance, the Mancos portion of the Hilliard–Baxter–Mancos TPS, represents the Mancos Shale in the Sand Wash Basin of Colorado. Even though these assessed areas extend beyond the WLCI boundary, the data provides a good representation of the distribution, quantity, and availability of significant natural gas resources in the portion of southwestern Wyoming that is included in the WLCI.

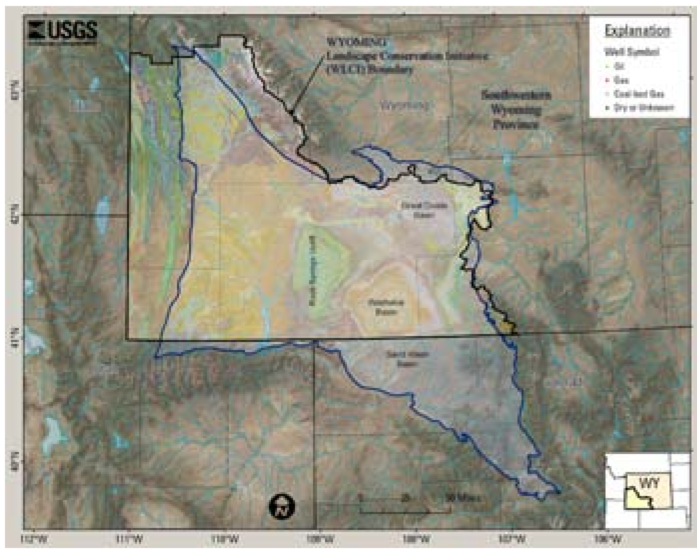

Figure 2. Map showing boundaries of the Wyoming Landscape Conservation Initiative and the Southwestern Wyoming Province with some of the major structural features labeled. The surface geology shown in the WLCI area is from the Geologic Map of Wyoming (Green and Drouillard, 1994).

Well data used in this report were retrieved from the WOGCC in the spring of 2008. The wells shown for each of the assessment units represent those wells in the WOGCC database that report reservoir names of the stratigraphic intervals (formations and groups) included in that particular AU. Because these formations and groups extend beyond individual assessment units, the wells shown also extend beyond a particular assessment unit and, therefore, some of the wells belong to adjacent continuous and (or) conventional AUs. The purpose of showing these wells is: (1) to indicate exploration and production activity in a particular stratigraphic interval, (2) to show what was known at the time of the 2002 USGS assessment of undiscovered resources, and (3) to show where exploration and production has occurred since the assessment. Because the well information shown with each AU is formation specific and not AU specific, individual wells can be shown with more than one AU. This report has attempted to summarize the geologic aspects of the oil and gas development using information from the detailed geologic studies described in U.S. Geological Survey Southwestern Wyoming Province Assessment Team, 2005.

Oil and Gas Development in Southwestern Wyoming—Energy Data and Services for the Wyoming Landscape Conservation Initiative (WLCI)

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Undiscovered Gas in the Mesaverde Total Petroleum System

The Mesaverde TPS contains the largest amount of estimated undiscovered natural gas (mean of 25.8 TCFG) in the Southwestern Wyoming Province and produces hydrocarbons from sandstone and coal reservoirs in the Upper Cretaceous Mesaverde Group (Johnson and others, 2005). The Mesaverde TPS encompasses about 11,500 mi^2 of the eastern part of the Southwestern Wyoming Province where the Lewis Shale is present (Johnson and others, 2005). The Lewis Shale, which overlies the Mesaverde Group and pinches out west of the Rock Springs uplift, as shown in the following cross-section, forms a regional seal separating the Mesaverde TPS from the overlying Lewis TPS. West of the pinch-out, there is no regional seal separating the Mesaverde TPS from overlying continental rocks of Late Cretaceous and Paleocene age, and the Mesaverde Group is combined with the overlying Upper Cretaceous Lance and Paleocene Fort Union Formations to form the Mesaverde–Lance–Fort Union Composite TPS (Johnson and others, 2005).

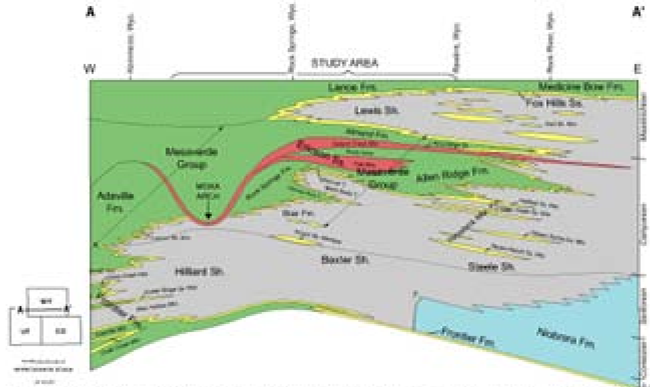

Figure 3. Generalized west to east cross section showing Upper Cretaceous stratigraphic units from northeastern Utah to southeastern Wyoming. Approximate limits of Southwestern Wyoming Province shown in brackets. Modified from Roehler (1990, his fig. 7) in Johnson and others (2005, their fig. 3). Abbreviations used: Fm., Formation; Mbr., Member; Ss., Sandstone; Sh., Shale; T., Tongue.

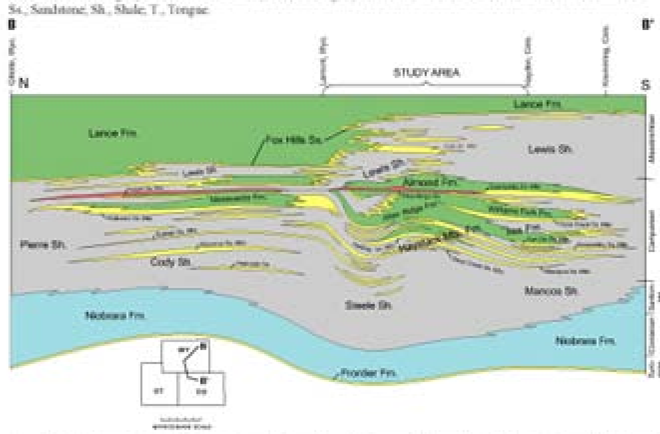

Figure 4. Generalized north-south cross section showing Upper Cretaceous stratigraphic units from northeastern Wyoming to north-central Colorado. Approximate limits of Southwestern Wyoming Province shown in brackets. Modified from Roehler (1990, his fig. 9) in Johnson and others (2005, their fig. 4). Abbreviations used: Fm., Formation; Mbr., Member; Ss., Sandstone; Sh., Shale.

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The Almond Continuous Gas Assessment Unit (13.3 TCFG)

The majority of hydrocarbons produced from the Mesaverde TPS at the time of the 2002 USGS assessment have been from marginal marine-bar sandstones in the upper part of the Almond Formation. These bar sandstones have produced most of the gas from the Almond Continuous Gas AU (Johnson and others, 2005). Figure 5 shows the extent of the Almond Continuous Gas AU, the mean estimate of undiscovered gas and gas liquids in that AU, and wells from the WOGCC. The wells shown have a reservoir name of Almond and a completion date of 2001 or earlier. A 2001 version of a commercial national wells database was used for the 2002 USGS assessment. The publicly available wells shown in figure 5 provide an example of the well data that was available at the time of the assessment.

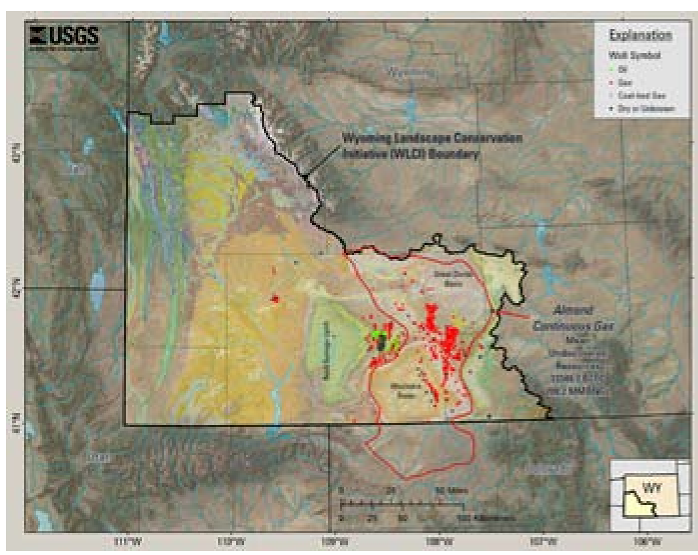

Figure 5. Almond Formation wells at the time of the assessment (through 2001).

