Bottom: Seven Mile Hill wind project (used with permission from Jeff Hymas, 2012, PacifiCorp).
Energy Map of Southwestern Wyoming, Part A—Coal and Wind

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Data Series 683

U.S. Department of the Interior
U.S. Geological Survey
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## Conversion Factors

Inch/Pound to SI

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The U.S. Geological Survey (USGS) and the Wyoming State Geological Survey (WSGS) have compiled Part A of the Energy Map of Southwestern Wyoming for the Wyoming Landscape Conservation Initiative (WLCI). The WLCI represents the USGS partnership with other Department of the Interior bureaus, State and local agencies, industry, academia, and private landowners committed to maintaining healthy landscapes, sustaining wildlife, and preserving recreational and grazing uses while developing energy resources in southwestern Wyoming. This product complements the 2009 and 2011 USGS publications on oil and gas development in southwestern Wyoming (http://pubs.usgs.gov/ds/437/), and the entire state of Wyoming (http://pubs.usgs.gov/ds/625/) by adding coal, including coalbed methane, and wind energy development in the area within the WLCI. Part A of the Energy Map is concerned primarily with the electrical power sources of coal and wind.

The expanded boundaries of the WLCI encompass all of Carbon, Lincoln, Sublette, Sweetwater, and Uinta Counties, Wyoming, as well as areas in Fremont County, Wyoming, that are in the Great Divide and Green River Basins. With updated oil and gas data, other energy resources across southwestern Wyoming, including oil shale, uranium, and solar, are planned for inclusion in Part B of the Energy Map.

Introduction

To further advance the objectives of the Wyoming Landscape Conservation Initiative (WLCI) the U.S. Geological Survey (USGS) and the Wyoming State Geological Survey (WSGS) have compiled Part A of the Energy Map of Southwestern Wyoming. Focusing primarily on electrical power sources, Part A of the energy map is a compilation of both published and previously unpublished coal (including coalbed gas) and wind energy resources data, presented in a Geographic Information System (GIS) data package. Data are included from U.S. Geological Survey (USGS) coal and coalbed gas assessments (see references on pl. 1, 2, 3 and 4), an updated coal map of Wyoming (Jones and others, 2009), geology and coal stratigraphy of the Rawlins-Little Snake River area (Hettinger and others, 2008), a coalbed natural gas map of the Atlantic Rim (Quillinan and others, 2009), and spatial mapping and attribution of Wyoming wind turbines (O’Donnell and Fancher, 2010). In addition, National Coal Resource Data System (NCRDS) stratigraphic data, coalbed gas wells from the Wyoming Oil and Gas Conservation Commission (WOGCC), and Bureau of Land Management (BLM) authorized and pending coalbed gas units are included. Energy maps, data, documentation and spatial data processing capabilities are available in a geodatabase (ESRI, 2012), published map file (PMF; ESRI, 2008b), ArcMap document (MXD; ESRI, 2000), Adobe Acrobat PDF map (Adobe Systems Incorporated, 2010, pl. 1) and other digital formats that can be downloaded at the USGS website.

Accompanying the map (pl. 1) and the geospatial data are four additional plates that describe the geology, energy resources and related infrastructure. These tabular plates include coal mine (pl. 2), coal field (pl. 3), coalbed gas assessment unit (pl. 4), and wind farm (pl. 5) information with hyperlinks to source publications and data on the internet. The plates can be printed and examined in hardcopy or accessed digitally in Excel (Microsoft, 2007) and as Adobe PDF files. The data represent decades of research by the USGS, WSGS, BLM, private industry, and others and can facilitate landscape-level science assessments, and resource management decisionmaking.

Coal

The sedimentary basins in Wyoming contain some of the largest fossil fuel deposits in the United States (U.S. Energy Information Administration (EIA), 2010). These basins developed throughout the Late Cretaceous–early Tertiary Periods during the Laramide Orogeny (fig. 1).

Throughout much of the Cretaceous Period, a good portion of the area that is today Wyoming, was at or near sea level. The climate was tropical to subtropical and temperatures were warmer, as evidenced by fossils in the rock record. A vast seaway occupied the Western Interior of North America, connecting the Circum-Boreal Sea with the proto-Gulf of...
Figure 1. Laramide sedimentary and structural basins and intervening uplifts in the Rocky Mountain region extending from southern Montana to northern New Mexico. Modified from Dickinson and others (1988) in Finn and Johnson (2005).
Mexico (Roberts and Kirschbaum, 1995). The body of water is known most commonly as the Western Interior Cretaceous Seaway. During the Late Cretaceous and into the early Tertiary, regional uplift forced the interior of the United States to rise, causing the epeiric sea to migrate to the northeast, thus severing the connection between the Arctic Sea and the Gulf of Mexico. Vegetation grew in coastal wetlands bordering the seaway from about 98 to 70 million years ago (fig. 2), and extensive coal deposits accumulated in lower coastal plain depositional settings (Johnson and others, 2005; Finn and others, 2005).

