Chapter 7: Energy in the Northwest Central US

Everything we do depends upon **energy**—without it there would be no civilization, no sunlight, no food and no life. Energy moves people and goods, produces electricity, heats our homes and businesses, and is used in manufacturing and other industrial processes. But what *is* energy? Energy is the **power** derived from the utilization of physical or chemical resources. In this chapter, we are especially interested in the energy used to provide light and **heat**, or to power machines.

For most of human history, the way we captured and used energy changed little. With very few exceptions*, materials were moved by human or animal power, and heat was produced largely through the burning of wood. Nearly all the energy to power human society was, in other words, **biomass**. But the transition from brute force and wood burning to the various industrial sources of energy—and the accompanying adoption of energy-intensive lifestyles—has occurred remarkably quickly, in the course of just the last several generations. This has caused changes in virtually every aspect of human life, from economics to war to architecture. Much of the rural US was without access to electricity until the 1930s, and cars have been around for only slightly longer. Our energy **system** (how we get energy and what we use it for) has changed and is changing remarkably quickly, though some aspects of the energy system are also remarkably resistant to change.

***Exceptions include the use of sails on boats by a very small percentage of the world's population to move people and goods, and the Chinese use of natural gas to boil brine in the production of salt beginning roughly 2000 years ago.**

Electricity is a good example of an *energy carrier*: a source of energy that has been subject to human-induced energy transfers or transformations.

Wind power, on the other hand, is a *primary energy source*: a source of energy found in nature that has not been subject to any human manipulation.

The use of **wind** to generate electricity, for example, grew very quickly in the late 2000s and early 2010s. In 2002, wind produced less than 11 million megawatt hours (MWh) of electricity in the US. In 2011, it produced more than 120 million MWh—more than 1000% growth in ten years! That aspect of change stands in contrast to our

energy • *the power derived from the use of physical or chemical resources.*

power • *the rate at which energy is transferred, usually measured in watts or, less frequently, horsepower.*

heat • *a form of energy transferred from one body to another as a result of a difference in temperature or a change in phase.*

biomass • *organic material from one or more organisms.*

system • *a set of connected things or parts forming a complex whole.*

wind • *the movement of air from areas of high pressure to areas of low pressure.*

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7 Energy

Review

fossil fuels • *fuel for human use that is made from the remains of ancient biomass.*

coal • *a combustible, compact black or dark-brown carbonaceous rock formed by the compaction of layers of partially decomposed vegetation.*

natural gas • *a hydrocarbon gas mixture composed primarily of methane (CH4), but also small quantites of hydrocarbons such as ethane and propane.*

joule • *the energy expended (or work done) to apply a force of one newton over a distance of one meter.*

kinetic energy • *the energy of a body in motion.*

degrade (energy) • *the transformation of energy into a form in which it is less available for doing work, such as heat.*

watt • *a unit of power measuring the rate of energy conversion or transfer designated by the International System of Units as one joule per second.*

long-lasting reliance on **fossil fuels**, such as **coal**, oil, and **natural gas**. Our reliance on fossil fuels is driven by a number of factors: the low upfront cost, very high energy densities, and the cost and durability of the infrastructure built to use fossil fuels.

Energy production and use not only changes across time, but also with geography, as we will see by looking at energy production and use across the different regions of the US.

What do different units of energy mean?

Heat is energy, and heat is at the root of all the ways that we move materials or generate light, so measurements of heat can be thought of as the most basic way to measure energy. The **British Thermal unit** (abbreviated Btu or BTU) is the most commonly used unit for heat energy and is approximately the amount of heat required to raise one pound of water by one degree Fahrenheit. A Btu is also roughly 1055 **joules**, or the amount of energy released by burning a single wooden match. A joule is the energy expended (or work done) to apply a force of one newton over a distance of one meter. Since a typical apple weighs about one newton, lifting an apple one meter requires about a joule of energy. That means that one Btu—the energy contained in a wooden match—is equivalent to the total amount of energy required to lift an apple 1000 meters, or one kilometer.

This comparison of the energy of heat to the energy of motion (**kinetic energy**) might be a little confusing, but energy is transformed from one type to another all the time in our energy system. This is perhaps most obvious with electricity, where electrical energy is transformed into light, heat, or motion at the flip of a switch. Those processes can also be reversed—light, heat, and motion can all be transformed into electricity. The machines that make those transitions in either direction are always imperfect, so energy always **degrades** into heat when it is transformed from one form to another.

The principle of *Conservation of Energy* tells us that energy is neither created nor destroyed, but can be altered from one form to another.

Another measure of energy, the kilowatt-hour (kWh), represents the amount of energy required to light ten 100-**watt** light bulbs for one hour. *Figure 7.1* compares different ways to make and use one kWh.

How do we look at energy in the Earth system?

The concepts used to understand energy in the Earth system are fundamental to all disciplines of science; energy is an interdisciplinary topic. One cannot study physics or understand biomes, photosynthesis, fire, evolution, seismology, **chemical reactions**, or genetics without considering energy. In the US, every successive generation has enjoyed the luxury of more advanced technology (e.g., the ability to travel more frequently, more quickly, and over

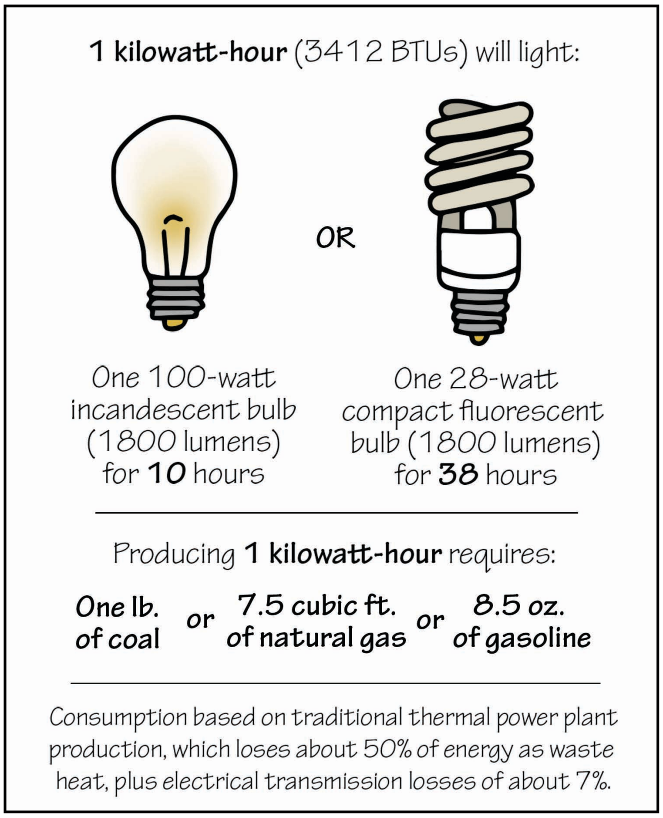

Figure 7.1: Examples of uses and sources of one kilowatt-hour.

greater distances). Especially as the global population grows and standards of living increase in some parts of the world, so too does global energy demand continue to grow.

Figure 7.2 shows the sources and uses of energy in the US, by sector. The Energy Information Administration (EIA) categorizes energy as coming from one of five sources (**petroleum**, natural gas, coal, **renewable energy**, and **nuclear** electric power) and being used in one of four energy sectors (transportation, industrial, residential & commercial, and electric power). All of the energy that powers our society comes from one of these five sources and is used in one of these four sectors.

The more we come to understand the Earth system, the more we realize that there is a finite amount of consumable energy, and that harvesting certain resources for use in energy consumption may have wide ranging and permanent effects on the planet's life. Understanding energy within the Earth system is the first step to making informed decisions about energy transitions.

Becoming "energy literate"

Energy is neither lost nor gained within the universe, but rather is constantly flowing through the Earth system. In order to fully understand energy in our

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chemical reaction • *a process that involves changes in the structure and energy content of atoms, molecules, or ions but not their nuclei.*

petroleum • *a naturally occurring, flammable liquid found in geologic formations beneath the Earth's surface.*

renewable energy • *energy obtained from sources that are virtually inexhaustible (defined in terms of comparison to the lifetime of the Sun) and replenish naturally over small time scales relative to human life spans.*

nuclear • *pertaining to a reaction, as in fission, fusion, or radioactive decay, that alters the energy, composition, or structure of an atomic nucleus.*

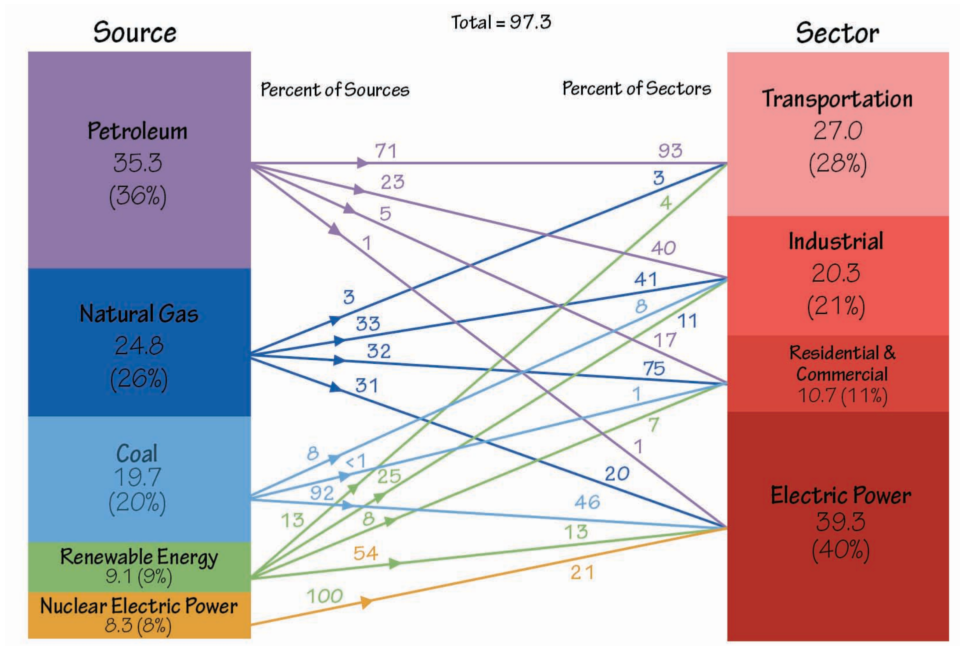

Figure 7.2. US energy production sources and use sectors for 2011. Petroleum provides more energy than any other source, and most of it is used for transportation. More energy is used to generate electricity than for any other use, and electricity is generated by all five energy sources. Nuclear is unique among sources in that all of the energy it generates goes to a single sector: electric power.

daily lives—and make informed decisions—we need to understand energy in the context of that system. Becoming energy literate gives us the tools to apply this understanding to solving problems and answering questions. The Seven Principles of Energy, as detailed in *Energy Literacy: Energy Principles and Fundamental Concepts for Energy Education* are listed in the following chart.

> ***Energy Literacy: Energy Principles and Fundamental Concepts for Energy Education*** **is a publication of the US Department of Energy. It can be accessed for free online; see Resources for more information.**

Each principle is defined by a set of fundamental concepts that can help clarify ties to curriculum. Keeping these energy principles in mind when we teach others about energy can help us contextualize and make relevant our own energy consumption and its effect on the Earth system.

Energy

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1	**Energy is a physical quantity that follows precise natural laws.**
2	**Physical processes on Earth are the result of energy flow through the Earth system.**
3	**Biological processes depend on energy flow through the Earth system.**
4	**Various sources of energy can be used to power human activities, and often this energy must be transferred from source to destination.**
5	**Energy decisions are influenced by economic, political, environmental, and social factors.**
6	**The amount of energy used by human society depends on many factors.**
7	**The quality of life of individuals and societies is affected by energy choices.**

Energy in the Northwest Central Regions

The Northwest Central US is rich in energy production, but varies significantly in the types of production among its regions. Some of the nation's largest coal and petroleum reserves exist in the Great Plains and Rocky Mountains, thanks to the extensive geologic basins found within these regions (*Figures 7.3–7.5*). A substantial quantity of corn for **biofuel** comes from the Central Lowland, because the region's **topography**, **soils**, and **climate** make it appropriate for large-scale agriculture. Large wind farms exist in the Great Plains where high wind speeds can develop over relatively flat lands with low surface friction. Large hydroelectric plants associated with the Snake River and its tributaries exist in the Basin and Range and Columbia Plateau. Even uranium for nuclear energy is mined in the Northwest Central US, primarily from basins in the Rocky Mountains. In each case, the energy developed is a function of the area's past geologic history and the economic viability of developing its resources. While fossil fuel development and use still dwarfs that of alternative energy sources, renewable energies continue to grow quickly.

Of the Northwest Central States, Idaho, Nebraska, and South Dakota produce more energy from "clean" sources (including biomass, nuclear, and renewables) than they do from fossil fuels. Idaho is especially rich in geothermal resources, and almost all energy produced there is generated from renewables and biofuels, which provide for nearly 80% of the state's total power consumption.