Marginal marine-bar sandstones of the Almond Formation persist a considerable distance west of the Almond

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Continuous Gas AU, west of the pinch-out of the Lewis Shale. The oil and gas produced from the bar sandstones to the west of the Almond Continuous Gas AU, are from other Mesaverde Group AUs that reside west of the Lewis Shale pinchout, some of which are described further in this document and all of which are described in Johnson and others, 2005, and Finn and others, 2005. Figure 6 shows the same data as in figure 5, but additional wells have been added from the WOGCC wells database to show how drilling of the Almond has progressed to the spring of 2008.

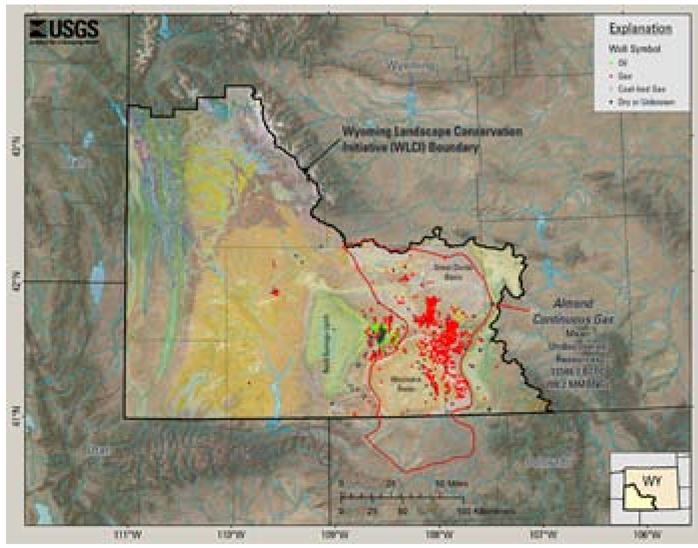

Figure 6. Almond Formation wells as of spring, 2008.

Since the 2002 assessment, 787 additional wells have been completed in Almond Formation reservoirs, 67 of which are shown to have produced from or terminated in Almond coal beds (WOGCC).

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The Rock Springs–Ericson Gas Assessment Unit (12.2 TCFG)

The Rock Springs–Ericson Gas AU (AU 50370662) covers about 4.36 million acres of the deeper parts of the Mesaverde TPS. As shown below in the generalized correlation chart, this AU includes: the Rock Springs and Ericson Formations in the western part of the Washakie and Great Divide Basins, the Allen Ridge Formation and Pine Ridge Sandstone in the eastern part of the Washakie and Great Divide Basins, and the Iles and lower part of the Williams Fork Formations in the Sand Wash Basin (Johnson and others, 2005).

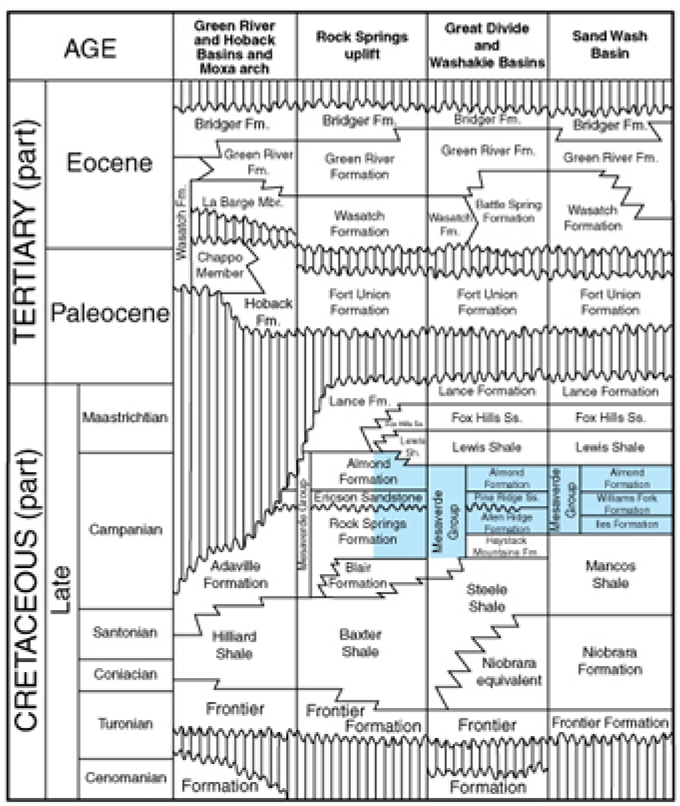

Figure 7. Generalized correlation chart for Upper Cretaceous and lower Tertiary stratigraphic units in the Southwestern Wyoming Province. Mesaverde Total Petroleum System shown in blue. Modified from Ryder (1988) *in* Johnson and others (2005).

As described in [Johnson and others (2005)] the Rock Springs–Ericson Continuous Gas AU, though largely untested, contains thick sequences of reservoir rocks that were deposited in settings similar to successfully developed, basin-centered accumulations throughout the Rocky Mountains. Figure 8 shows the extent of the Rock Springs–Ericson Continuous Gas AU, the mean estimate of undiscovered gas and gas liquids in that AU, and wells from the [WOGCC] that have a reservoir name of Rock Springs or Ericson and a completion date of 2001 or earlier.

[Figure 8.] Rock Springs Formation–Ericson Sandstone wells at the time of the assessment (through 2001).

At the time of the assessment, most of the tests of this AU date to the 1970s and 1980s when our understanding of how to produce from the tight reservoirs in basin-centered accumulation was in its infancy [(Johnson and others, 2005)]. Testing of this AU largely ceased once the productive potential of the marginal marine-bar sandstones in the Almond was recognized. [Johnson and others (2005)] state that these estimates assume future production for the Rock Springs–Ericson AU would be significantly greater than production from the AU thus far because most completions are more than 12 years old, and drilling and completion practices have improved significantly since these wells were completed. An analogy for the lenticular sandstone reservoirs in the Rock Springs Formation is the productive lenticular sandstones in the lower part of the Williams Fork Formation in the Piceance Basin Continuous Gas AU [(Johnson and Roberts, 2003)]. Lenticular sandstones in both AUs were deposited in coastal plain and fluvial settings [(Johnson and others, 2005)]. These sandstones in the Piceance Basin are currently being developed using spacing of as little as 20 acres [(Johnson and others, 2005)]. An analogy for the marginal marine sandstones in the Rock Springs Formation is the production from similar bar sandstones in the overlying Almond Formation [(Johnson and others, 2005)]. The large number of currently producing Almond wells within the boundaries of the Rock Springs-Ericson AU may help spur development, as these wells could be deepened to test the Rock Springs Formation and Ericson Sandstone for a fraction of the cost of a new well (Johnson and others, 2005). Figure 9 shows the same data as the map above, but additional wells have been added to show how, according to the WOGCC wells database, drilling of the Rock Springs and Allen Ridge Formations and the Ericson Sandstone has progressed to the spring of 2008.

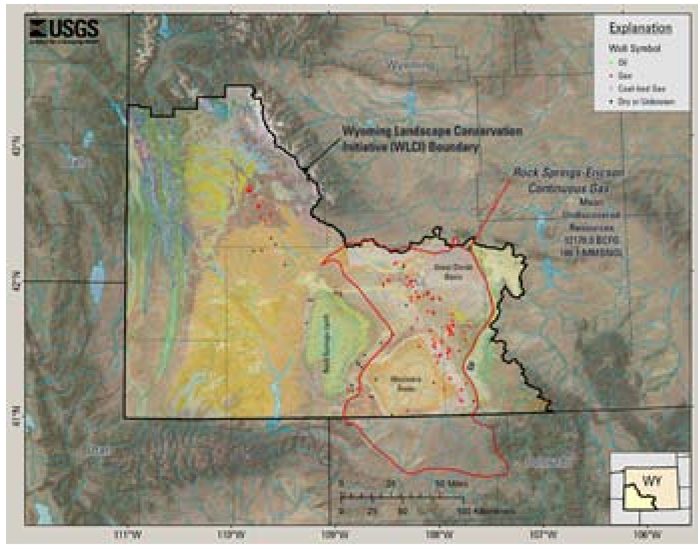

Figure 9. Rock Springs Formation-Ericson Sandstone wells as of spring, 2008.