Over time, the seaway retreated, and marine and coastal-plain environments became restricted to areas north and east of Wyoming, in what is now North and South Dakota. During the Paleocene Epoch (about 65 to 56 million years ago), wetlands in Wyoming developed in low lying floodplains and along fluvial corridors (fig. 3). Over geologic periods of time, the accumulation of organic material derived from these wetlands formed peat. Uplift during the Laramide Orogeny divided the area into structural basins and intervening highlands (fig. 1). Great volumes of erosional debris were carried from the uplands by rivers and streams, and deposited in the subsiding basins. These sediments buried and preserved the organic material, where it eventually was transformed into coal. Coalification is a slow two-phase process; the first (biogenesis) is the bacterial decay of plant matter. The second, heat-driven phase (thermogenesis) is a function of temperature, as maintained by the insulating effect of thick layers of sediment above the proto-coal through time (millions of years), (Jones, 2009).

In Wyoming, coal was initially discovered in 1843 by the Fremont Expedition. Commercial mining began with the arrival of the railroad in the 1860s. The first commercial mines were located in Carbon and Rock Springs, where large amounts of coal were needed to power steam engines for the railroad (U.S. BLM, 2008a). Today, coal is used to generate about 50 percent of our nation’s electricity, and coal-fired power plants dominate Wyoming electrical generation (U.S. EIA, 2010). Within the WLCI, there are several active surface coal mines in the Hams Fork, Green River and Hanna coal fields (pls. 1, 2, and 3). Some of the coal mines are no longer active and have been abandoned or reclaimed. For the former Rosebud Mine in the Hanna Basin, what began as a voluntary revegetation program in 1965, evolved into the complete reclamation of 4,000 acres (©Kiewit, 2010). The only active underground coal mine is currently the Jim Bridger longwall operation on the east flank of the Rock Springs uplift.

Some coals contain enough gas to be potentially economic. Coalbed methane (CBM) is natural gas that formed in coal deposits during and after the coalification process. CBM, also referred to as coalbed gas or coalbed natural gas (CBNG), is used for a variety of purposes ranging from domestic heating to commercial electrical power generation (WSGS, 2010a). Evidence for the occurrence of CBM includes direct measurements in wells and coal cores, gas-related explosions and fires in underground coal mines, inferences from the rank of coal, surface venting of gas, and thermal histories of coal fields (DeBruin and others, 2004). According to WSGS geologist Scott Quilliman, "CBNG activity in the area southwest of Rawlins started in 2000 with a handful of exploratory wells. As of November, 2009, there were 676 wells drilled. Of these, 277 were producing CBNG." (WSGS, 2010b; pl. 1). For the Atlantic Rim area, the BLM has approved 2,000 wells—1,800 for CBM and 200 for conventional natural gas (WSGS, 2010b).

In 2002 and 2003, the USGS assessed coalbed gas resources in the Southwestern Wyoming and the Wyoming Thrust Belt Provinces. Using a geologic-based assessment methodology, the USGS estimated a mean of 1.89 trillion cubic feet (TCF) of undiscovered coalbed gas in seven coalbed gas assessment units (AUs), six in the Southwestern Wyoming Province (Kirschbaum and others, 2002) and one in the Wyoming Thrust Belt Province (pl. 4; Kirschbaum and others, 2004). Although these AUs extend beyond the boundary of the WLCI, 74 percent of the area covered by these AUs is within the WLCI.

**Wind**

Because national and regional forecasts project an increase in consumption of electrical energy continuing into the foreseeable future, renewable energy, including wind generation, is expected to provide a larger component to maintain adequate electrical power (U.S. BLM, 2010b). One of the most favorable locations for wind power development in the Nation is located in southern Wyoming. Across southern Wyoming from the Utah border on the west to the Nebraska border on the east, a gap in the Rocky Mountains channels strong winds generated from across the plains, making this area ideally suited for wind power development (U.S. EIA, 2010, and fig. 4). In the 1986 Wind Energy Resource Atlas of the United States (Elliott and others, 1986), the Solar Energy Research Institute (now the National Renewable Energy Laboratory), reported that in this 150-km (90 mi)-wide gap, areas of highest wind are where there is enhanced channeling by the terrain (for example, between two mountain ranges) and (or) where there is terrain-induced flow acceleration (for example, over hilltops, uplands, or low ridges).