Regions

biofuel • *carbon-based fuel produced from renewable sources of biomass like plants and garbage.*

topography • *the landscape of an area, including the presence or absence of hills and the slopes between high and low areas.*

soil • *the collection of natural materials that collect on Earth's surface, above the bedrock.*

climate • *a description of the average temperature, range of temperature, humidity, precipitation, and other atmospheric/hydrospheric conditions a region experiences over a period of many years (usually more than 30).*

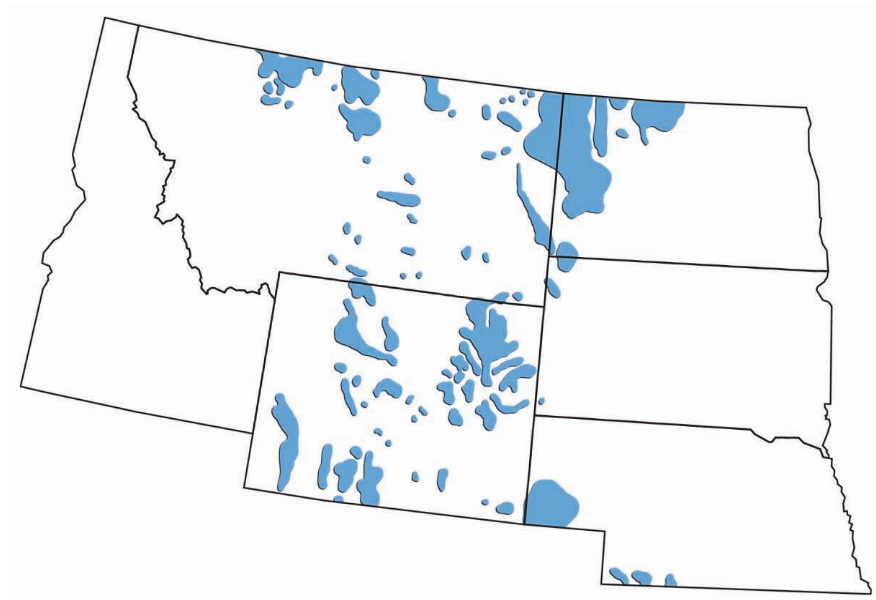


Figure 7.3: Petroleum-producing regions of the Northwest Central US.

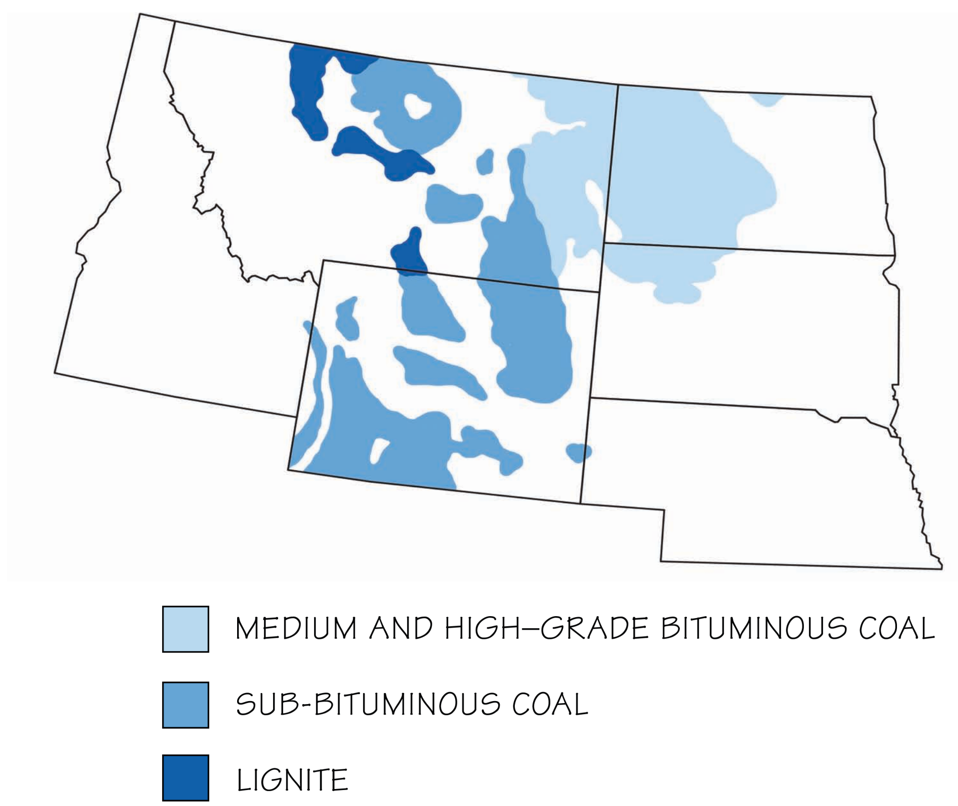


Figure 7.4: Coal-producing regions of the Northwest Central US. The Great Plains is a particularly significant coal producing area.

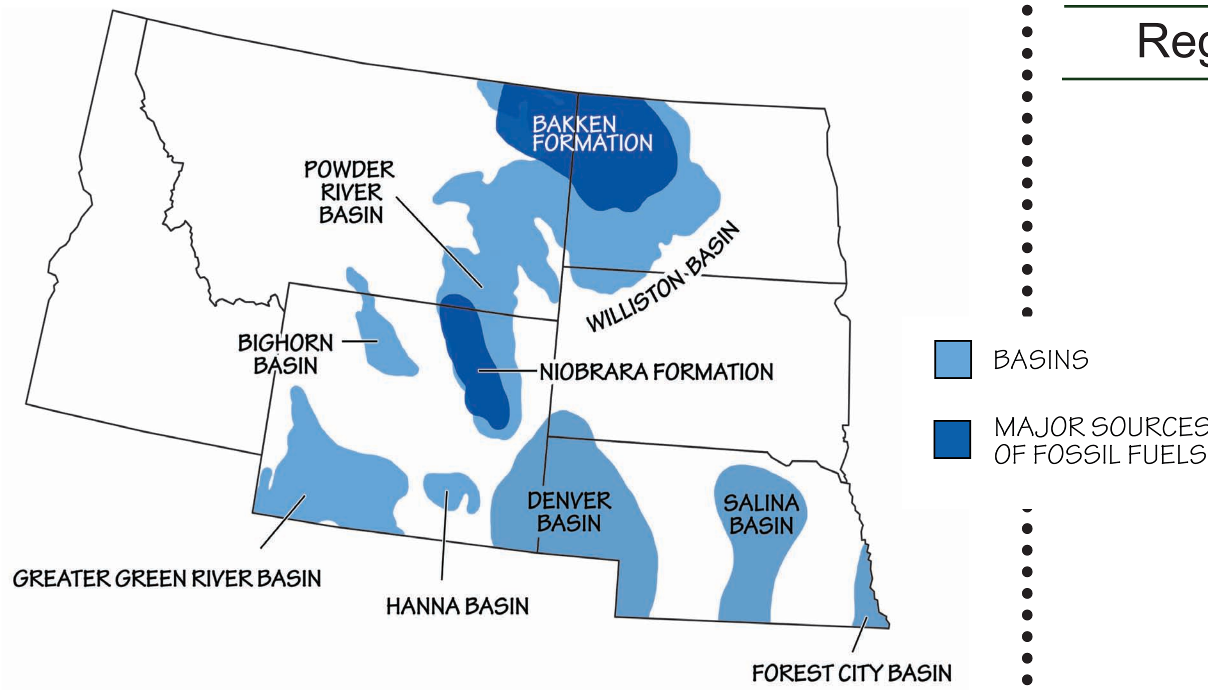


Figure 7.5: Sedimentary basins containing significant fossil fuel accumulations in the Northwest Central US.

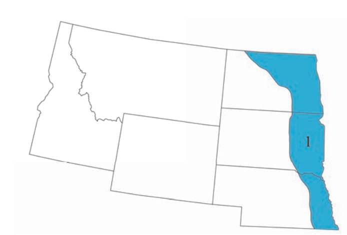
Energy in the Central Lowland

Region 1

Due to its geological history, the Central Lowland is not a major producer of fossil fuels, but in recent years the region's energy production has increased for two energy sources related to its topography: wind energy and corn-based ethanol. Even given these new sources, the Central Lowland of the Northwest Central is not considered a center of production. Wind energy potential is even higher to the west in the Great Plains, and the bulk of corn production for ethanol occurs to the east, in the Midwestern US.

Fossil Fuels

Fossil fuel production in the Central Lowland is primarily limited to a small part of the Forest City Basin in the southeast corner of Nebraska and the Salina Basin in south-central Nebraska, also known as the Central Nebraska Basin (*see Figure 7.5*). The Salina Basin in Nebraska did not experience the appropriate combination of heat, pressure, and organic matter to generate a large petroleum potential.



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Energy

Region 1

Fossil Fuels

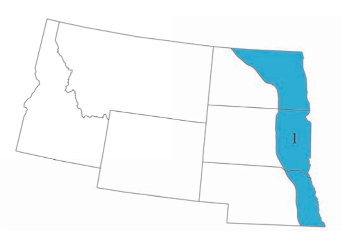
Fossil fuels—oil, natural gas, and coal—are made of the preserved organic remains of ancient organisms. Coal and lignite result from the burial, compaction, and heating of preserved plant matter, whereas petroleum and natural gas originate deep underground through a slow process involving the low-grade heating of sedimentary source rocks that contain an abundance of organic matter. In either case, organic matter is only preserved when the rate of accumulation is higher than the rate of decay. This happens most often when the oxygen supply is sufficiently low that oxygen-loving bacteria cannot thrive, greatly slowing breakdown of organic matter. In this way, the organic matter can be incorporated into the buried sediment. The organics are compacted and heated with the rest of the rock, eventually transforming into fossil fuels.

The history of surface environments, evolution of life, and geologic processes beneath the surface have all influenced where fossil fuel deposits formed and accumulated. The largest oil and gas reserves were at one time nutrient-rich seas with abundant surface phytoplankton and organic rich bottom sediments; the largest coal beds were swampy environments where fallen forest trees and leaves were buried in stagnant muds.

Alternative Energy

Much of the Central Lowland is part of the "corn belt," the largest corn-producing area in the US, which supports over a hundred-billion-dollar-a-year industry that helps feed the world but that also produces plastics, biofuel, and livestock feed. In the Northwest Central, this region has become a leading area for the production of corn-based biofuels (*Figure 7.6*). In fact, the processing and production of crops for biofuel has been expanding here since the 1980s. Corn ethanol is the most common liquid biofuel in the United States, with the majority blended into gasoline for use in passenger vehicles. About 40% of US-grown corn is now used to produce ethanol.

See Chapter 8: Soils for more information about the Central Lowland's fertile agricultural soils.



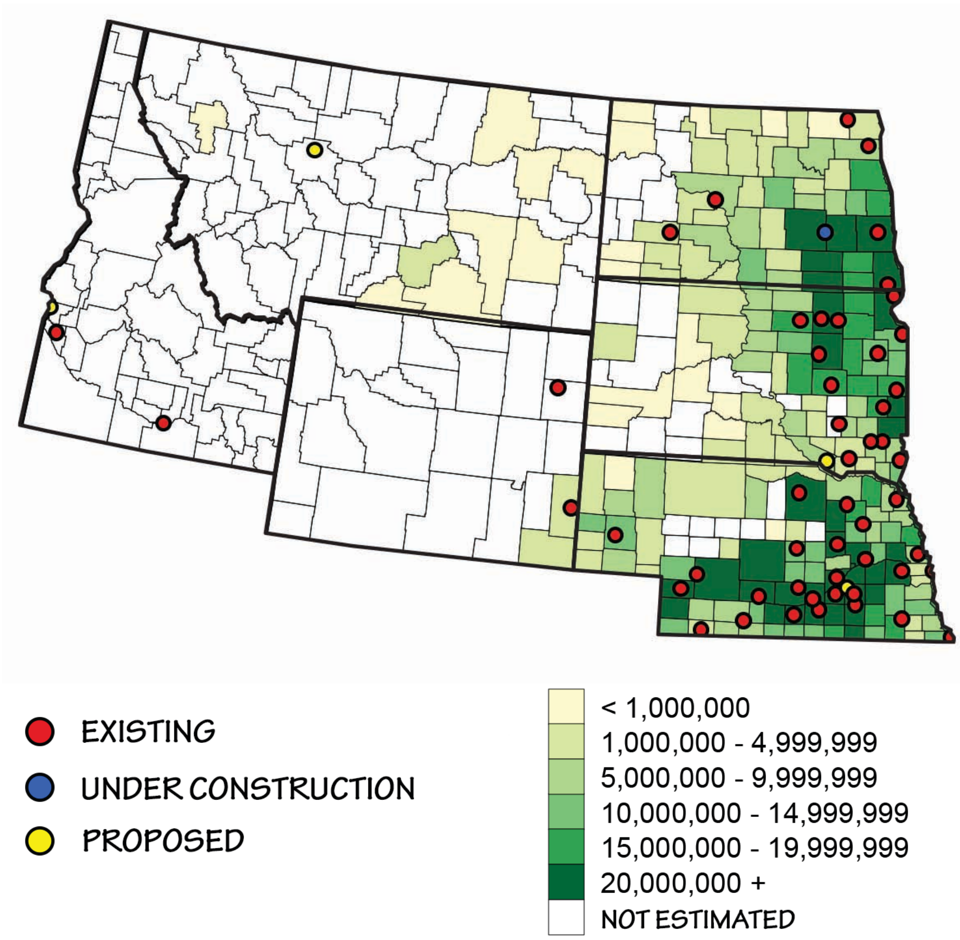
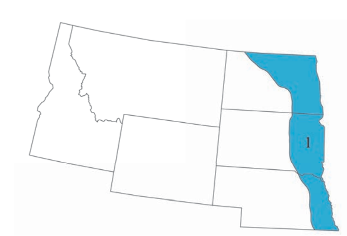


Figure 7.6: Corn production (bushels) and locations of ethanol plants in the Northwest Central US by county and location (as of 2013).