The WOGCC well data shows that since the 2002 assessment, 205 additional wells are reported to have been completed in the Ericson Sandstone and the Rock Springs and Allen Ridge Formations, 91 of which are shown to have produced from or terminated in coal beds.

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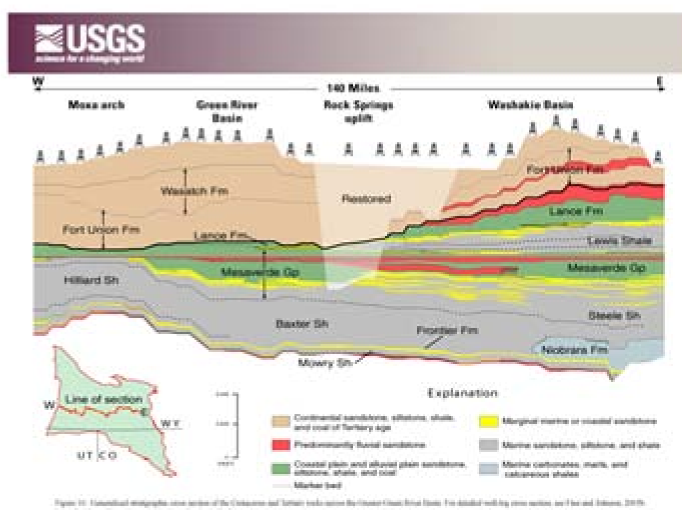
Undiscovered Gas in the Mesaverde–Lance–Fort Union Composite Total Petroleum System

For the 2002 assessment, the Mesaverde–Lance–Fort Union Composite TPS is considered as one total petroleum system because all of the units were deposited in a nonmarine continental setting and contain similar gas-prone source rocks, and because there is no regional seal within the entire stratigraphic succession to inhibit the vertical migration of gas (Finn and others, 2005). In the generalized stratigraphic cross section and generalized correlation chart (fig. 10), where the Lewis Shale is present, to the east, the same stratigraphic interval is subdivided into three TPSs in ascending order: the Mesaverde TPS, the Lewis TPS, and the Lance–Fort Union Composite TPS (Finn and others, 2005). The upper limit of the Composite TPS is placed at the base of the lowest regionally extensive lacustrine shale seal in the Wasatch or Green River Formation (Finn and others, 2005).



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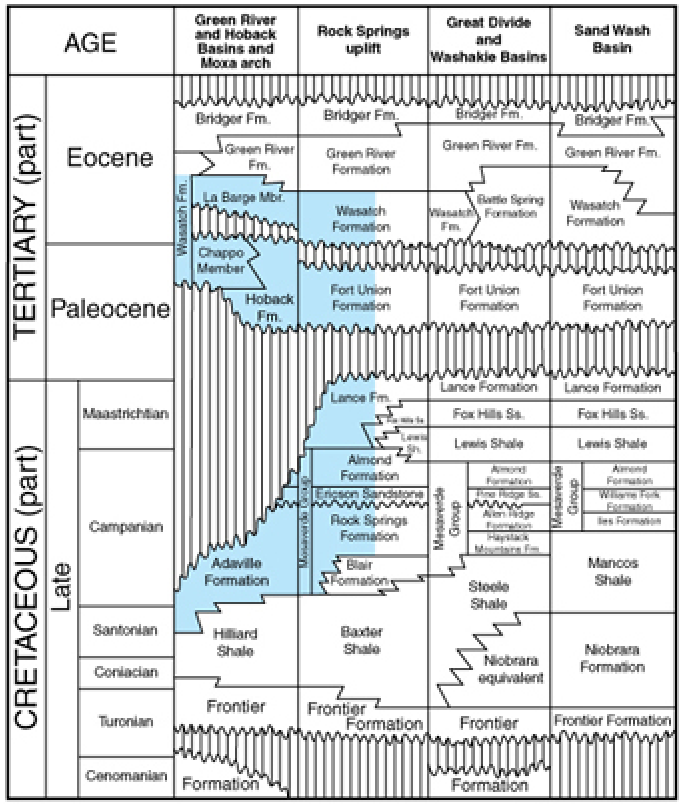

Figure 11. Generalized correlation chart for Cretaceous and lower Tertiary stratigraphic units in the Southwestern Wyoming Province. Mesaverde–Lance–Fort Union Composite Total Petroleum System shown in blue. Modified from Ryder (1988) in Finn and others (2005).

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The Mesaverde–Lance–Fort Union Continuous Gas Assessment Unit (13.6 TCFG)

The Mesaverde–Lance–Fort Union Continuous Gas AU encompasses the deeper part of the Composite TPS where thermal maturities at the base of the Rock Springs Formation and equivalent rocks are 0.8 percent R_o or greater (Finn and others, 2005). Two gas fields, Jonah and Pinedale, are included in the Mesaverde–Lance–Fort Union continuous gas AU (Finn and others, 2005). Figure 12 shows the extent of the Mesaverde–Lance–Fort Union Continuous Gas AU, the mean estimate of undiscovered gas and gas liquids in that AU, the Jonah and Pinedale gas fields, and wells from the WOGCC that produce from or terminate in units of the Mesaverde–Lance–Fort Union Composite TPS and have a completion date of 2001 or earlier. Notice that wells that produce from the Mesaverde Group appear between the Great Divide Basin and the Washakie Basin in the area occupied by the Almond Continuous Gas AU. These wells that are attributed in the database as producing from the Mesaverde, most likely produce from the Almond bar sandstones within the Mesaverde Group.

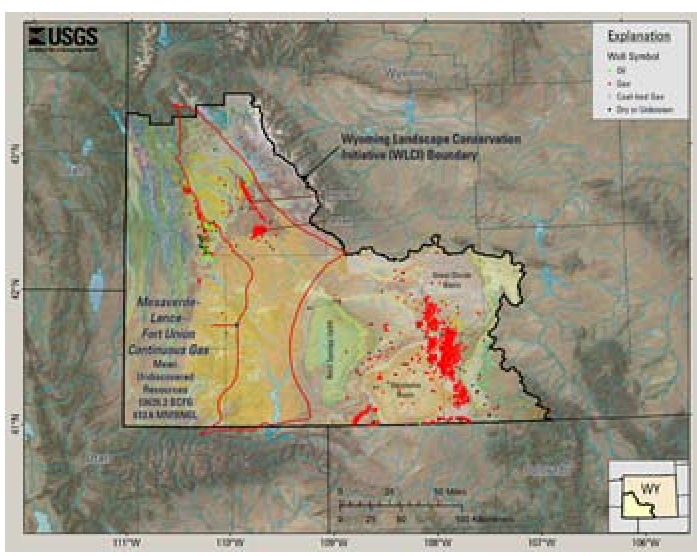

Figure 12. Mesaverde Group, Lance and Fort Union Formation wells at the time of the assessment (through 2001).

Figure 13 includes the same data as figure 12, with post-2001 wells added to show how, according to the WOGCC wells database, drilling of the Mesaverde Group, the Lance Formation and the Fort Union Formation has progressed to the spring of 2008.

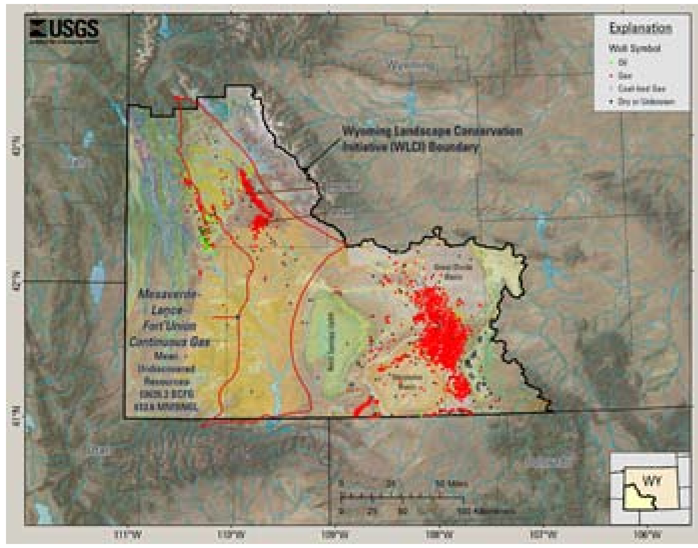

Figure 13. Mesaverde Group, Lance and Fort Union Formation wells as of spring, 2008.