In 2010, the U.S. Department of Energy’s Wind Program and the National Renewable Energy Laboratory (NREL) published a wind resource map for the state of Wyoming (U.S. Department of Energy and AWS Truepower, 2010; fig. 4). The wind resource map shows the predicted mean annual wind speeds at an 80-meter (m) height, presented at a spatial resolution of about 2 km. Areas with annual average wind speeds around 6.5 m/s and greater at an 80-m height are generally considered to have a resource suitable for wind development. Utility-scale, land-based wind turbines are typically installed between 80-100 meters (U.S. Department of Energy and AWS Truepower, 2010). NREL estimated the windy land area and
Figure 2. Paleogeographic reconstruction of the Cretaceous Western Interior Seaway during the Late Cretaceous (modified from Roberts and others, 1995; Roberts and Kirschbaum, 1995).
Wind energy potential in various capacity factor ranges for each state using AWS Truepower’s gross capacity factor data. Maps and wind potential estimates for the state of Wyoming are available at the U.S. Department of Energy’s Wind Powering America website at http://www.windpoweringamerica.gov/wind_resource_maps.asp?stateab=wy.

One large area of exceptionally good wind energy potential extends from the Rawlins area eastward to Medicine Bow and then south along the Laramie Mountains to the Colorado border (fig. 4; Elliott and others 1986). In the expansive treeless plateau between Laramie and Rawlins, Foote Creek Rim is one of the windiest places in America, with average wind speeds of 25 mph; 25–70 percent windier than other good wind sites (see pls. 1, 5; U.S. BLM, 2008b). The Foote Creek Rim Wind Farm, near Arlington, was the first commercial wind farm to go online in Wyoming, beginning operations in 1999 (U.S. BLM, 2008b). In extreme southwestern Wyoming, wind measurements at Bridger Butte, near Fort Bridger, showed class 6 annual average wind power at heights to 50 m (164 ft). Areas designated class 3 or greater are suitable for most wind turbine applications; fig. 4, Elliott and others, 1986. Two wind farms on Bridger Butte, Mountain Wind I and Mountain Wind II, began operations in 2008 (© PacifiCorp, 2010, pl. 1 and 5). Winter is the season of maximum wind power, with class 7 (the highest) power in the best areas. In summer, the season of minimum wind power, class 3 power can be expected in the best areas (Elliott and others, 1986).

Seven current wind farms operating in southwestern Wyoming are producing about 674 megawatts (MW) from approximately 504 wind turbines (pls. 1, 5). Five additional wind energy projects are proposed, in progress or under construction, and may add as many as 1,639 additional wind turbines capable of producing 2,700 to 3,700 MW of energy (pls. 1, 5).
Part A of the Energy Map of Southwestern Wyoming (pl. 1) displays many overlapping coal and wind features. Plate 1 was created directly from the ArcMap project (ESRI, 2000), which contains a number of additional layers not shown on the hardcopy map—that is, coal thickness and overburden categories, surface geology, surface and mineral ownership, and a variety of base cartographic GIS services. All of the layers included in the interactive map are described in table 1 with hyperlinks to source data information websites. Not described are geographic data, including county lines, lakes and rivers, and map annotations (largely from Jones and others, 2009). Further instructions for accessing the interactive map are included in the next section, 'Downloadable Data and the Interactive Map'.

Table 1.  link

Downloadable Data and the Interactive Map

Part A of the Energy Map of Southwestern Wyoming is available as a GIS map project (both MXD and PMF formats) that can be downloaded at the USGS website. The GIS lets us visualize, question, analyze, and understand the coal and wind data in many ways that reveal relationships, patterns, and trends more effectively than with the static PDF map. The publishing process uses the ArcMap project (MXD) and creates a special file called a published map file (PMF). ArcGIS Publisher (ESRI, 2008a) is the extension used to create the PMF from the MXD; it packages the required data with the PMF file for easy distribution. PMFs can be viewed, explored, or printed using any ArcGIS (ESRI, 2000) desktop product, including ArcMap and the free ArcReader (ESRI, 2008b) application. Users can download and install the free.

Figure 4.  Wyoming wind potential map (written commun., U.S. Department of Energy and AWS Truepower, 2012). Areas with annual average wind speeds around 6.5 m/s and greater at an 80-m height are generally considered to have a resource suitable for wind development. Wind potential estimates for the state of Wyoming are available at the U.S. Department of Energy’s Wind Powering America website at http://www.windpoweringamerica.gov/wind_resource_maps.asp?stateab=wy.
ArcReader software from ESRI. To access the MXD requires ArcGIS 9.3.1 or later software (ESRI, 2000).

As described in the Introduction section of this report, the Energy Map of Southwestern Wyoming, Part A, is a compilation of both published and previously unpublished energy resource data. For the previously published data, the accompanying metadata have been retained as published. The difference between the original published data and the version included here is that, other than the coalbed gas assessment units (AU), the features have been clipped to the WLCI boundary. Although they appear clipped to the WLCI boundary on the map, each of the AU areas in its entirety is included in the geodatabase.