Two nuclear power plants are present in the Central Lowland, both in Nebraska. The Cooper Nuclear Station and the Fort Calhoun Nuclear Generating Station are both located along the Missouri River, and they produce a combined 1244.6 megawatts of power.

See Chapter 10: Earth Hazards to learn about major Missouri River floods that endangered Nebraska's nuclear power plants.

The Central Lowland and adjacent Great Plains regions, with their broad and flat topography, have become major sources of wind energy. North Dakota produces nearly two gigawatts of wind power, and its low population grants it the highest per capita generation of wind power in the country. Most of the state's wind power is located in the Great Plains, which is discussed in greater detail in the next section of this chapter.



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Region 2

Energy in the Great Plains

Region 2

The Great Plains region is a broad expanse of flat land underlain by thick sequences of **sedimentary rock** and primarily covered in grassland and prairie. Ancient sedimentation patterns and tectonic activity have favored the placement of widespread fossil fuel resources in this region. Organic-rich sediments were deposited in **inland seas** that spread across much of the region, and **Cenozoic** swamps contributed plant matter to form thick beds of coal. The Great Plains' sedimentary basins contain vast oil, gas, and coal reserves that dominate energy production here (*see Figure 7.5*), but the area's topography and climate also make it appropriate for large wind farms.

Coal

The world's largest known **lignite** coal deposit, weighing in at an estimated 351 billion tons, is found in western North Dakota's Williston Basin. This area is known as the Fort Union coal region, named after the Fort Union Formation, a thick sequence of **Paleocene**-aged coal deposits lying above **Cretaceous**-aged marine sediments from the Western Interior Seaway. North Dakota's supply of lignite is estimated to last more than 800 years, and the deposits are used for synthetic **fuels** (made of carbon monoxide and hydrogen) as well as fuel for nearby power plants. Coal mining in this area began in the 1870s, when small seasonal mines sprung up along the main routes of transportation in the area. Over 250 mines were in operation by the 1920s. Today, there are only six large coal mines in western North Dakota, from which 32 million tons of coal are extracted annually. One of these, the Freedom Mine, is the 12th largest coal mine in the US.

In Wyoming, great quantities of coal are produced annually from the Powder River Basin (*see Figure 7.4*). Like the Williston Basin, the Powder River Basin contains a thick sequence of Cretaceous marine **shales** and **sandstones** formed in the Western Interior Seaway, overlain by Paleocene-aged coals of the Fort Union Formation. These coals have experienced greater heat and pressure from burial than those in the Williston Basin, and thus are higher-grade sub-**bituminous** coals. In fact, the Powder River Basin contains the largest resources of low-**sulfur**, low-ash, sub-bituminous coal in the US. These deposits provide more than 40% of the US coal supply, making Wyoming the largest coal-producing state (*Figure 7.7*). The Black Thunder Coal Mine is currently the most productive coal mine in the US, providing 8% of the country's coal and 20% of Wyoming's total coal production. This mine utilizes the world's largest dragline excavator, employed to strip the overlying rock and sediment and expose the underlying coal seams.

The Great Plains of Montana also produce sub-bituminous coal from the northern extension of the Powder River Basin and lignite from the western extension of Williston Basin deposits (*see Figure 7.4*). Montana ranks 6th in the nation among coal-producing states. Considerably more coal resources lie below currently mineable depths, that is, below about 150 meters (500 feet). Not surprisingly, these zones are being considered for potential underground

inland sea • *a shallow sea covering the central area of a continent during periods of high sea level.*

Cenozoic • *the geologic time period spanning from 66 million years ago to the present.*

lignite • *a soft, brownish-black coal in which the alteration of plant matter has proceeded farther than in peat but not as far as in bituminous coal.*

Paleocene • *a geologic time interval spanning from about 66 to 56 million years ago.*

Cretaceous • *a geologic time period spanning from 144 to 66 million years ago.*

fuel • *a material substance that possesses internal energy that can be transferred to the surroundings for specific uses.*

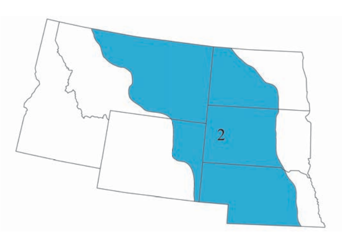


Figure 7.7: Coal mining in Wyoming. Mining of thick sub-bituminous coal beds in the Paleocene Fort Union and other formations make Wyoming the largest coal-producing state in America.

coal gasification projects that would convert coal to gas below the surface and then bring the gas to the surface through wells.

Oil and Gas

Oil deposits from the Great Plains region are also among the largest in the US. It is possible to make sense of why we find petroleum and natural gas in these areas by understanding the history of marine environments. Mud with relatively high organic matter content tends to accumulate in shallow continental seas and in coastal marine environments. The Northwest Central has been home to both types of environments throughout its geologic past.

See Chapter 1: Geologic History to learn more about the changing face of the Northwest Central through geologic time.

Conventionally, finding oil and gas has not been as simple as finding organic-rich rock layers. Oil and gas can flow both within and between rock layers, wherever the number and size of paths between pores, **fractures**, and other spaces (**permeability**) is large enough. Because oil and gas are under pressure, they will move gradually upward to areas of lower pressure and will rise all the way to seeps at the surface unless they are blocked by a **caprock**—that is, one or more layers with permeability so low that they effectively block the flow of liquids and gases. If the fossil fuel happens to rise beneath a caprock in the shape of a concave surface (such as an **anticline** or certain **faults**), the

shale • *a dark, fine-grained, laminated sedimentary rock formed by the compression of successive layers of silt- and clay-rich sediment.*

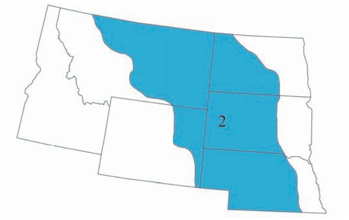
sandstone • *sedimentary rock formed by cementing together grains of sand.*

bituminous coal • *a relatively soft coal containing a tarlike substance called bitumen, which is usually formed as a result of high pressure on lignite.*

sulfur • *a bright yellow chemical element (S) that is essential to life.*

fracture • *a physical property of minerals, formed when a mineral crystal breaks.*

permeability • *a capacity for fluids and gas to move through fractures within a rock, or the spaces between its grains.*



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Energy

Region 2

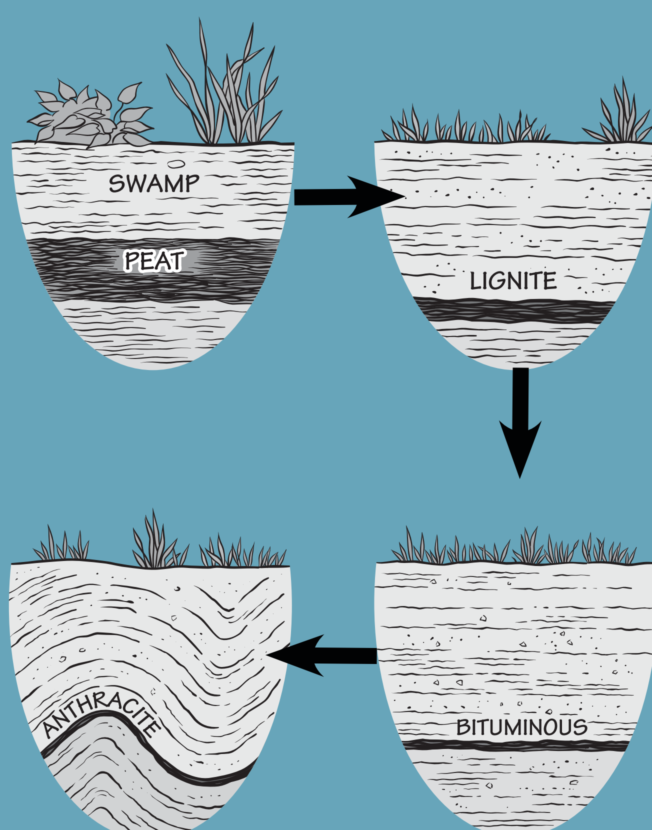
anthracite • *a dense, shiny coal that has a high carbon content and little volatile matter.*

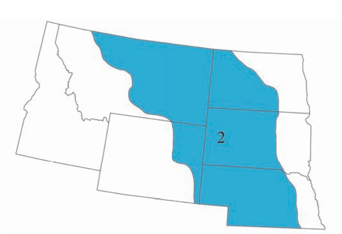
Carboniferous • *a geologic time period that extends from 359 to 299 million years ago.*

Coal

As leaves and wood are buried more and more deeply, pressure on them builds from overlying sediments, squeezing and compressing them into coal. The coal becomes gradually more enriched in carbon as water and other components are squeezed out: peat becomes lignite, bituminous, and eventually *anthracite* coal, which contains up to 95% carbon. Anthracite has the fewest pollutants of the four types of coal, because it has the highest amount of pure carbon. By the time a peat bed has been turned into a layer of anthracite, the layer is one-tenth its original thickness.

The *Carboniferous* period takes its name from the carbon in coal. Globally, a remarkable amount of today's coal formed from the plants of the Carboniferous, which included thick forests of trees with woody vascular tissues. However, in the Northwest Central US most coal is from plants of the Paleocene and Eocene epochs.

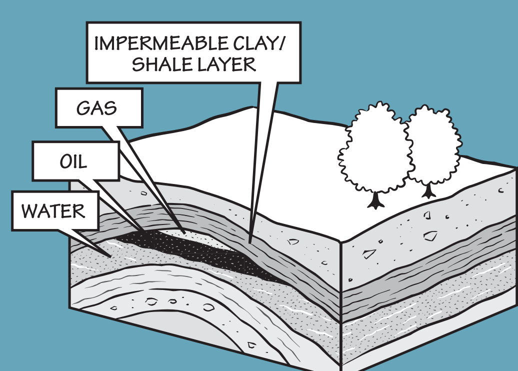




Oil and Gas

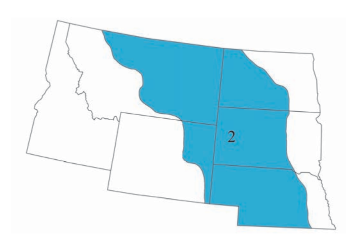
Oil and gas form from organic matter in the pores of sediments subjected to heat and pressure. The organic matter is primarily composed of photosynthetic plankton that die and sink in vast numbers to the bottom of large water bodies. Shale in particular is often organic rich, because organic matter settles and accumulates in the same places that mud (*clay* and *silt* particles) settles out of the water. In most environments, organic matter is recycled by bacteria before it can be buried, but the quiet waters where mud accumulates are often relatively stagnant and low in oxygen. In these places, the bacterial decay rate is low relative to the rate of organic matter sinking and to the rate that the organic matter becomes buried in muddy sediments. Under such conditions, enough organic matter may accumulate to make up several percent or more of the deposited sediment.

Because oil and gas are under pressure, they will move gradually upward to areas of lower pressure through tiny connections between pore spaces and natural fractures in the rocks. Reservoir rocks typically have a considerable amount of pore space, and to be viable there must be a way of trapping the oil and gas, such as through a geologic structure or a change in rock type that will prevent the resource from escaping. Often, natural gas and oil are trapped below the surface under impermeable layers that do not have sufficient spaces for liquids and gases to travel through. Folds or "arches" in impermeable layers, or faults in rock layers, are common ways of trapping oil and gas below the surface.



clay • *the common name for a number of very fine-grained, earthy materials that become plastic (flow or change shape) when wet.*

silt • *fine granular sediment most commonly composed of quartz and feldspar crystals.*



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Energy

Region 2

fossil fuels may accumulate in what geologists call a “reservoir.” Reservoirs are typically found in porous sedimentary layers and thin natural fractures. Most oil and gas has been extracted using the conventional technique of searching for such reservoirs and then drilling into them, which allows the gas or oil to come to the surface through a vertical well. Reservoir rocks in the Great Plains include **dolomites**, **chalks**, and organic-rich shales.

There have been estimates of some 400 billion barrels of untapped oil in the Bakken Formation, and large reserves of both oil and natural gas in the Niobrara Formation, though estimates of the size of oil and gas reserves that can or will be economically extracted are in dispute. The Fort Union Formation in the Powder River Basin is also a significant source of coalbed methane. Thanks to these geological units, this region is a net exporter of energy, providing much of the central US with its oil and gas.

The Bakken Formation formed in the late **Devonian** and early **Mississippian**, in a continental sea that filled what we now call the Williston Basin. The Bakken is known only from coring, as it does not outcrop at the surface. The source rock for the formation’s oil is present in its upper and lower dark shale layers, and a reservoir layer of dolomite lies between the shales. Since 2000, oil production rates in the Bakken Formation expanded enormously through the application of horizontal drilling combined with high volume hydraulic fracturing. This method fractures rocks beneath the surface, releasing gas and oil trapped in source rocks that have very low permeability (also known as “tight” layers). Hydraulic fracturing uses high volumes of water introduced at high pressure through horizontal wells along the source rock layer, to create thousands of tiny fractures (*Figure 7.8*). Most horizontal wells are drilled where the source rock is about 100–150 meters (330–490 feet) thick. The fractures are held open by small grains of **sand** carried by gel in the water, increasing its viscosity. A number of chemicals are added to the water to increase the recovery of fossil fuels, including a chemical to reduce friction as the mixture is introduced (thus the term “slickwater”). “Slickwater, high-volume hydraulic fracturing”—often shortened to “hydraulic fracturing” or simply “fracking”— has greatly increased the accessibility of available fossil fuel resources and the production rate of oil and gas. It has also been controversial, in part because of associated environmental impacts. Unlike some famous “fracked” formations in other areas, such as the Barnett Shale in Texas and Marcellus Shale in Pennsylvania, the part of the Bakken Formation most intensively hydraulically fractured has been its **dolostone** reservoir unit rather than the dark shale source rock. This unconventional drilling activity is centered in North Dakota, which has become the nation’s second largest oil-producing state after Texas (*Figure 7.9*).