Since the 2002 assessment, 4,162 additional wells have been completed in the Mesaverde Group, Lance and Fort Union Formations, 300 of which are shown to have produced from or terminated in coal beds (WOGCC).

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Undiscovered Gas in the Lewis Total Petroleum System

The Lewis TPS within the Southwestern Wyoming Province of Wyoming, Colorado, and Utah is a complex of marine strata that contains significant quantities of gas (Hettinger and Roberts, 2005). At the time of the USGS assessment, Hettinger and Roberts (2005) reported that between 600 and 675 BCFG and minor amounts of oil had been produced since 1974. Previous investigations reveal that the sandstone reservoirs have a net thickness of as much as 600 feet. The sandstones were deposited in deltaic and turbidite systems, and some basin-floor sand lobes extend across as many as 30 townships (Hettinger and Roberts, 2005).

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The Lewis Continuous Gas Assessment Unit (13.5 TCFG)

Hettinger and Roberts (2005) report that over its extent, about 18 to 69 percent of the Lewis Continuous Gas AU has potential for additions to reserves in the next 30 years. These areas are estimated to contain between 8,765 and 19,667 BCFG, with a calculated mean of about 13,536 BCFG (Hettinger and Roberts, 2005). Gas discoveries in the next 30 years are likely to be similar in size to historical discoveries, but success ratios are expected to be significantly higher owing to improved exploration strategies, improved completion techniques, and an improved understanding of the basin-centered system (Hettinger and Roberts, 2005). Drilling success ratios are anticipated to range from 80 to 90 percent (with a median of 85 percent, Hettinger and Roberts, 2005). In Great Divide Basin, the Lewis Shale contains sandstones that were cited specifically as examples of stratigraphic sweet spots (Law, 2002, p. 1913), which are local areas of enhanced reservoir quality. Although about 600 BCFG has been produced from the Lewis Shale (Doelger and others, 1999), its production is impossible to determine precisely due to commingling with other formations (Hettinger and Roberts, 2005). The Lewis Continuous Gas AU occupies the deeper parts of the basin that are characterized by an overpressured, gas-saturated, basin-centered system (Hettinger and Roberts, 2005). The deep-basin accumulations may have the best reservoir potential for stratigraphic trapping because they contain laterally continuous basin-floor sandstones overlain by deep-water shales that provide good seals (Pyles, 2000; Pyles and Slatt, 2000). Figure 14 shows the outline of the Lewis Continuous Gas AU, the mean estimate of undiscovered gas and gas liquids in that AU, and wells from the WOGCC that have a reservoir name of Lewis and a completion date of 2001 or earlier.

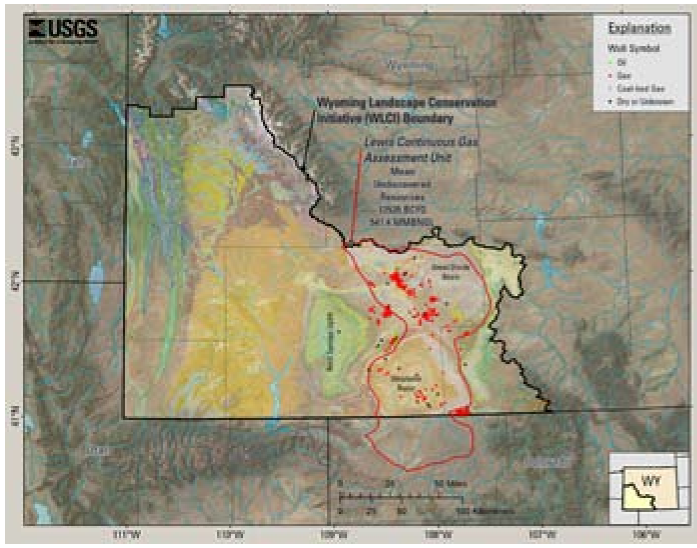

Figure 14. Lewis Shale wells at the time of the assessment (through 2001).

Figure 15 includes the same data as figure 14, with post-2001 wells added to show how drilling of the Lewis Shale has progressed to the spring of 2008 (WOGCC).

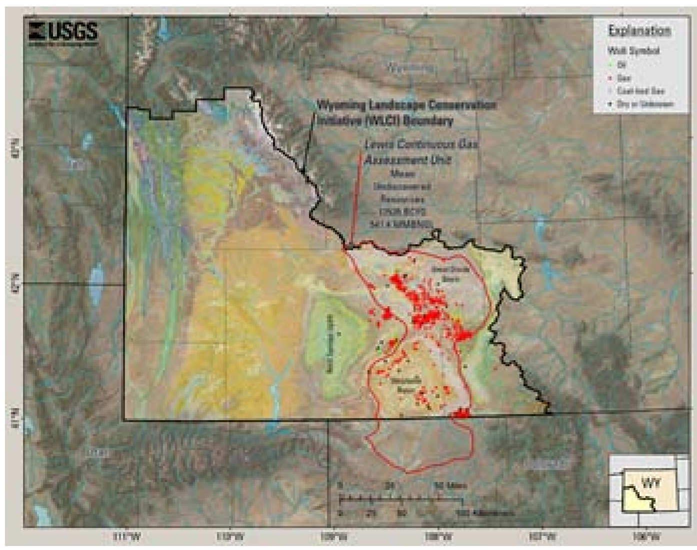

Figure 15. Lewis Shale wells as of spring, 2008.

Since the 2002 assessment, 354 additional wells have been completed in the Lewis Shale (WOGCC).

Oil and Gas Development in Southwestern Wyoming—Energy Data and Services for the Wyoming Landscape Conservation Initiative (WLCI)

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Undiscovered Gas in the Hilliard-Baxter-Mancos Total Petroleum System

The Hilliard-Baxter-Mancos interval, as shown on the generalized correlation chart (fig. 16), was deposited in offshore to nearshore marine settings in the Rocky Mountain foreland basin during an extended period of time in the Late Cretaceous, when the shoreline was predominantly to the west of the TPS (Finn and Johnson, 2005a). The stratigraphic interval included in the TPS ranges from about 3,500 to 6,000 ft thick and contains thick intervals of organic-rich marine shales that are potential source rocks, and thick silty and sandy nearshore to offshore marine intervals that are potential reservoir rocks. This TPS has been sparsely explored, but some promising discoveries have been made (Finn and Johnson, 2005a).

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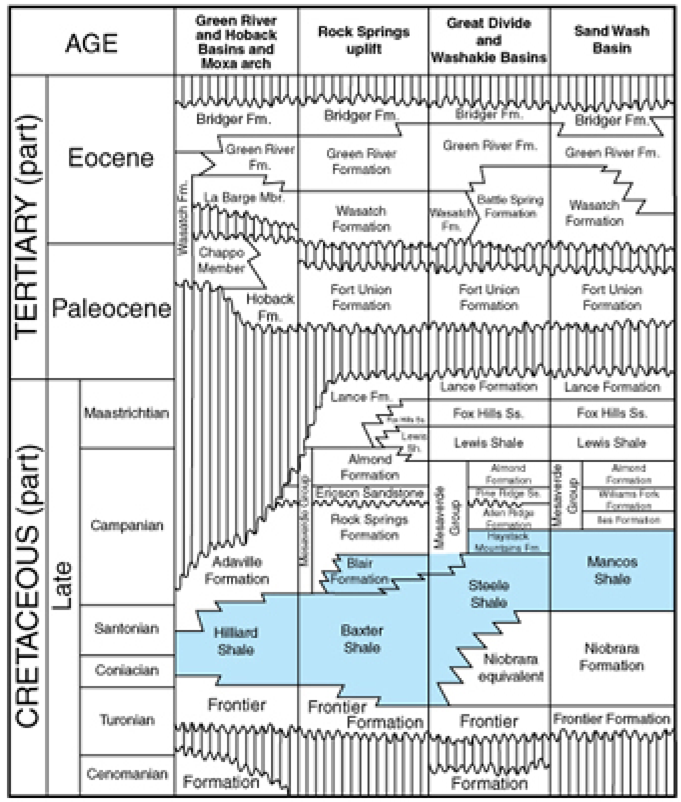

Figure 16. Generalized correlation chart of Upper Cretaceous and lower Tertiary stratigraphic units in the Southwestern Wyoming Province. Modified from Ryder (1988) in Finn and Johnson (2005a).