All data are stored in a file-based geodatabase (WLCI_CoalWindMap.gdb) using the World Geodetic System (WGS) 1984 projection, which is a standard projection for distributing geospatial data. For the ArcGIS.com web services (formerly ArcGIS Online; ESRI, 2010), data descriptions, sources, and credits are stored as layer properties. Included in the geodatabase for each coal bed or zone in the 1999 assessment, are the data-point locations (drill hole or outcrop), and the spatial query layers that contain representations of numerous themes for multiple theme queries. Attributes of the spatial query layer include coal thickness category, overburden category, mine name, quadrangle name, surface ownership, and subsurface coal ownership.

Environmental Quality

The USGS has a long standing program assessing energy resources, including coal, gas, oil, uranium, and geothermal, as well as assessing environmental and health effects of the development and utilization of these resources. Investigation of geologic, technologic, environmental, and economic factors controlling the production and use of both conventional fuels (oil, gas and coal) and unconventional fuels such as gas hydrates, coalbed methane, oil shale, heavy oil and natural bitumen, and tar sands is carried out by the USGS Energy Resources Program. Schweinfurth (2009) described how the continued and increasingly large-scale use of coal in the United States and in many industrialized and developing nations has raised speculation about possible hazards to environmental quality and human health. There is still much to be learned about coal to make its use less harmful to humans and nature and more useful for the general welfare (Schweinfurth, 2009).

One type of renewable electricity is produced from wind, which may reduce greenhouse gas emissions produced from burning fossil fuels in power plants. The BLM reports that generating energy from wind is only one aspect of developing renewable energy resources on the public lands in Wyoming. The lack of power transmission infrastructure in the relatively remote and unpopulated areas of Wyoming with high wind potential would require the construction of new power transmission lines (U.S. BLM, 2010c). Wind turbines can interfere with viewsheds of pristine areas of natural beauty like some of Wyoming’s historic trails, and the wind turbine air-warning systems cause light pollution and potential adverse impacts on rural communities and family ranches. Further studies on the technology and design of wind turbines and more careful placement, such as outside of migratory paths, are needed to address the problem of bat and bird fatalities. In areas like the city of Rawlins where both private and Federal oil and gas rights are present, the need for turbines, oil and gas wells, ranching and recreation must coexist (Heather Nino, U.S. BLM in Nuccio and others, 2010).

Data included in this report show that electrical generation in southwestern Wyoming is largely from coal, wind and hydroelectric. Table 2 shows that most of southwestern Wyoming’s current electrical generation capacity is from coal-power generating facilities (approximately 3,024 MW).

Electrical generation is based on many factors, including, but not limited to load and demand. Wind energy can only generate power if the wind is blowing within a certain range. Wind turbines will shut off if wind speeds are too slow, too fast, or too gusty. Considering these aspects, we can only generalize potential electrical power sources.

Southwestern Wyoming wind energy nameplate capacity is currently about 674 MW, and hydro about 100 MW. Approximately 79 percent of electrical generation capacity is from coal, approximately 18 percent from wind and approximately 3 percent from hydro (fig. 5).
Table 2. Southwestern Wyoming electrical generation capacity, November 2010.

[MW, approximate values]

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<td><strong>199</strong></td>
<td>wind</td>
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Summary

Both coal and wind are among the energy resources being developed in southwestern Wyoming. Collecting baseline data to assess what is known about southwestern Wyoming’s energy resources and ecosystems, and developing methods for archiving and disseminating this information to collaborators and the public (Nuccio and others, 2010), are the focus of the USGS and partners of the WLCI. Work to assemble a comprehensive inventory of pertinent data available to the public as an online resource is being done for the WLCI. An integrated assessment (IA) was initiated to synthesize what has been learned about WLCI systems to date, and to develop associated decision tools, maps, and a comprehensive report (Bowen and others, 2010). To further advance the objectives of the USGS and the WLCI, the Energy Map of Southwestern Wyoming, Part A, represents decades of research by the USGS, WSGS, and others, and will facilitate landscape-level science assessments, and informed resource management decision making. Energy maps, data, documentation and spatial data processing capabilities for this report can be found at http://pubs.usgs.gov/ds/683.

Acknowledgments

The Energy Map of Southwestern Wyoming was funded by the USGS Wyoming Landscape Conservation Initiative project. Part A of the Energy Map of Southwestern Wyoming is a compilation of both published and previously unpublished energy resources data. Because the coal map of Wyoming (Jones and others, 2009), was published as GIS layers, some of the data, symbology, and many of the annotations included on plate 1 were taken directly from that source. The manuscript was technically reviewed by David C. Scott and William R. Keefer of the USGS, and we thank them for their thoughtful evaluations and suggestions. Lisa Binder (USGS) is gratefully acknowledged for editorial review.

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