The Niobrara Formation, also known as the Niobrara Chalk or Niobrara Shale, extends from the Gulf of Mexico to the Arctic, and originates from sedimentary deposition in the late Cretaceous Western Interior Seaway. Where the formation outcrops at the surface, it is famous for its **fossil** faunas. The Niobrara is tapped for fossil fuels in the Denver Basin (also known as the Julesburg or D-J Basin), which underlies northeastern Colorado, a small corner of southeast Wyoming, and southwest Nebraska. The formation contains alternating chalks and organic-rich **marls** and shales; the marls and shales are a source of petroleum, and the adjacent chalks have become reservoir rocks. Natural gas and oil from

***dolomite* •** *a carbonate mineral, consisting of calcium magnesium carbonate ($CaMg(CO_3)_2$).*

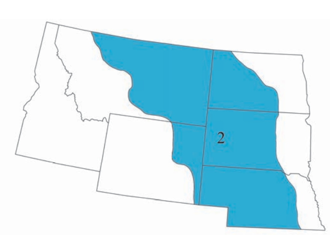
***chalk* •** *a soft, fine-grained, easily pulverized, white-to-grayish variety of limestone, composed of the shells of minute planktonic single-celled algae.*

***Devonian* •** *a geologic time period spanning from 419 to 359 million years ago.*

***Mississippian* •** *a subperiod of the Carboniferous, spanning from 359 to 323 million years ago.*

***sand* •** *rock material in the form of loose, rounded, or angular grains, and formed as a result of the weathering and decomposition of rocks.*

***dolostone* •** *a rock primarily composed of dolomite, a carbonate mineral.*



fossil • *preserved evidence of ancient life.*

marl • *a fine-grained sedimentary rock consisting of clay minerals, calcite and/or aragonite, and silt.*

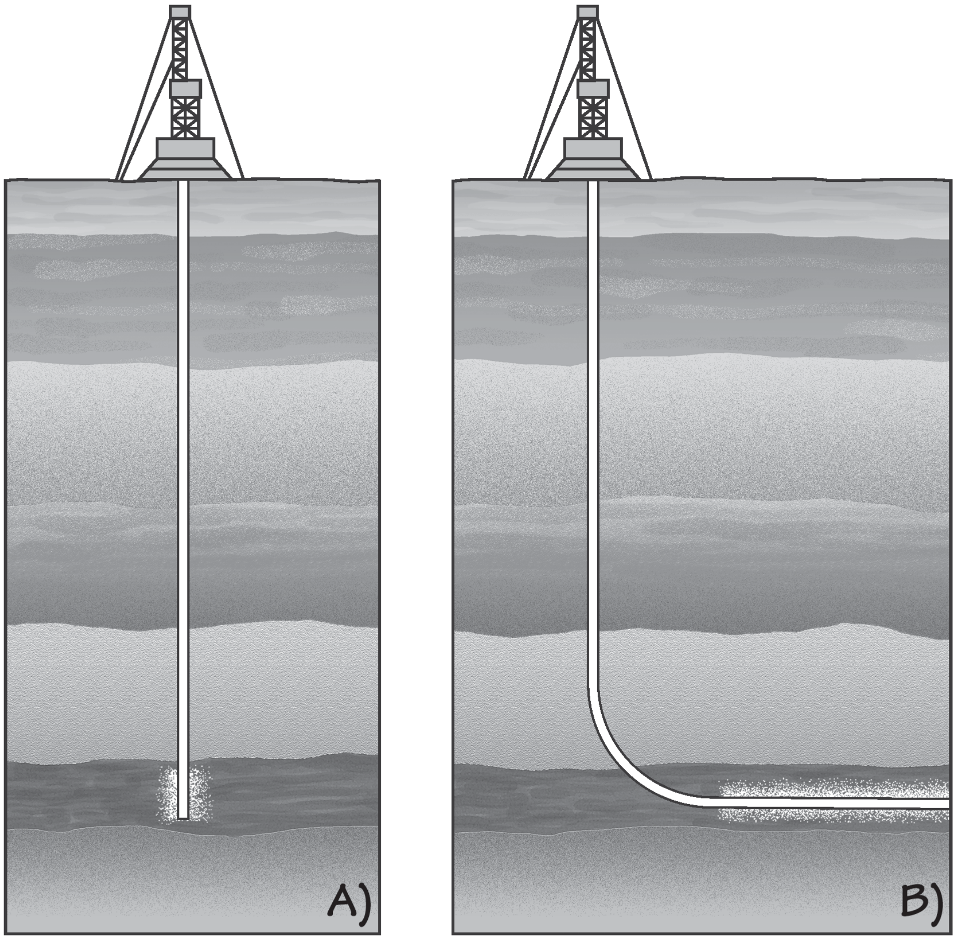
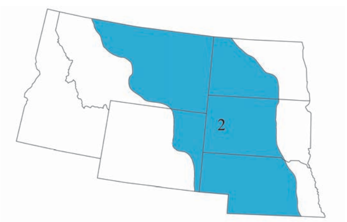


Figure 7.8: Oil wells (not to scale). A) A conventional vertical well. B) An unconventional horizontal well. Hydraulic fracturing may be carried out along horizontal wells running for a mile or more along layers with oil or gas trapped in pore spaces.

Figure 7.9: Oil pumpjacks in McKenzie County, North Dakota. The flame on the right-hand side is a flare that burns off natural gas separated from the oil.



__atmosphere__ • a layer of gases surrounding a planet.

__coalification__ • the process by which coal is formed from plant materials through compression and heating over long periods of time.

__aquifer__ • a water-bearing formation of gravel, permeable rock, or sand that is capable of providing water, in usable quantities, to springs or wells.

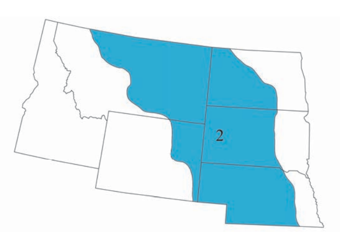
How does oil drilling work?

Once an oil trap or reservoir rock has been detected on land, oil crews excavate a broad flat pit for equipment and supplies around the area where the well will be drilled. Once the initial hole is prepared, an apparatus called a drilling rig is set up. The rig is a complex piece of machinery designed to drill through rock to a predetermined depth. A typical drilling rig usually contains generators to power the system, motors and hoists to lift the rotary drill, and circulation systems to remove rock from the borehole and lubricate the drill bit with mud. It also contains high-pressure blowout prevention equipment to prevent pressurized oil or gas from rising uncontrollably to the surface after being tapped. The support structure used to hold the drilling apparatus is called a derrick. In the early days of oil exploration, drilling rigs were semi-permanent structures and derricks were left onsite after the wells were completed. Today, however, most rigs are mobile and can be moved from well to well. Once the well has been drilled to a depth just above the oil reservoir, a cement casing is poured into the well to structurally reinforce it. Once the casing is set and sealed, oil is then allowed to flow into the well, the rig is removed, and production equipment can be put in place to extract the oil.

conventional drilling have been extracted from the Niobrara since the early 1900s, and in the past decade unconventional drilling below about 1830 meters (6000 feet) has greatly increased oil production in southeastern Wyoming.

See Chapter 3: Fossils to learn about fossils of the Niobrara Formation.

The Powder River Basin hosts significant quantities of coalbed methane. Coal mines have long been vented to the **atmosphere**, in part because of the build-up of methane (CH_4, the primary gas in natural gas) released from fissures around the coal. This methane is a byproduct of the process of **coalification**, by which ancient plant material was transformed into coal, and it accounts for over 5% of US methane production. While originally considered a hazard to be mitigated in subsurface mines, methods have been developed to trap this methane as an additional energy source. In some subsurface coal seams, water saturates fractures in the seam, transforming it into an **aquifer** (which



in some places may be clean enough to be part of the local water supply). If there is sufficient water pressure, methane present in the coal fractures may be trapped in the coal. To extract this methane, water can be removed via wells, thereby reducing pressure and allowing the gas to escape toward lower pressures along the well bore (*Figure 7.10*). Methane is then separated from the water. After the water is removed, it may take some years for the aquifer to be recharged, that is, refilled with water that infiltrates below the surface to the aquifer. Production rates climbed steeply beginning in the early 1990s, though in recent years it has decreased both in absolute and relative quantity as shale gas methane production has increased. Wyoming is one of the three leading US states for coalbed methane production (approximately equal to that of Colorado and New Mexico), each of which account for about 25% or more of the national total.

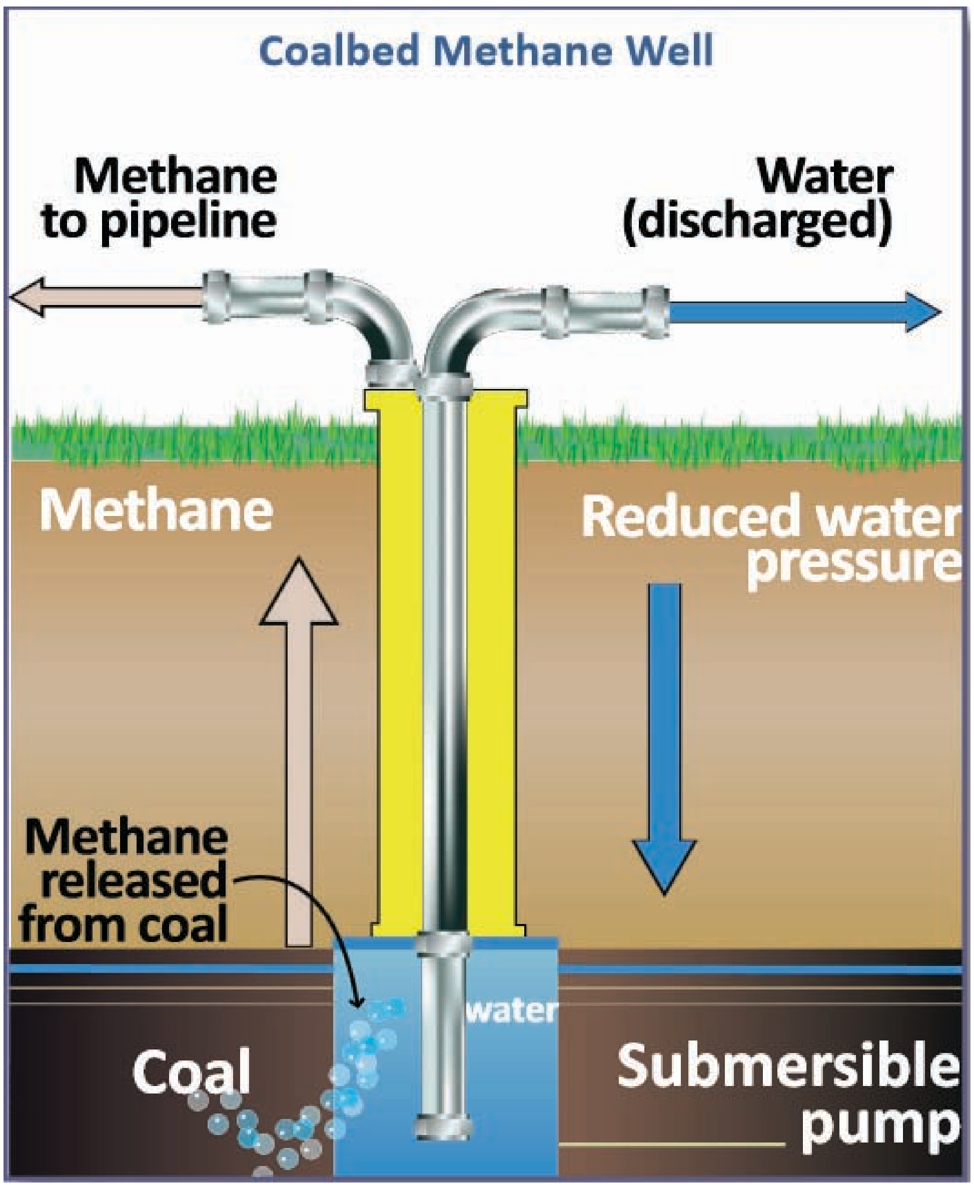
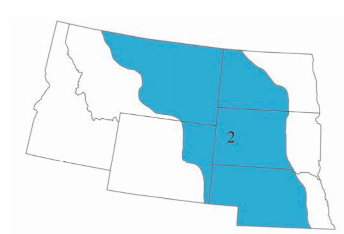


Figure 7.10: Coalbed methane production involves using water or other fluids to reduce pressure on the coal seam by creating a crack through which the methane can escape into a well.