Oil and Gas Development in Southwestern Wyoming—Energy Data and Services for the Wyoming Landscape Conservation Initiative (WLCI)

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The Hilliard-Baxter-Mancos Continuous Gas Assessment Unit (11.8 TCFG)

Reservoir rocks are sandstones and interbedded sandstone, siltstone, and shale deposited mainly in nearshore marine, marine shelf, marine slope, and deep basin-floor settings (Roehler, 1990). In most cases, these reservoirs are encased in marine shale. These rocks, which are included in this TPS because they are largely encased offshore marine rocks, include reservoir sandstones deposited in shoreface, tidally dominated delta front, and estuarine depositional settings (Mellere and Steel, 1995). For a detailed geologic discussion of the Hilliard-Baxter-Mancos Continuous Gas AU, see Finn and Johnson (2005a). Figure 17 shows the Hilliard-Baxter-Mancos Continuous Gas AU, the mean estimate of undiscovered gas and gas liquids in that AU, and wells from the WOGCC that have a reservoir name of Baxter, Blair, Hilliard or Steele and a completion date of 2001 or earlier.

Figure 17. Hilliard, Baxter, Steele and Mancos Shale wells at the time of the assessment (through 2001).

Figure 18 includes the same data as figure 17, with post-2001 wells added to show how drilling of the Hilliard, Baxter, and Steele Shales and the Blair Formation has progressed to the spring of 2008 (WOGCC).

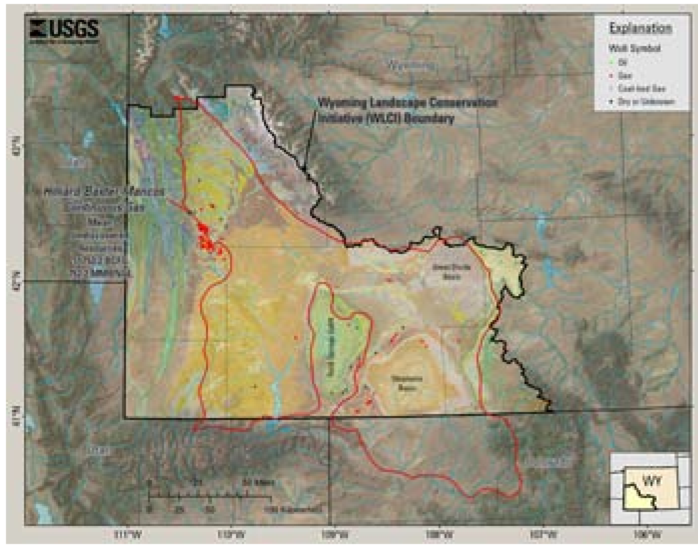

Figure 18. Hilliard, Baxter, Steele and Mancos Shale wells as of spring, 2008.

Since the 2002 assessment, 199 additional wells have been completed in the Hilliard, Baxter, and Steele Shales and the Blair Formation (WOGCC).

Oil and Gas Development in Southwestern Wyoming—Energy Data and Services for the Wyoming Landscape Conservation Initiative (WLCI)

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Undiscovered Gas in the Mowry Composite Total Petroleum System

Kirschbaum and Roberts, 2005, report that the TPS is a composite system because it contains petroleum generated from multiple source rocks including marine shale units of the Mowry and Thermopolis Shales and their equivalents, possibly contributions from marine shale of the Allen Hollow Shale Member of the Frontier Formation, and from coaly and lacustrine facies in continental units of the Bear River, Frontier, and Dakota Formations. Oil and gas migrated into fluvial, tidal, deltaic, and shoreface sandstone reservoirs of the Bear River and Frontier, Cloverly, Dakota Sandstone Formations, and Muddy Sandstone Member of the Thermopolis Shale (Kirschbaum and Roberts, 2005). The hydrocarbons were trapped in structural, stratigraphic, and basin-centered accumulations (Kirschbaum and Roberts, 2005). Seals include thick, continuous marine shale and in some cases terrestrial to estuarine mudstone units, diagenetic seals, and capillary pressure seals (Kirschbaum and Roberts, 2005).

Oil and Gas Development in Southwestern Wyoming—Energy Data and Services for the Wyoming Landscape Conservation Initiative (WLCI)

By Laura R.H. Biewick

The Mowry Continuous Gas Assessment Unit (8.5 TCFG)

The Mowry is a composite system because there are multiple source rocks present within about a 1,000-ft stratigraphic interval, and the relative contribution of petroleum from individual sources cannot be distinguished on the basis of data presently available (Kirschbaum and Roberts, 2005). The name Mowry is applied to the TPS because it is by far the most important contributor to the petroleum system (Burtner and Warner, 1984). Hydrocarbons have not been directly typed back to the Mowry, but the Mowry/Aspen is the Cretaceous shale with the highest total organic carbon content (Burtner and Warner, 1984) and is thought to be the dominant contributor of petroleum (Burtner and Warner, 1984; Law and Clayton, 1987). On outcrops just west of the Province boundary, the Frontier Formation consists of five members in ascending order: the Chalk Creek, Coalville, Allen Hollow, Oyster Ridge, and Dry Hollow Members (Hale, 1960; M'Gonigle and others, 1995). Along the northeast margin of the province, the Frontier Formation is 600–1,000 ft thick and is divided into three members: in ascending order: the Belle Fourche, the Emigrant Gap (formerly called the unnamed member), and the Wall Creek (Merewether, 1983; Mieras, 1993). Production from conventional accumulations of the Mowry Composite TPS is from anticlines, fault-bounded closures, stratigraphic traps, or combinations of the three (Cardinal and Stewart, 1979; Miller and others, 1992). The most important structure influencing conventional accumulation is the Rock Springs uplift (Kirschbaum and Roberts, 2005). Production from continuous (unconventional) accumulations is concentrated on the Moxa arch, presumably associated with intense fracturing and minor faulting on the structure (see Dutton and others, 1992; Anderson and Dietz, 2003).

Figure 19 shows the location of the Mowry Continuous Gas AU, the mean estimate of undiscovered gas and gas liquids in that AU, and wells from the WOGCC that produce from or terminate in units of the Mowry

Composite TPS and have a completion date of 2001 or earlier.

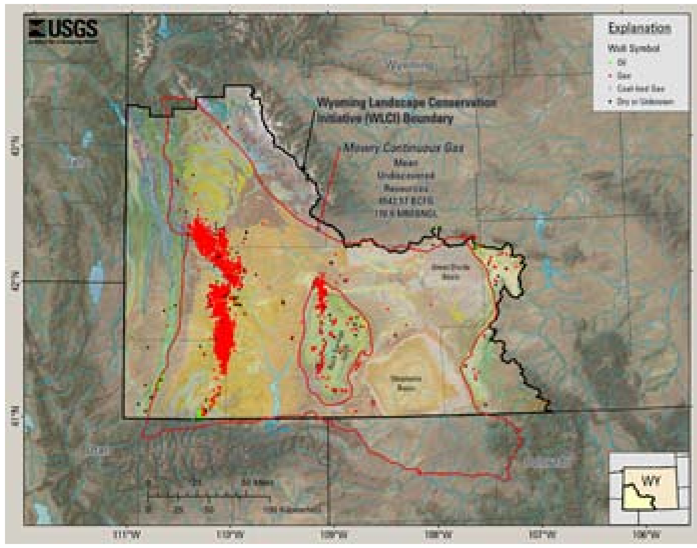

Figure 19. Wells from units of the Mowry Composite TPS at the time of the assessment (through 2001).

Figure 20 includes the same data as figure 19, with post-2001 wells added to show how drilling of wells to units of the Mowry Composite TPS has progressed to the spring of 2008 WOGCC.