Region 2

__Eocene__ • a geologic time period extending from 56 to 33 million years ago.

__Oligocene__ • a geologic time interval spanning from about 34 to 23 million years ago.

Wind Energy

The Great Plains (in this case referring to the full area that runs from Texas to Montana and into Canada) has been called the "Saudi Arabia of Wind Energy," at least in terms of potential (*Figure 7.11*). Wind energy provides about a third of the renewable energy produced in the US, with hydroelectric representing about half; solar, geothermal, and biomass account for the remaining sixth. In contrast to hydroelectric, wind energy is growing rapidly—it grew tenfold on a national scale from 2004 to 2014, and wind farms on the Great Plains have played a significant role in that growth. In the Northwest Central, the five Great Plains states are among the top 16 states for wind energy as a percentage of state electricity generation (South Dakota 25%, North Dakota 18%, Wyoming 9%, Nebraska 7%, and Montana 7%). This is all the more remarkable considering the rate of local petroleum and coal extraction.

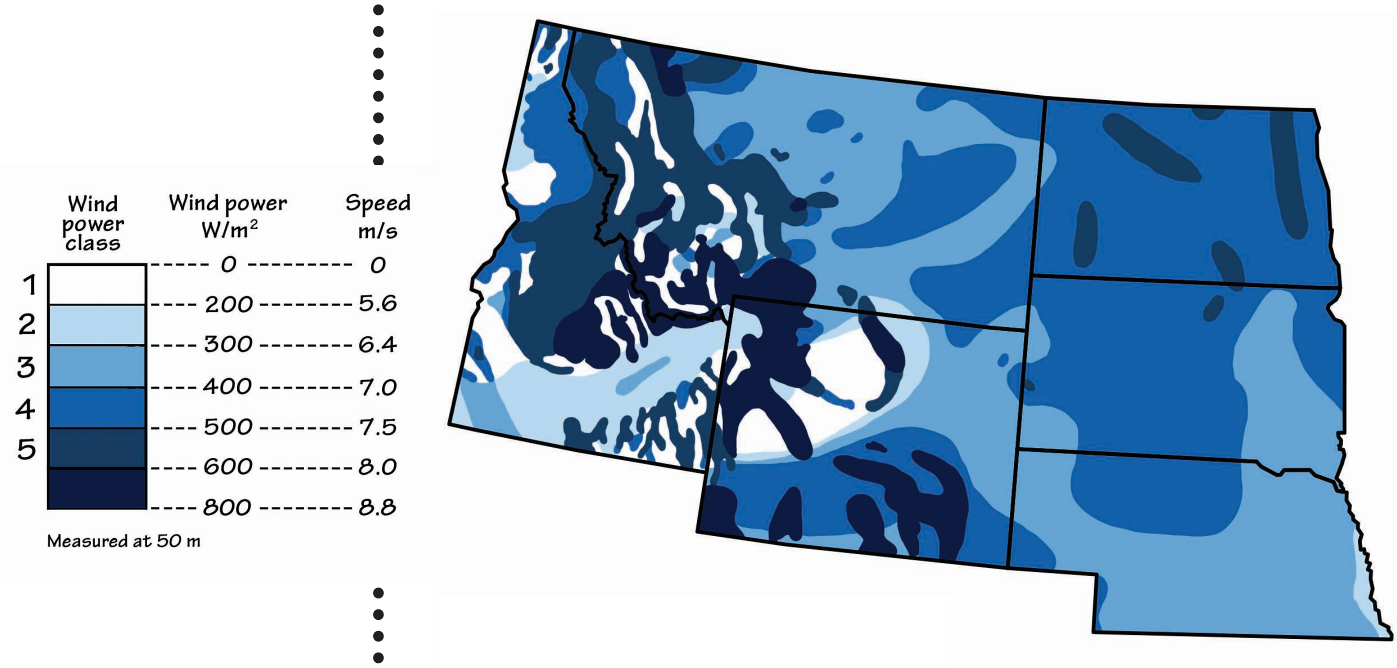
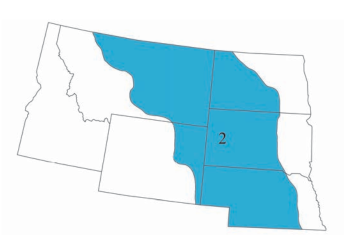


Figure 7.11: Wind energy potential in the Northwest Central US.

Uranium

Uranium used in nuclear power plants is mined from certain sedimentary rocks in the Great Plains. Economic deposits of uranium are found in Paleocene and **Eocene** sandstones in the southern Powder River Basin of Wyoming and in **Oligocene** rocks in northwest Nebraska (Crow Butte). The Paleocene lignitic coals of North Dakota also contain significant uranium content. Despite the prevalence of uranium resources throughout the Great Plains, however, nuclear power is not generated here.



Energy 7

Regions 2–3

Wind Energy and Landscape

Economically useful wind energy depends on steady high winds. Variation in wind speed is in large part influenced by the shape and elevation of the land surface. For example, higher elevations tend to have higher wind speeds, and flat areas can allow winds to pick up speed without interruption; thus high plateaus are especially appropriate for large wind farms. Since plateaus with low grass or no vegetation (or water bodies) have less wind friction than do areas of land with higher crops or forests, they facilitate higher winds. For all these reasons, the Great Plains region has high average wind speeds throughout its extent.

The Rockies and the Basin and Range, however, may have *locally* high wind speeds that can support strategically placed wind farms. For example, constricted valleys parallel to wind flow may funnel air into high velocities. Elevated ridges perpendicular to wind flow can also force fast winds across them. Thus, the wind velocities of these areas can vary geographically in quite complicated ways.

Laramide Orogeny • *a period of mountain building that began in the Late Cretaceous, and is responsible for the formation of the Rocky Mountains.*

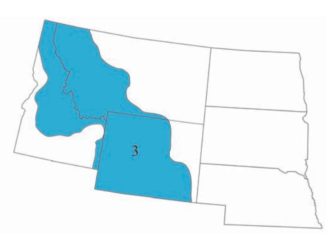
mineral • *a naturally occurring solid with a specific chemical composition and crystalline structure.*

Energy in the Rocky Mountains
Region 3

The high topography of the Rocky Mountains provides context both for hydroelectric power and wind energy. The same rugged peaks and valleys that contribute to localized high winds also make large-scale wind energy development difficult. The Rocky Mountains region is also known for coal, oil, and gas, in this case from large freshwater sedimentary deposits in the Greater Green River Basin.

Oil and Gas

Petroleum resources are extracted in the Greater Green River Basin (*see Figure 7.5*). The Greater Green River Basin is itself made up of several smaller basins and arches between them, formed during the **Laramide Orogeny** from the end of the Cretaceous period into the Eocene. The basin is known for its Eocene-aged surface rocks that contain both **mineral** and fossil fuel resources,



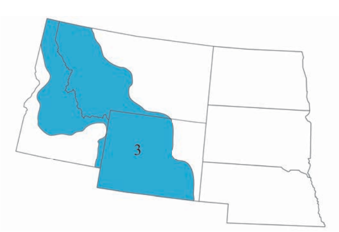
delta • *a typically wedge-shaped deposit formed as sediment is eroded from mountains and transported by streams across lower elevations.*

along with its unusually well-preserved terrestrial fossils in the Green River Formation. Fossil fuels, thought to be derived from blue-green algae living in ancient lakes, are found in particularly thick sequences of Eocene oil shale. The Green River Formation hosts the largest known oil shale deposits in the world.

See Chapter 5: Mineral Resources to learn more about the wide variety of minerals found in the Rocky Mountains.

The Greater Green River Basin also contains other fossil fuel resources of lesser renown. For example, the largest of the arches in the basin, the Rock Springs Uplift (which divides the basin into the Green River Basin on the west and smaller basins in the east) contains coal deposits that were first mined as fuel for the Union Pacific Railroad during the building of the Transcontinental Railroad and subsequent railroad operations. Conventional oil and gas drilling has also occurred in the basin, in Cretaceous-aged **deltaic** rocks from the Western Interior Seaway (*Figure 7.12*). The Wamsutter gas field, occupying a 89-kilometer-long (55-mile-long) portion of Wyoming's Red Desert, has recently experienced an energy boom, with more than 2000 gas wells projected to be operational there by 2020.

Figure 7.12: Natural gas drilling rigs in the Upper Green River Valley.



Hydroelectric Power

Since the Rocky Mountains provide an abundance of water to lower regions in the east and west, hydroelectric power is substantial in this area (*Figure 7.13*). The Clark Fork and Kootenai Rivers (tributaries of the Columbia River that flow through Montana and Idaho) are major rivers that provide the potential for much of the Rocky Mountains' hydropower, which uses the gravitational force of falling or rushing water to rotate turbines that convert the water's force into energy. The three largest hydropower plants in Montana—Noxon Rapids Dam (580.5 MW), Libby Dam (525 MW), and Hungry Horse Dam (428 MW)—are located along these rivers and their tributaries, helping to make Montana one of the largest producers of hydropower in the US (*Figure 7.14*).

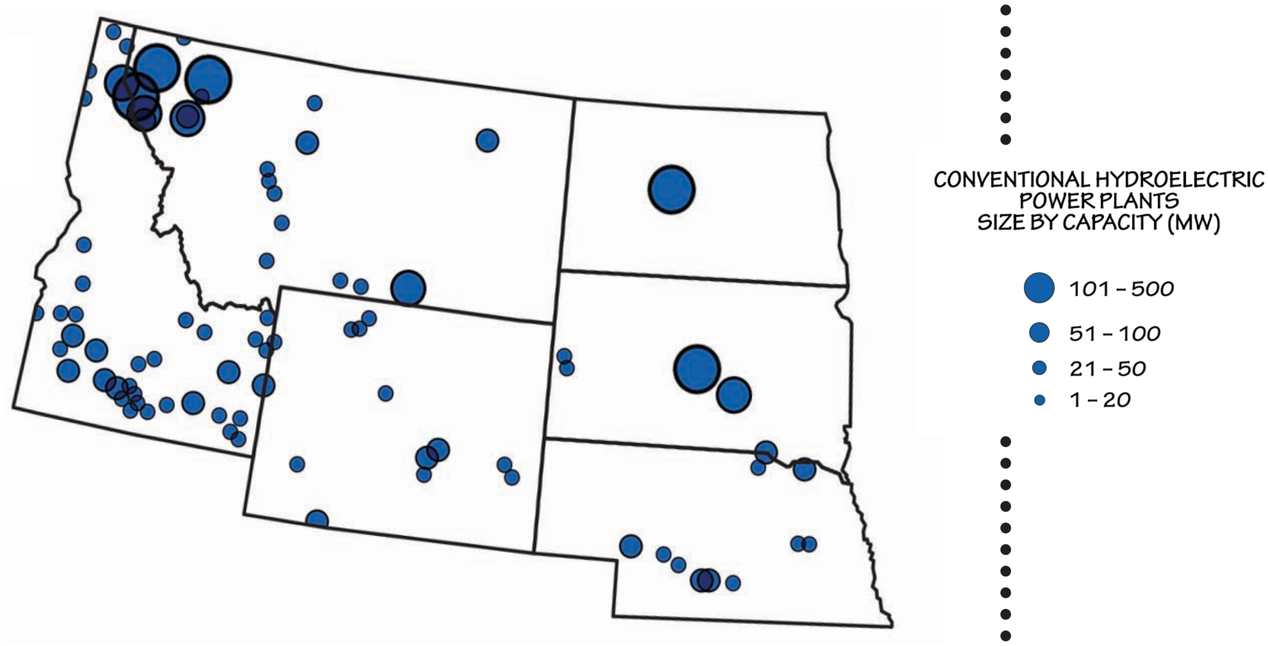
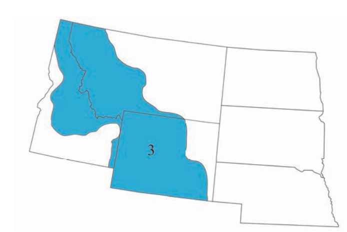


Figure 7.13: Hydroelectric plants in the Northwest Central.

Wind Power

The Rocky Mountains region has some of the highest potential for wind energy in the US (*see Figure 7.11*), though the area's terrain and lack of infrastructure can make tapping into this resource challenging. Windmills along I-80 in southeast Wyoming near Medicine Bow, where a gap exists in the Rockies, were among the first large-scale wind farms in the US. These facilitated high voltage transmission lines along the Interstate. There are a number of locations in southwestern Montana and northwestern Wyoming where valleys are oriented such that winds are funneled relatively consistently through the year; these areas have future potential for expanded wind farms.



Regions 3–4

basalt • *an extrusive igneous rock, and the most common rock type on the surface of the Earth.*

volcanism • *the eruption of molten rock onto the surface of the crust.*

Figure 7.14: Libby Dam, on the Kootenai River in Lincoln County, Montana. This dam is 129 meters (422 feet) tall and 931 meters (3055 feet) long, with a generating capacity of up to 600 megawatts.

Energy in the Columbia Plateau
Region 4

The active tectonics that resulted in the Columbia Plateau flood **basalts** and the growth of the Rocky Mountains to the east have created a region rich in hydroelectric and wind energy, as well as the potential for geothermal energy. More comprehensive development of geothermal energy may be an area of growth in the future. Fossil fuel development, however, has not been significant in the Columbia Plateau.

Fossil Fuels

The Columbia Plateau has seen very little fossil fuel development because it is covered by thick **volcanic** deposits that make exploration and recovery challenging. The volcanic rocks overlie Cenozoic lake deposits and older marine rocks that may contain oil and gas resources, but they have not been considered economically viable to develop.