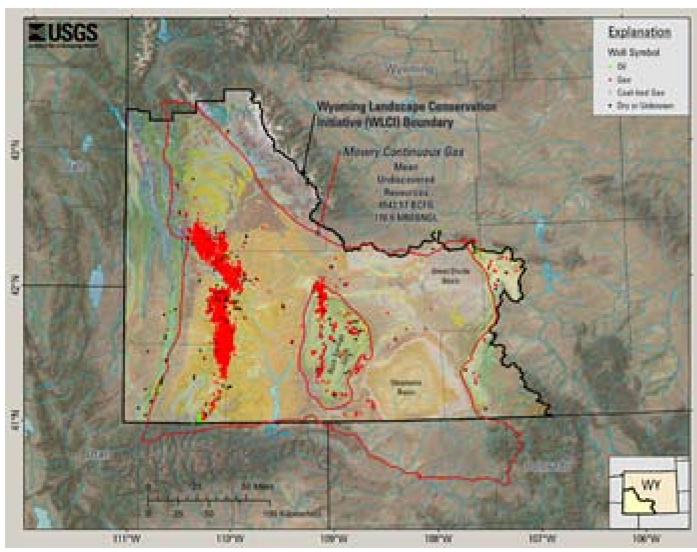

Figure 20. Wells that produce from units of the Mowry Composite TPS as of spring, 2008.

Since the 2002 assessment, 1003 additional wells have been completed in the units of the Mowry Composite TPS (WOGCC).

Oil and Gas Development in Southwestern Wyoming—Energy Data and Services for the Wyoming Landscape Conservation Initiative (WLCI)

By Laura R.H. Biewick

Undiscovered Gas in the Lance–Fort Union Composite Total Petroleum System

The Lance–Fort Union Composite TPS, as shown in the generalized stratigraphic chart (fig. 21), contains undiscovered gas resources in continuous accumulations, including potential basin-centered gas and coalbed-gas resources, and gas and oil resources in shallow conventional accumulations (Roberts, 2005). Within the TPS four AUs have been defined: the Lance–Fort Union Continuous Gas AU, the Lance Coalbed Gas AU, the Fort Union Coalbed Gas AU, and the Lance–Fort Union Conventional Oil and Gas AU. Conventional accumulations are more maturely explored, whereas continuous accumulations are only partially explored or essentially untested (Roberts, 2005). Most of the historical production has targeted shallow sandstone reservoirs in conventional traps along Cherokee ridge and, to a lesser degree, on the Wamsutter arch (Roberts, 2005). A limited number of wells have produced or are producing gas from sandstone reservoirs interpreted to be within continuous (basin-centered) accumulations in the Washakie and Great Divide Basins (Roberts, 2005). These accumulations are at depths where overpressured and low-permeability reservoir conditions exist, and where thermal maturities in Lance and (or) Fort Union source rocks are above the maturity threshold for thermogenic gas generation (Roberts, 2005). To date, there has been limited testing but no commercial production of coalbed gas from formations within the TPS (Roberts, 2005). Coal beds and associated noncoal, carbonaceous strata within the Lance and Fort Union Formations are considered to be the primary source rocks for hydrocarbon generation within the Lance–Fort Union Composite TPS (Roberts, 2005).

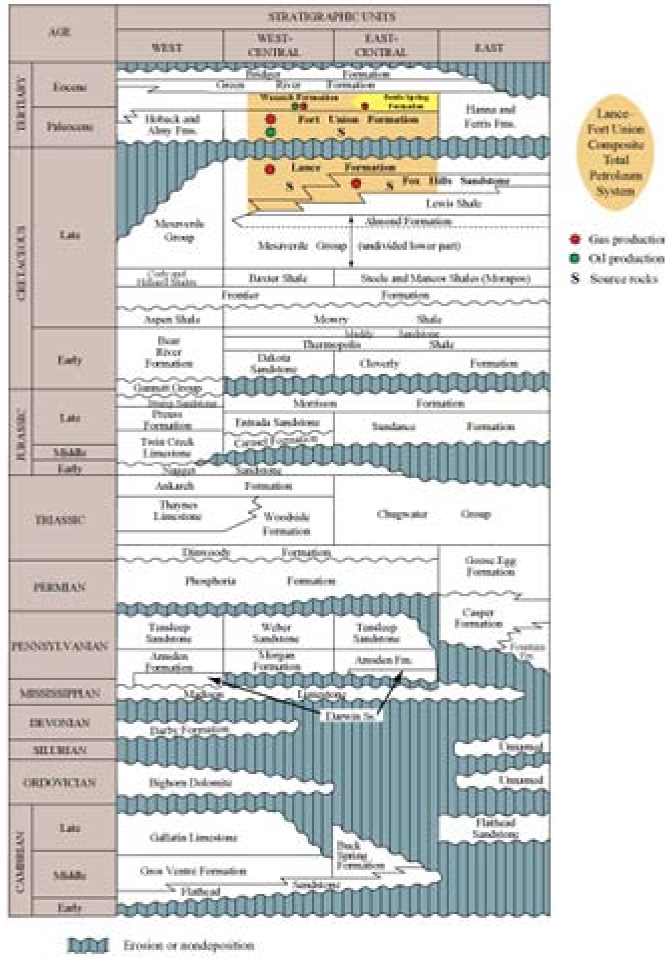

Figure 21. Generalized stratigraphic chart for the Southwestern Wyoming Province in Wyoming, Colorado, and Utah, showing units in the Lance–Fort Union Composite Total Petroleum System and intervals of hydrocarbon production and source rocks. Wasatch Formation includes age equivalent units in the Battle Spring Formation in the Great Divide Basin. Modified from Law (1996) in Roberts (2005).

Oil and Gas Development in Southwestern Wyoming—Energy Data and Services for the Wyoming Landscape Conservation Initiative (WLCI)

By Laura R.H. Biewick

The Lance–Fort Union Continuous Gas Assessment Unit (7.6 TCFG)

The Lance–Fort Union Continuous Gas AU includes areas where thermal maturity (R_o) values are 0.8 percent or greater in potential source rocks near the base of the TPS (Fox Hills Sandstone and lower Lance Formation). The AU boundary is defined by the surface (vertical) projection of the 0.8 percent isoreflectance (R_o) line estimated for the top of the Lewis Shale (Hettinger and Roberts, 2005), which underlies the Lance–Fort Union Composite TPS (Roberts, 2005). At this level of thermal maturity, gas-prone source rocks have the ability to generate and expel significant amounts of gas (Meissner, 1984; Law, 1984; Roberts and others, 2005), and for this reason the potential for gas accumulation exists throughout the entire AU (Roberts, 2005). At the time of the assessment, an estimated 110 wells are considered to have tested the AU. Given that historical exploration for continuous gas accumulations within the Lance–Fort Union Composite TPS is limited, it is unlikely that production results to date are entirely representative of the future gas potential (Roberts, 2005).

Figure 22 shows the extent of the Lance–Fort Union Continuous Gas AU, the mean estimate of undiscovered gas and gas liquids in that AU, and wells from the WOGCC that produce from units of the Lance–Fort Union Composite TPS and have a completion date of 2001 or earlier. Wells shown outside of the AU boundary, tested or produced from the Fort Union, Lance or Wasatch Formations within other AUs.

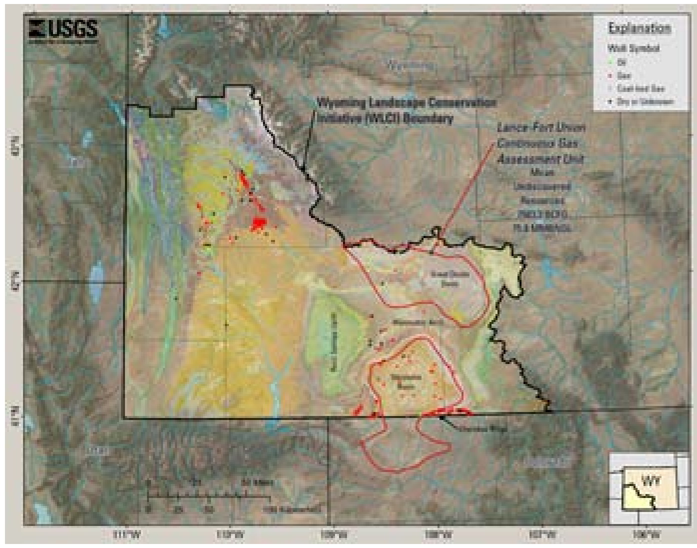

Figure 22. Wells from units of the Lance–Fort Union Composite TPS at the time of the assessment (through 2001).