Alternative Energy

With the Owyhee Mountain Range to the west and the Caribou Mountains and Forest bordering the east, the Snake River Valley and Bruneau Valley are host to many lakes and waterways. With its mouth at the Columbia River, the Snake River is over 1600 kilometers (1000 miles) long and is the largest tributary

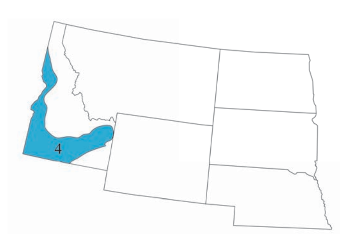
that empties into the Pacific Ocean. With all of this water, it is no surprise that hydropower is a primary source of energy in the region—58% of Idaho's electricity comes from hydropower (*see Figure 7.13*). There are 15 dams along the Snake River; some provide irrigation for farming, but there are many that provide hydropower. There are also over 30 hydroelectric power stations on or near the Snake River in this region, three of the largest of which—Brownlee Dam (585 MW), Hells Canyon Dam (391 MW), and Oxbow Dam (190 MW)—are along the Idaho-Oregon border.

There are other renewable energy resources on the Columbia Plateau, including geothermal, biofuel, and wind energy. Although not yet a significant source of energy for the region, research and development into both geothermal and wind power is aimed at making both sources a lucrative option for the area.

Most of Idaho's wind farms run in a southward arc along the highway route from Boise in the west to Idaho Falls in the east. The Goshen North Wind Farm near Idaho Falls, at an elevation of over 1400 meters (4600 feet), is the state's largest wind farm. It has the capacity to produce about 125 MW. Wind accounts for about 16% of Idaho's electricity generation (*Figure 7.15*).

Figure 7.15: Wind turbines dot the landscape at this wind farm in Power County, Idaho.

Geothermal energy potential is abundant on the Columbia Plateau in Idaho; however, immediately east, on Yellowstone Plateau near the western edge of Wyoming, geothermal heat is not developed for energy because of the area's status as a National Park. Though geothermal accounts for only a small percentage of Idaho's electricity generation relative to hydroelectric and wind power, the state ranks sixth nationally in the use of geothermal energy (*Figure 7.16*).



Energy

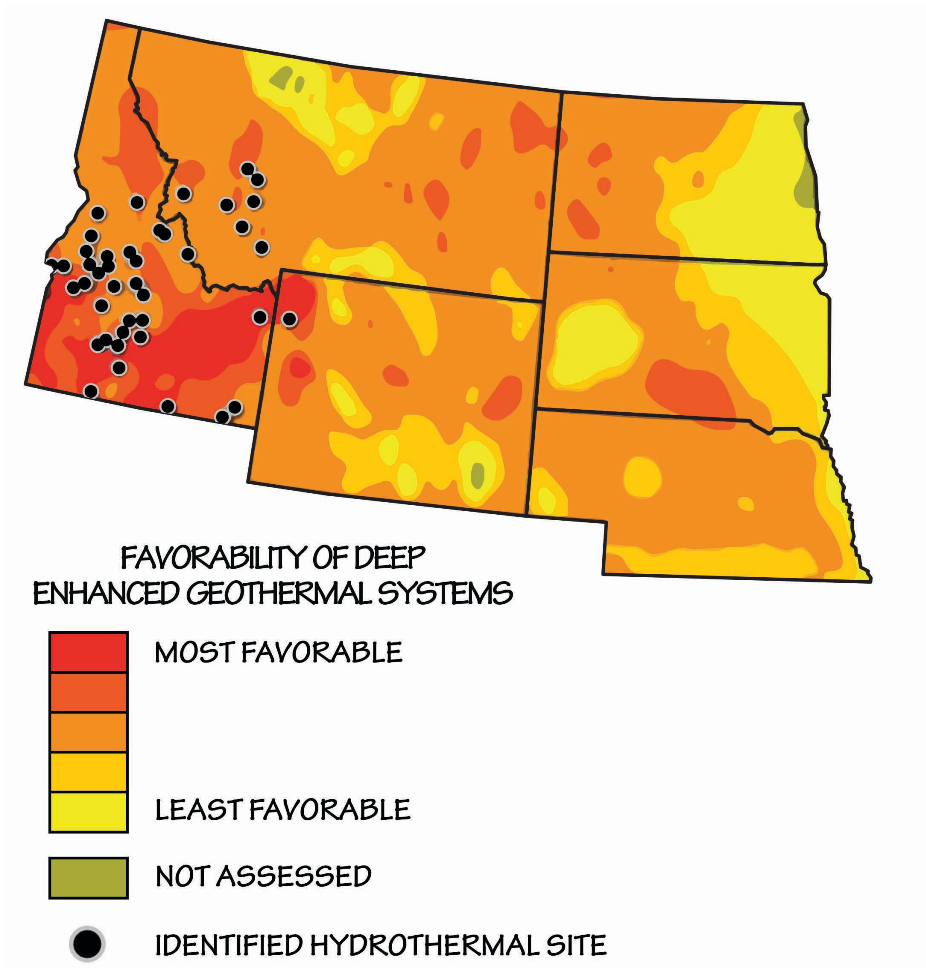
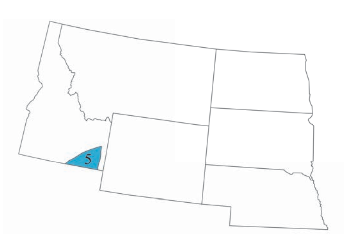


Figure 7.16: Geothermal energy resources iin the Northwest Central.

Energy in the Basin and Range
Region 5

Like the Columbia Plateau region, active tectonism yields an opportunity for the growth of geothermal energy in the Basin and Range. Hydroelectric power development is associated with the region's steep topography, in particular that of the Snake River, which flows from western Wyoming through the Snake River Plain of southern Idaho and discharges water at a rate of over 1500 cubic meters per second (54,000 cubic feet per second). The largest hydroelectric plant in the Basin and Range is Palisades Dam on the Snake River, though it is less than half the size (about 175 MW) of the largest hydro plant in the Columbia Plateau region.



Energy 7

Geothermal energy comes from heat within the Earth, which is created on an ongoing basis by **radioactivity**. This energy powers **mantle convection** and **plate tectonics**. The highest-temperature conditions exist in tectonically active areas, including the Basin and Range, Iceland (a mid-Atlantic ridge), Japan (an area of **subduction**), and Hawaii and Yellowstone (areas with **hot spots**). Idaho's Basin and Range is home to the Raft River Geothermal Power Plant. Operated by Geothermal, Inc., the plant is actually a former US Department of Energy (USDOE) geothermal research and demonstration facility (*Figure 7.17*). The facility uses a "binary" energy system developed and tested by the USDOE. Unlike typical geothermal power plants that make direct use of vapor from heated water to spin turbines, this system passes hot geothermal water through a heat exchanger to heat a secondary liquid that vaporizes at a significantly lower temperature than water. This enhances the energy capture capacity of the system, thus increasing energy production.

Figure 7.17: The 13 MW Raft River Geothermal Plant near Malta, Idaho was the first commercial-sized binary cycle geothermal plant in the world. The plant's condensers and heat exchangers are pictured here.

Region 5

radioactivity • *the emission of radiation by an unstable atom.*

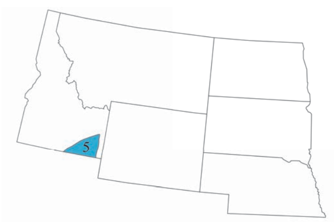
mantle • *the layer of the Earth between the crust and core.*

convection • *the rise of buoyant material and the sinking of denser material.*

plate tectonics • *the process by which the plates of the Earth's crust move and interact with one another at their boundaries.*

subduction • *the process by which one plate moves under another, sinking into the mantle.*

hot spot • *a volcanic region thought to be fed by underlying mantle that is anomalously hot compared with the mantle elsewhere.*



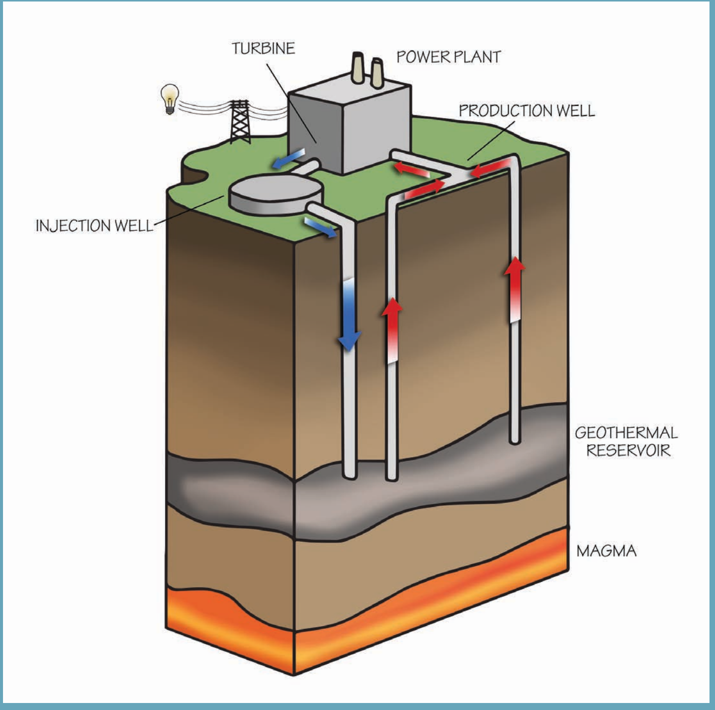
Energy

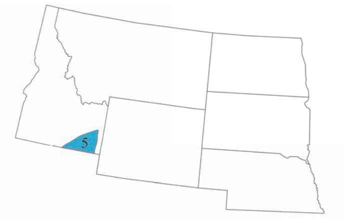
Region 5

How does geothermal energy work?

Geothermal power stations use steam to power turbines that generate electricity. The steam is created either by tapping a source of heated groundwater or by injecting water deep into the Earth where it is heated to boiling. Pressurized steam is then piped back up to the power plant, where its force turns a turbine and generates power. Water that cycles through the power plant is injected back into the underground reservoir to preserve the resource.

There are three geothermal sources that can be used to create electricity. Geopressurized or dry steam power plants utilize an existing heated groundwater source, generally around 177°C (350°F) in temperature. Petrothermal or flash steam power plants are the most common type of geothermal plant in operation today, and they actively inject water to create steam. Binary cycle power plants are able to use a lower temperature geothermal reservoir by using the warm water to heat a liquid with a lower boiling point, such as butane. The liquid butane becomes steam, which is used to power the turbine.





Energy 7

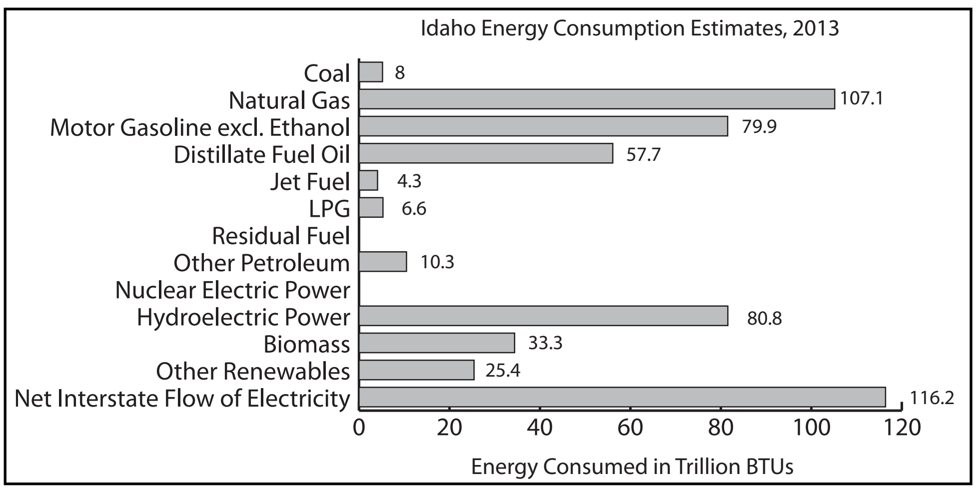
State Facts

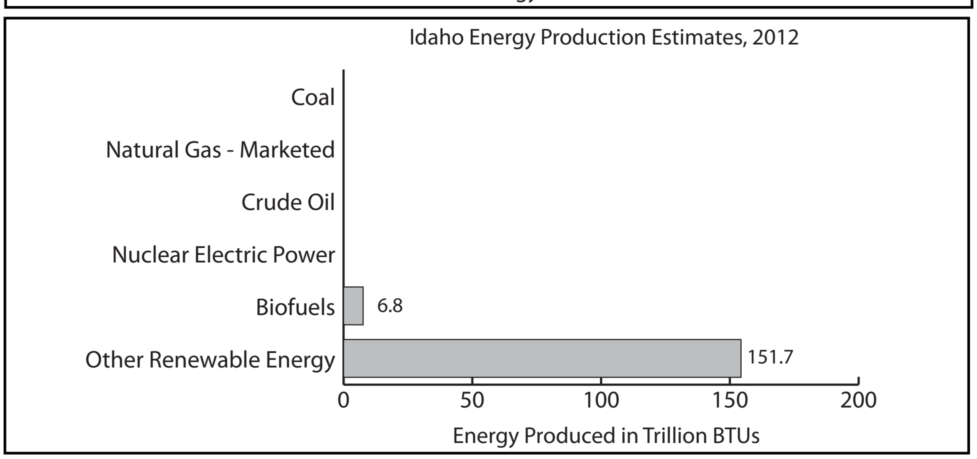
Energy Facts by State

Because of many local laws and guidelines, energy production and use is highly dictated by each state government. Below is a state-by-state assessment of energy production and use in the Northwest Central (from http://www.eia.gov).

Idaho

- Idaho is rich in renewable energy resources; geothermal energy capable of generating electricity at commercial levels is present in most of the state.
- In 2012, Idaho's in-state net electricity generation equaled 55% of the state's total electric industry retail sales. The remainder came from other states and international imports.
- In 2013, 78% of Idaho's net electricity generation came from renewable energy resources, and Idaho had the lowest average electricity prices in the United States.
- Hydroelectric power supplied 58% of net electricity generation in Idaho in 2013.
- Idaho's wind generation increased by nearly 35% in 2013, providing 16% of net electricity generation.



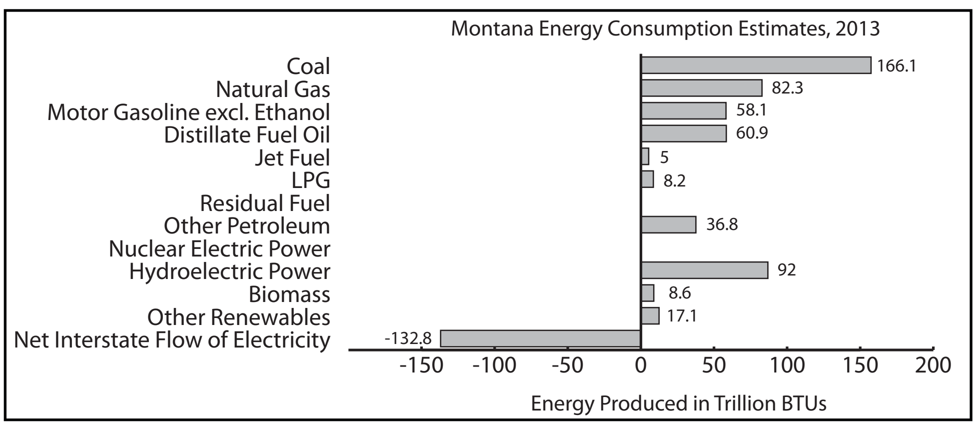


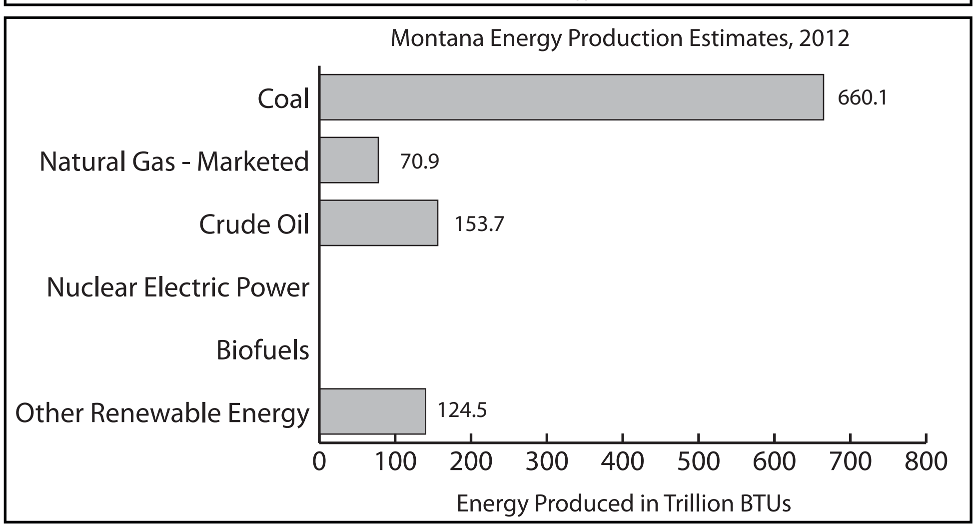
7 Energy

State Facts

Montana

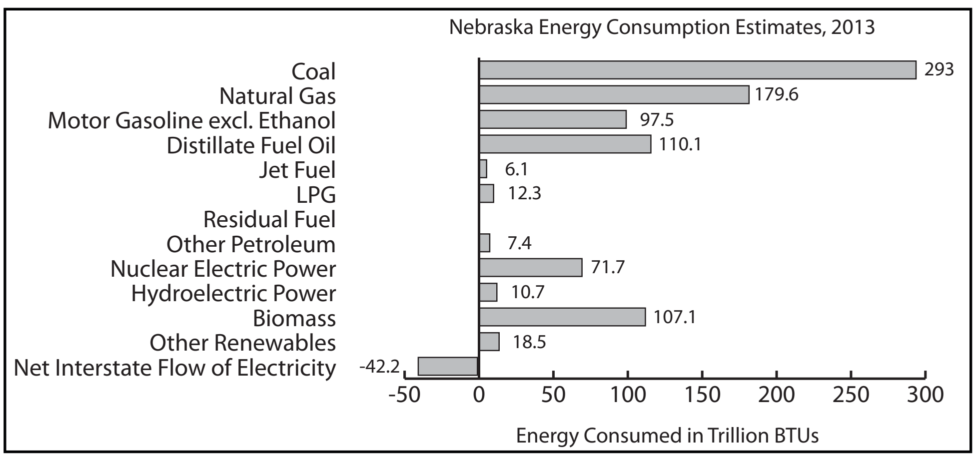
- The Williston Basin of Montana and North Dakota holds one of the largest accumulations of crude oil in the United States; its Bakken and Three Forks formations are currently estimated to be capable of producing 7.4 billion barrels of oil.
- As of the end of 2012, Montana held over one-fourth of the nation's estimated recoverable coal reserves at producing mines and was the eighth largest coal-producing state. It produced 3.6% of US coal in 2012 and distributed coal to nine other states.
- Montana's four refineries, with almost 30% of US Petroleum Administration for Defense District 4 (Colorado, Idaho, Montana, Utah, and Wyoming) refining capacity in 2012, are able to process heavy Canadian crude oil for regional markets.
- Wind electric power generation in Montana grew by almost 32% in 2013 and supplied 6% of the state's net electricity generation.
- Montana has created a Renewable Energy Resource Standard requiring that public utilities and competitive electricity suppliers obtain 15% of electricity sales from renewable energy resources by 2015.

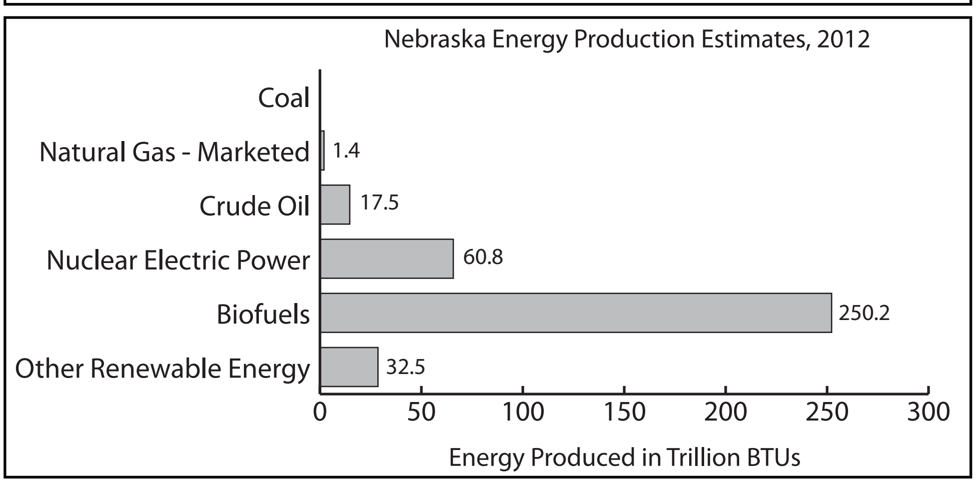




Nebraska

- The Niobrara shale formation is an emerging oil play that includes southwest Nebraska, northeast Colorado, and northwest Kansas.
- The National Renewable Energy Laboratory estimates that almost 92% of Nebraska has suitable conditions for wind-powered electricity generation.
- In 2013, Nebraska ranked 22nd among the 50 states in crude oil production. Most of the production came from small oil reserves in the western part of the state.
- Nebraska's net electricity generation from its two nuclear reactors was 38% lower in 2013 than in 2010, as a result of the temporary closure of the Fort Calhoun nuclear power plant between April 2011 and December 2013.
- Nebraska ranked second in the nation, after Iowa, in corn-based ethanol production capacity in 2014.



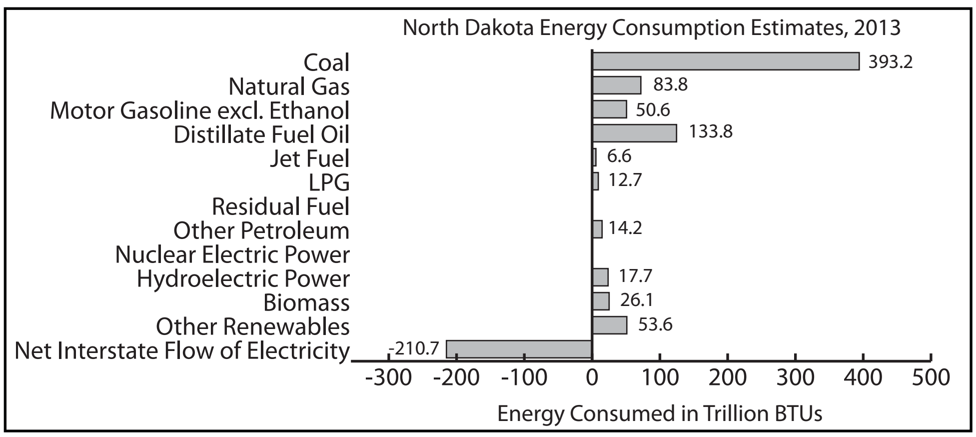


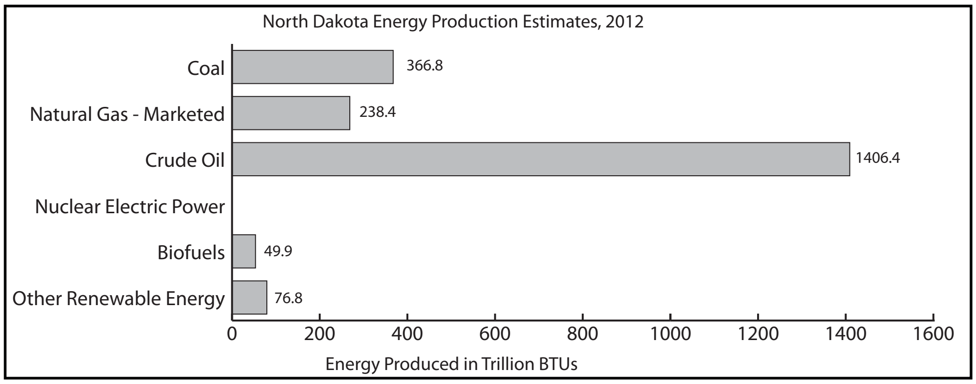
Energy

State Facts

North Dakota

- Although North Dakota's total energy consumption is among the lowest in the nation as a result of its small population, the state's consumption per capita ranks among the highest, in part because of the energy-intensive industrial sector and high heating demand in winter.
- North Dakota had 6% of the nation's recoverable coal reserves at producing mines as of 2012; the state's coal production, which all came from surface mines, accounted for 2.7% of US coal production in 2012.
- In 2013, North Dakota was the second largest crude oil-producing state in the nation and accounted for over 11.5% of total US crude oil production; a 177% increase in production from 2010 to 2013 was primarily driven by horizontal drilling and hydraulic fracturing in the Bakken formation.
- In 2013, 79% of North Dakota's net electricity generation came from coal, almost 16% came from wind energy, and about 5% came from conventional hydroelectric power sources.
- North Dakota has abundant wind resources and ranked 6th in the nation in wind energy potential, 11th in utility-scale generation, and 12th in installed capacity in 2013.