Figure 23 includes the same data as figure 22, with post-2001 wells added to show how drilling of wells to units of the Lance–Fort Union Composite TPS has progressed to the spring of 2008 (WOGCC).

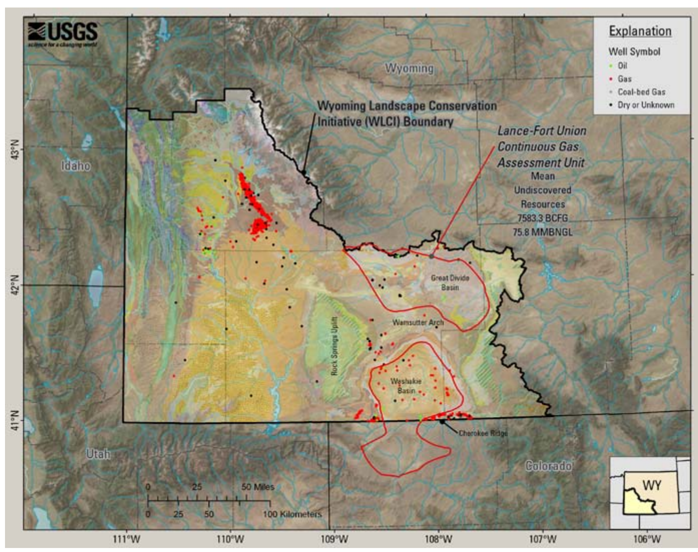

Figure 23. Wells that produce from units of the Lance–Fort Union Composite TPS as of spring, 2008.

Since the 2002 assessment, 2506 additional wells, mostly outside the Lance-Fort Union Continuous AU, have been completed in the units of the Lance-Fort Union Composite TPS, 25 of which are shown to have produced from or terminated in coal beds (WOGCC).

Oil and Gas Development in Southwestern Wyoming—Energy Data and Services for the Wyoming Landscape Conservation Initiative (WLCI)

By Laura R.H. Biewick

Reservoirs That Contain the Majority of Undiscovered Gas Resources

Because the well information shown above with each AU is formation specific and not AU specific, individual wells are shown with more than one AU. For example, the Lance–Fort Union Continuous AU produced from some of the same formations as the Mesaverde–Lance–Fort Union Continuous AU, but covers a different geographic area. By looking at all seven AUs in which the majority of undiscovered gas resources are distributed, and the wells that produce from or terminate in geologic units of these AUs, we can see the well data that was available at the time of the 2002 USGS assessment of undiscovered gas resources (fig. 24).

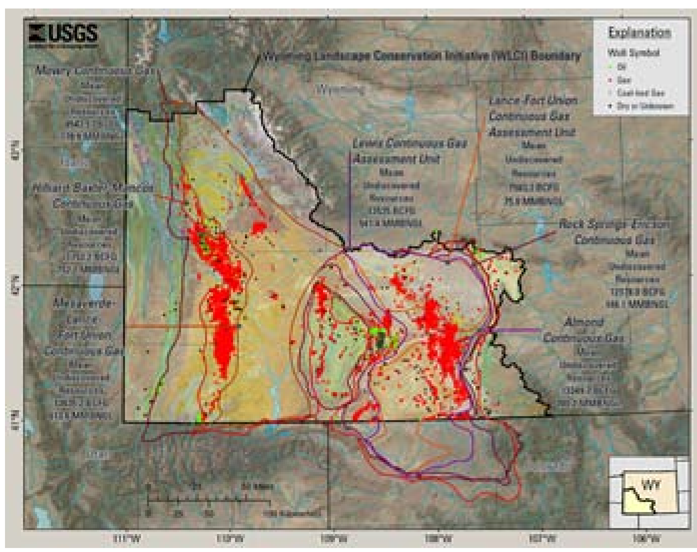

Figure 24. Map showing all seven AUs that contain the majority of undiscovered gas resources with wells that produced from or terminated in units of these AUs at the time of the 2002 assessment.

Because of the depth component, viewing multiple AUs in static maps makes it difficult to distinguish between individual stratigraphic intervals that make up each AU.

This type of data can be better analyzed using GIS technology in interactive maps, such as the published map files and the internet map services that are described in Live GIS Data and Maps. We can, however, look at the same information with additional wells that have been drilled since the assessment. These additional wells cover the time frame of 2002 to the spring of 2008 (fig. 25).

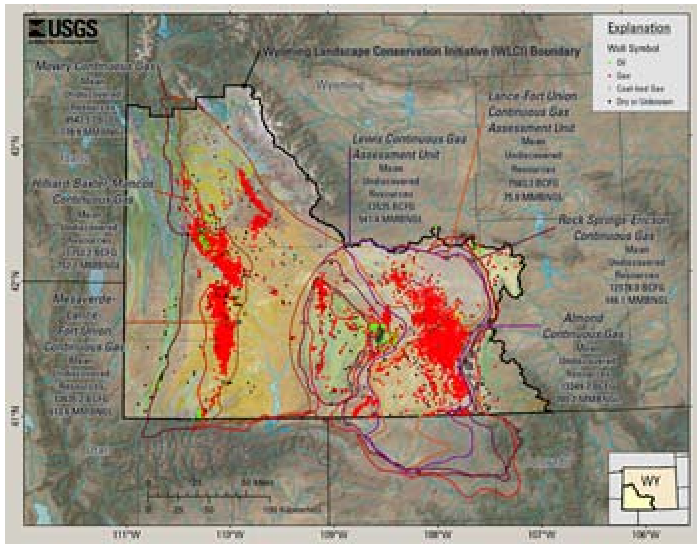

Figure 25. Map showing all seven AUs that contain the majority of undiscovered gas resources with wells that produce from or terminate in units of these AUs.

To get a better idea of the drilling activity since the 2002 assessment, figure 26 shows only those wells that have been drilled from 2002 through the spring of 2008 in the seven AUs that contain the majority of undiscovered gas resources.

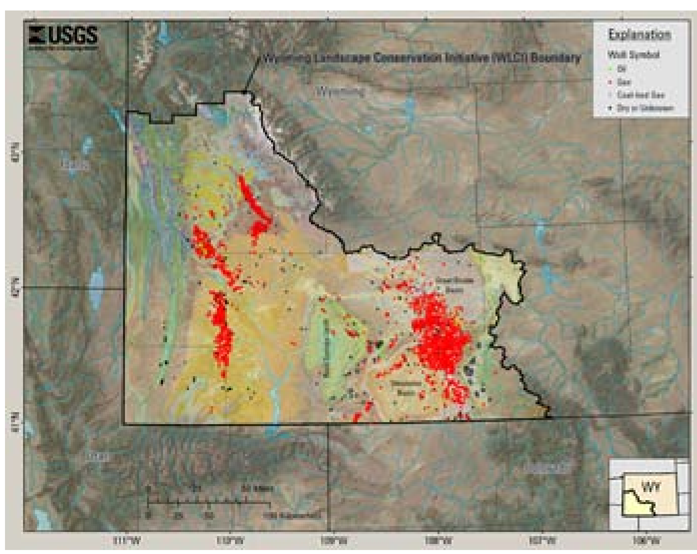

Figure 26. Map showing only those wells that have been drilled from 2002 through the Spring of 2008 in the seven AUs that contain the majority of undiscovered gas resources.

Figure 26 shows that since the 2002 USGS assessment until the spring of 2008, there have been 6,171 wells completed in the seven AUs that contain the majority of the undiscovered gas resources. Of these wells, 461 have produced from or terminated in coal beds. The reservoir names and the number of wells from each reservoir, according to the WOGCC, are as follows:

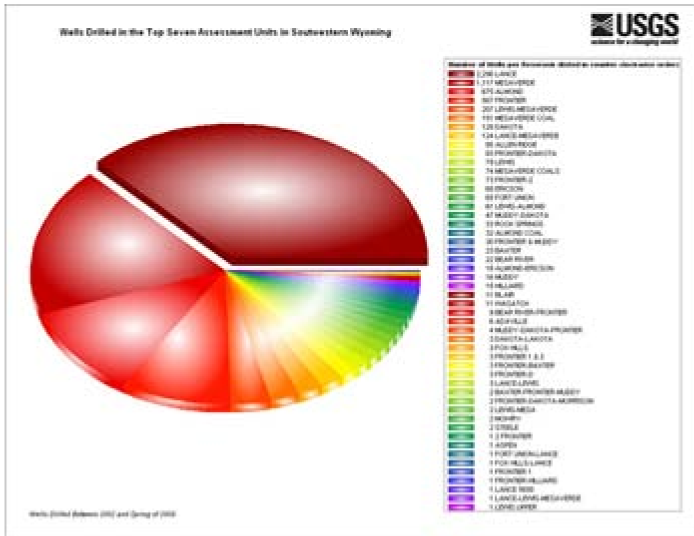

Figure 27. ArcMap (ESRI, 2000b) pie chart showing the number of wells drilled to each reservoir in the top seven assessment units since 2002.

Figure 28 shows those wells that have been completed from 2002 through the spring of 2008 in reservoirs that do not contain the majority of gas resources.

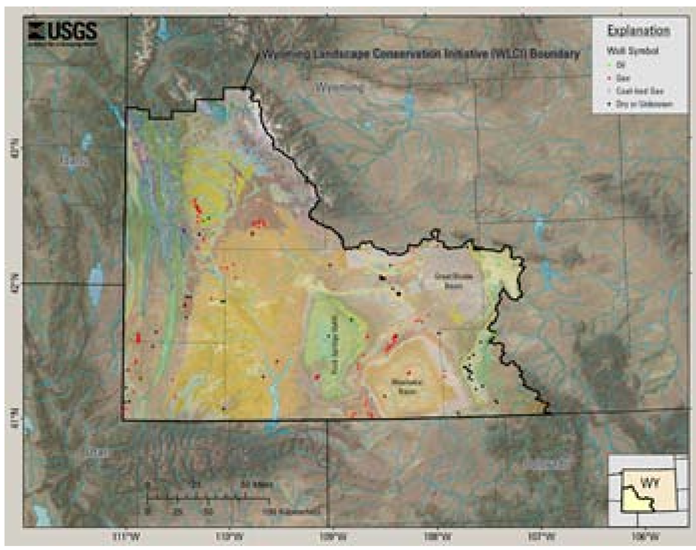

Figure 28. Map showing only those wells that have been drilled from 2002 through the Spring of 2008 in other than the seven AUs that contain the majority of undiscovered gas resources.

Since 2002, 372 wells have been drilled in reservoirs that did not contain the majority of undiscovered gas resources in the Southwestern Wyoming Province. Of these 372 wells, 37 have no reservoir name association in the WOGCC database.

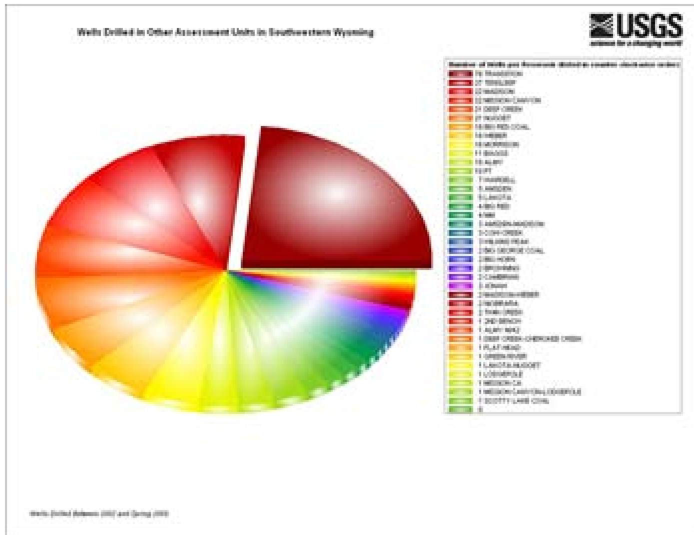

Figure 29. ArcMap (ESRI, 2000b) pie chart showing the number of wells drilled to each reservoir in other than the top seven assessment units since 2002.

Oil and Gas Development in Southwestern Wyoming—Energy Data and Services for the Wyoming Landscape Conservation Initiative (WLCI)

By Laura R.H. Biewick

Live GIS Data and Maps

The objective of this report was to assemble a comprehensive inventory of energy data pertinent to the conservation decisionmaking process and to make these data available online for scientists, resource managers engaged in the Initiative, and other researchers. The way to most efficiently analyze oil and gas development in the WLCI is through the use of geospatial technologies. Maps, data and GIS capabilities are available over the Web at the Energy Resources Science Center WLCI website .

A Web mapping application has been developed by the USGS using ArcGIS Server (ESRI, 2008b) technology. The USGS Web map applications and services provide a number of useful geoprocessing and cartographic functions via an internet browser. The USGS uses ArcGIS Server to distribute maps and GIS capabilities over the Web. ArcGIS Server can work with many different clients, including Google Earth, Microsoft Virtual Earth, ArcGIS Explorer, ArcMap and others. Because it is beyond the scope of this report to describe how to add the USGS ArcGIS Server services to all of these clients, just one of these clients will be described as an example, and that is ArcMap. To add the ArcGIS Server services to an individuals ArcMap (ESRI, 2000b) document, one must add GIS Services from the GIS Server named http://certmapper.cr.usgs.gov/arcgis/services. Several folders and individual services reside on this server, and the number of services is being continuously expanded. Three services reside in a folder named *WLCI*, and the names of those services are *oil_gas08*, *historical08*, and *wells08*. Another service resides in the *geology* folder and that service name is *wyoming*. Base-map reference data are included using map services from ArcGIS Online (ESRI, 2008a). ArcGIS Online provides free maps and other content for your ArcGIS. ArcGIS Online services can be added to your ArcMap document by adding GIS Services from http://server.arcgisonline.com/arcgis/services. One of the map services used for this product is *ESRI_Imagery_World_2D*.

To share and distribute these maps and GIS data, the customized ArcMap (ESRI, 2000b) projects are also available for download at the Energy Resources Science Center WLCI website . ArcGIS Publisher (ESRI, 2008c) was used to create a published map file (.pmf) from each ArcMap document (.mxd). Published maps can be viewed, explored, or printed using any ArcGIS (ESRI, 2000b) desktop product, including the no-cost ArcReader (ESRI, 2008d) application. Users can download and install the ArcReader software from ESRI. Next, download the compressed packaged data for each published map file (.pmf) from the Energy Resources Science Center WLCI website (10 MB each). The compressed pmf files can be accessed by clicking on the *GIS Data/Interactive Maps* tab. The available pmfs are listed in the GIS Data Finder. GIS downloadable data are also available in shapefile or geodatabase format, as well as detailed documentation, in the form of Federal Geographic Data Committee (FGDC)-compliant metadata.

Oil and Gas Development in Southwestern Wyoming—Energy Data and Services for the Wyoming Landscape Conservation Initiative (WLCI)

By Laura R.H. Biewick

In Summary

The goal of the WLCI is to implement a long-term, science based program to assess and enhance the quality and quantity of aquatic and terrestrial habitats at landscape scale in southwestern Wyoming, while facilitating responsible development of other natural resources (Wyoming Landscape Conservation Initiative). The detailed geologic analysis of the Southwestern Wyoming Province resulted in estimates of undiscovered oil and gas resources with mean values of 84.6 trillion cubic feet of natural gas, 131 million barrels of oil, and 2.6 billion barrels of total natural gas liquids (Kirschbaum and others, 2002). Southwestern Wyoming will continue to be one of the largest sources of natural gas in the U.S.

Oil and gas data sets included herein can be accessed and shared among many different clients. This report is meant to facilitate the integration of existing data with new knowledge and technologies to analyze energy resources development and to assist in habitat conservation planning. This document evaluates and maps existing geology-based information to further forecast where future potential development actions might occur.

Oil and Gas Development in Southwestern Wyoming—Energy Data and Services for the Wyoming Landshcape Conservation Initiative (WLCI)

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