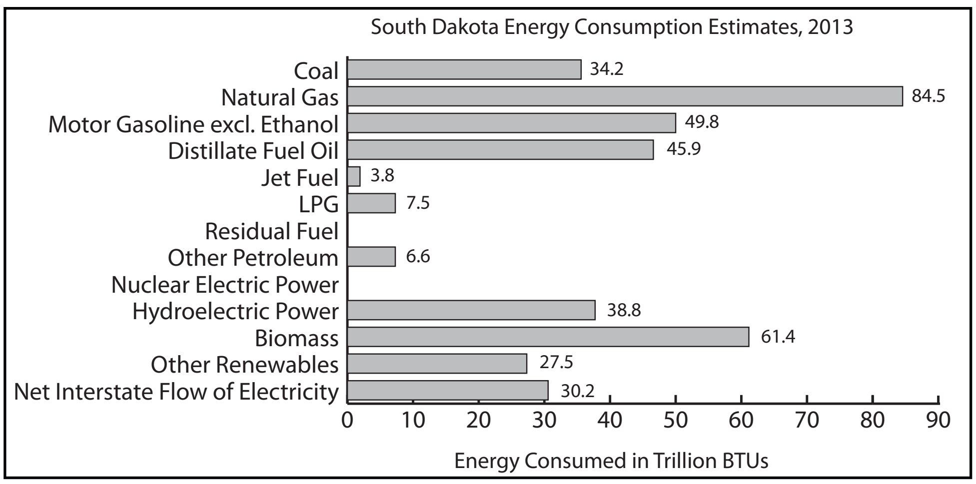


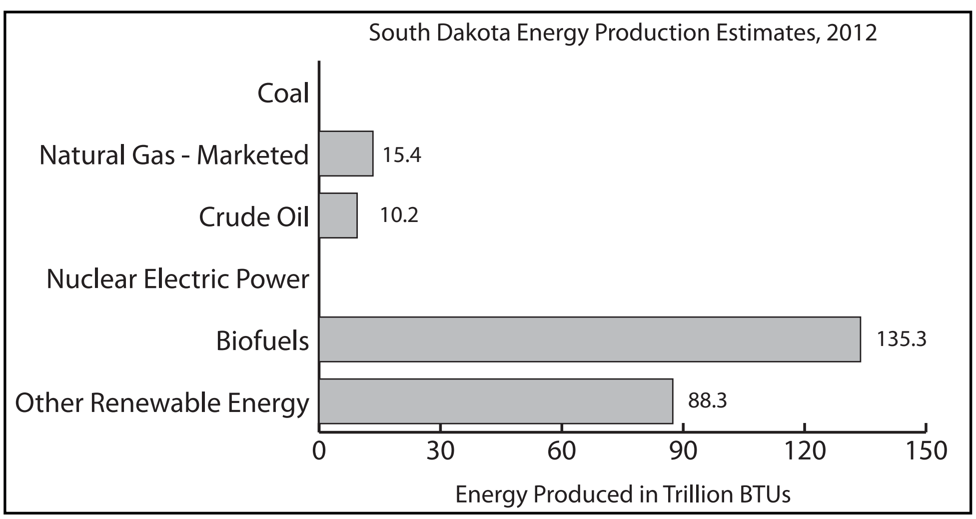


State Facts

South Dakota

- The National Renewable Energy Laboratory estimates that 88% of South Dakota's land area is suitable for wind resource development.
- In 2013, South Dakota had more net electricity generated from hydroelectric power than from any other source.
- Wind and hydroelectric power provided 65% of South Dakota's total net electricity generation in 2013.
- South Dakota ranked fifth in the nation in ethanol production capacity in 2014.
- South Dakotans' price for electricity averaged 8.83 cents per kilowatt hour in 2013 across all sectors, compared to the national average of 10.08 cents per kilowatt hour.



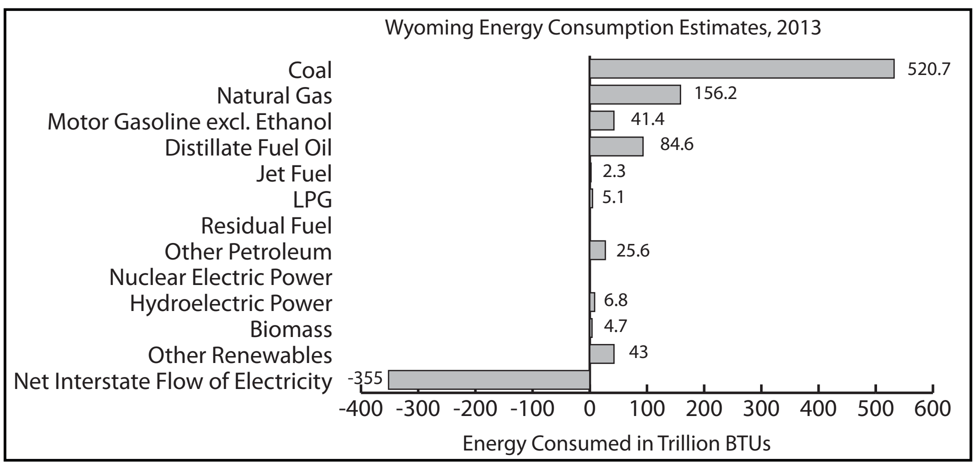


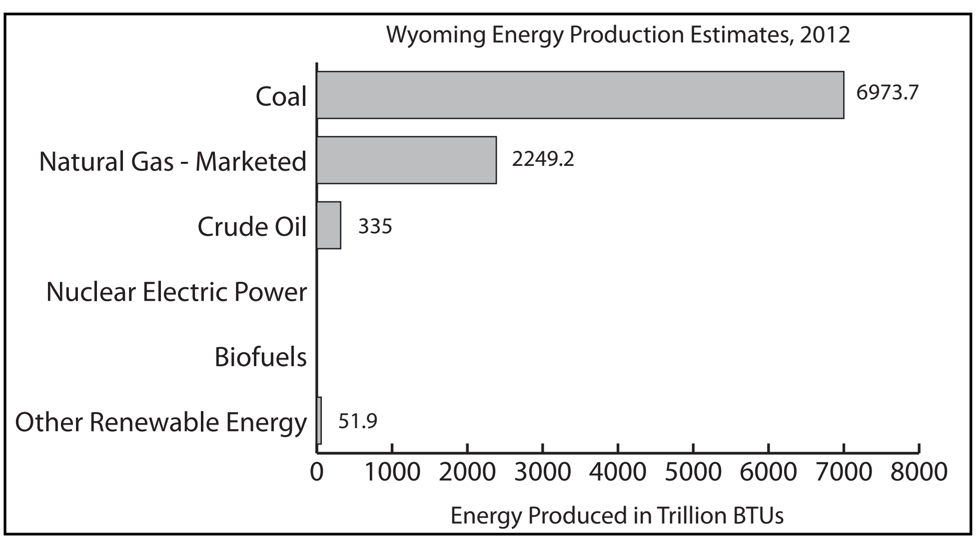
Energy

State Facts

Wyoming

- Wyoming produced 39% of all coal mined in the United States in 2012.
- In 2012, 34 states received coal from Wyoming mines, with 9 states, including Wyoming, obtaining more than 90% of their domestic coal from Wyoming.
- Wyoming accounted for 7.4% of US marketed natural gas production in 2013.
- In 2013, almost 89% of net electricity generation in Wyoming came from coal and about 10% came from renewable energy resources, primarily wind.
- Wyoming had the third lowest average electricity price of any state in 2013.





Climate Change

Energy and Climate Change
The Future of Energy in the US

Americans have come to rely on a diverse and abundant energy system, one that provides a continuous supply of energy with few interruptions. However, **climate change** is projected to play a big part in altering our supply, production, and demand for energy. Increases in temperatures will be accompanied by an increase in energy for cooling, while projected increases in the occurrence of **hurricanes**, floods, **tornados**, and other extreme **weather** events will continue to have a significant effect on the infrastructure of power grids and energy delivery systems. Drought and water shortages are already affecting energy production and supply. For example, in the Northeast, mild winter temperatures prior to the winter of 2013–2014 had decreased energy demands for heat, but they did not fully offset increased demands for cooling, and the regionally harsher winter of 2013–2014 saw increased demands for heating fuels. These types of disruptions affect us both locally and nationally, are diverse in nature, and will require equally diverse solutions.

See Chapter 9: Climate for more information about climate change in the Northwest Central.

Energy is a **commodity**, and supply and demand around the world will also affect the US energy system. As the global population grows, and industrialization of the world continues, demand for energy will increase even further as resources are depleted. These factors can significantly affect US energy costs through competition for imported and exported energy products. Mediation of our energy production could have a huge positive impact on climate change. Unfortunately, there is no energy production system or source currently available that is truly **sustainable**. All forms of energy have negative impacts on the environment, as do many of the ways in which we use them.

Until we have a sustainable means of producing and delivering energy, we need to consider which means of energy production and transport make the least impact; we are faced with a sort of "energy triage." The answer to this problem will be multifaceted, depending in large part on which energy resources and delivery methods are available in each part of the US. The sources of energy that provide the least impact for the best price for people living in the Northwest Central are probably not the same as for those in other areas, such as the Southwest or Northeast.

Adaptation—changing our habits of energy use and delivery—can also make it easier for our existing energy infrastructure to adjust to the needs brought on by climate change. Investing in adaptation can pay off in the short term by reducing risks and vulnerabilities, thus minimizing future risks. Increasing sustainable energy practices (including harvesting and production) and

climate change • *See global warming: the current increase in the average temperature worldwide, caused by the buildup of greenhouse gases in the atmosphere.*

hurricane • *a rapidly rotating storm system with heavy winds, a low-pressure center, and a spiral arrangement of thunderstorms.*

tornado • *a vertical funnel-shaped storm with a visible horizontal rotation.*

weather • *the measure of short-term conditions of the atmosphere such as temperature, wind speed, and humidity.*

commodity • *a good for which there is demand, but which is treated as equivalent across all markets, no matter who produces it.*

sustainable • *able to be maintained at a steady level without exhausting natural resources or causing severe ecological damage, as in a behavior or practice.*

efficiency • *the use of a relatively small amount of energy for a given task, purpose, or service; achieving a specific output with less energy input.*

improving infrastructure and delivery methods can go a long way toward not only decreasing the effects of climate change, but also our energy security.

Some of these changes are grounded in the development of new technologies for energy production and energy **efficiency**; others may be related to changes in behavior. These changes in technology and behavior may go hand in hand; roughly 2% of electricity production now goes to data centers, for example—a use that did not exist in 1985. Additionally, the Internet is rapidly changing other ways we use energy, allowing us to telecommute and changing the way we shop.

In closing, some key points to keep in mind regarding the future of energy are:

1. Extreme weather events are affecting energy production and delivery facilities, causing supply disruptions of varying lengths and magnitudes and affecting other infrastructure that depends on energy supply. The frequency and intensity of extreme weather events are expected to increase.

See Chapter 10: Earth Hazards to learn more about extreme weather events.

2. Higher summer temperatures are likely to increase electricity use, causing higher summer peak loads, while warmer winters are likely to decrease energy demands for heating. Net energy use is projected to increase as rising demands for cooling outpace declining heating energy demands.

3. Both episodic and long-lasting changes in water availability will constrain different forms of energy production.

4. In the longer term, sea level rise will affect the coastal facilities and infrastructure on which many energy systems, markets, and consumers depend.

5. As we invest in new energy technologies, future energy systems will differ from those of the present in uncertain ways. Depending on the way in which our energy system changes, climate change will introduce both new risks and new opportunities.

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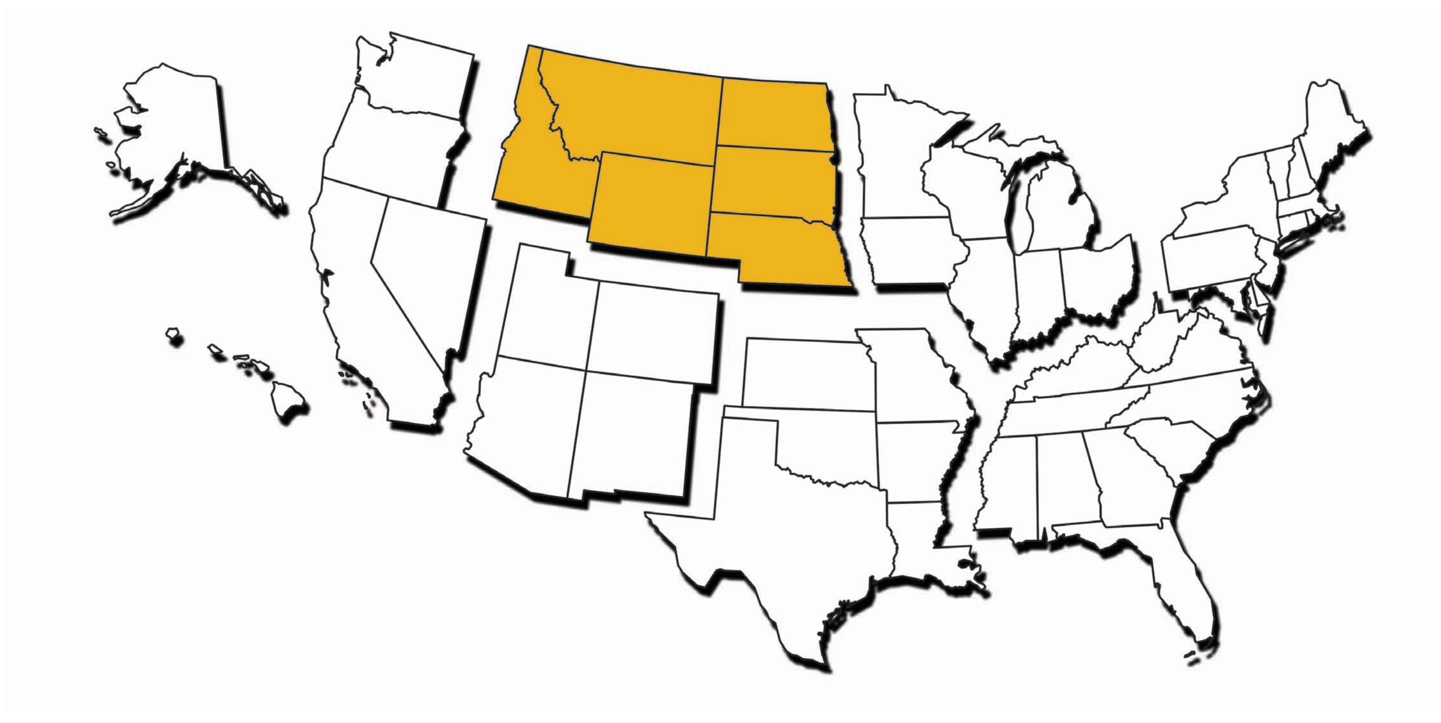
The **Teacher-Friendly** Guide™

to the Earth Science of the Northwest Central US



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On the back cover: Blended geologic and digital elevation map of the Northwest Central US. Each color represents the age of the bedrock at the surface. Adapted from Barton, K.E., Howell, D.G., Vigil, J.F., *The North America Tapestry of Time and Terrain*, US Geological Survey Geologic Investigations Series I-2781, http://pubs.usgs.gov/imap/i2781.