NCF-Envirothon 2024 New York

Current Issue Part A Study Resources

Key Topic #1: Introduction to Energy and Traditional Energy Infrastructure

1. Define energy and explain how energy is relevant in our everyday lives.
2. Describe the different levels at which energy decisions are made, and what factors affect energy decision-making.
3. Explain the setup and design of traditional energy infrastructure and distribution systems.
4. Explain how traditional non-renewable energy sources such as petroleum, coal, and natural gas are extracted and utilized to create energy.
5. Identify the environmental, social, and economic advantages and disadvantages of these traditional non-renewable energy sources, and evaluate their suitability for meeting the world's energy needs in the future.
6. Identify threats to the energy system for both traditional and renewable sources.

Study Resources

Resource Title	Source	Located on
Introduction to Energy	*Paleontological Research Institution, 2022*	Pages 4 - 20
VIDEO: Energy Decisions (5 minutes)	*US Department of Energy, 2015*	Page 21
Electricity System Overview	*US Department of Energy, 2017*	Pages 22 - 34
Petroleum	*National Energy Education Development, 2021*	Pages 35 - 38
Coal	*National Energy Education Development, 2021*	Pages 39 - 42
Natural Gas	*National Energy Education Development, 2021*	Pages 43 - 46
Understanding Power System Threats and Impacts	*USAID and National Renewable Energy Laboratory, 2019*	Pages 47 - 52

Study Resources begin on the next page! ➡

Introduction to Energy

Paleontological Research Institution – April 7, 2022

Page snapshot: Introduction to energy, including definition of energy and units used to measure energy, fossil fuel types and their extraction, renewable energy, and the future of energy in the United States.

Credits: *Most of the text of this page is derived from "Energy in the Southeastern US" by Carlyn S. Buckler, Peter L. Nester, Stephen F Greb, and Robert J. Moye, chapter 6 in The Teacher-Friendly Guide to the Earth Science of the Southeastern U.S., 2nd. ed., edited by Andrielle N. Swaby, Mark D. Lucas, and Robert M. Ross (published in 2016 by the Paleontological Research Institution; currently out of print), with some text coming from other volumes of the Teacher-Friendly Guide series. The book was adapted for the web by Elizabeth J. Hermsen and Jonathan R. Hendricks in 2021–2022. Changes include formatting and revisions to the text and images. Credits for individual images are given in figure captions.*

What is energy?

Energy is an interdisciplinary topic, and the concepts used to understand energy in the Earth system are fundamental to all disciplines of science. One cannot study physics or understand biomes, photosynthesis, fire, evolution, seismology, chemical reactions, or genetics without considering energy. 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, and heats our homes and businesses. It is used in manufacturing and other industrial processes.

But what is energy? Energy is power that is derived from the utilization of physical or chemical resources. Wind and solar power, fossil fuels, nuclear energy, and hydroelectricity are primary energy sources. Primary energy sources are energy sources that occur in nature. Secondary energy sources, also known as energy carriers, have been transformed into energy used directly by humans. Examples of secondary energy sources are electricity and gasoline.

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. Heat was produced largely through the burning of wood. Exceptions include the use of sails on boats by a very small percentage of the world's population to move people and goods. In China, people used natural gas to boil brine in the production of salt beginning roughly 2000 years ago. Nearly all the energy to power human society was, in other words, biomass; it was produced by humans, by other animals, or by burning wood.

The transition from brute force and burning wood to the production and use of various industrial sources of energy has occurred remarkably quickly, happening in the course of just a few generations. Much of the rural US was without access to electricity until the 1930s, and cars have been around for only slightly longer. Yet, many of us take these conveniences for granted today. The transition to industrial sources of energy has caused changes in virtually every aspect of human life, from transportation to economics to war to architecture. 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 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.

Our energy system—how we get energy and what we use it for—is still changing remarkably quickly in some ways, while it is very resistant to change in others. The use of wind to generate electricity, for example, grew rapidly in the late 2000s and early 2010s. In 2002, wind produced less than 11 million megawatt hours (MWh) of electricity in the US, whereas in 2011, wind produced more than 120 million MWh. In contrast, we continue to rely heavily on fossil fuels like coal, oil, and natural gas to produce electricity, supply heat, and fuel transportation. Our reliance on fossil fuels is driven by a number of factors, including low upfront cost, very high energy densities, and the cost and durability of the infrastructure built to use fossil fuels.

Traffic on Interstate 95-North, Miami, in 2012. Fossil fuels are being used to power the cars. Photo by B137 (Wikimedia Commons, Creative Commons Attribution-ShareAlike 4.0 International license, photo cropped and resized).

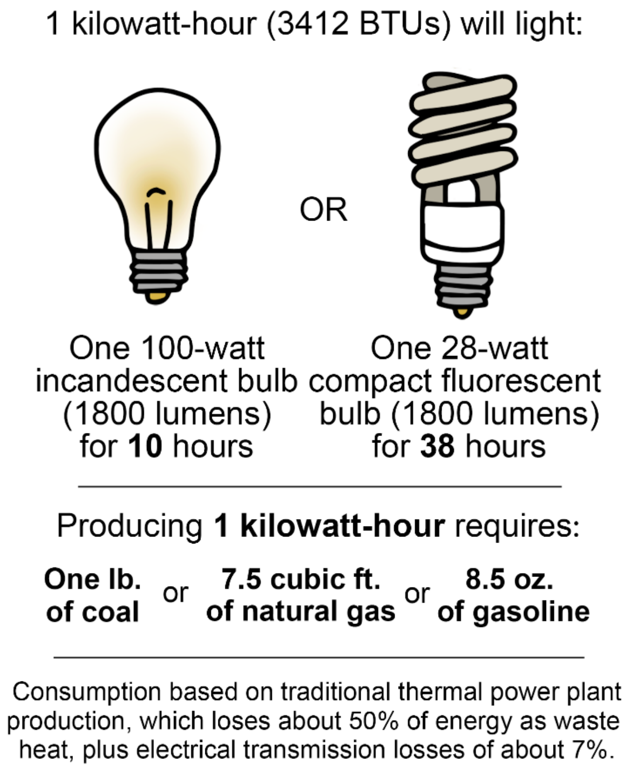
What do different units of energy mean?

Heat is energy. 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. By definition, one BTU is approximately the amount of heat required to raise one pound of water by one degree Fahrenheit. One BTU is also about 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 (about 100 grams or 3.6 ounces), lifting an apple one meter requires about a joule of energy. A BTU is roughly 1055 joules. 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 1055 meters (about 3461 feet) or a bit over one kilometer (about 0.66 or 2/3 miles).

This comparison of the energy of heat to the energy of motion—also called kinetic energy—might be a little confusing. However, energy is transformed from one type to another all the time in our energy system. This is perhaps most obvious with electricity. 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 transformations in either direction are always imperfect, so energy always degrades into heat when it is transformed 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. One kWh is about 3412 BTUs or about 3.6 million joules.

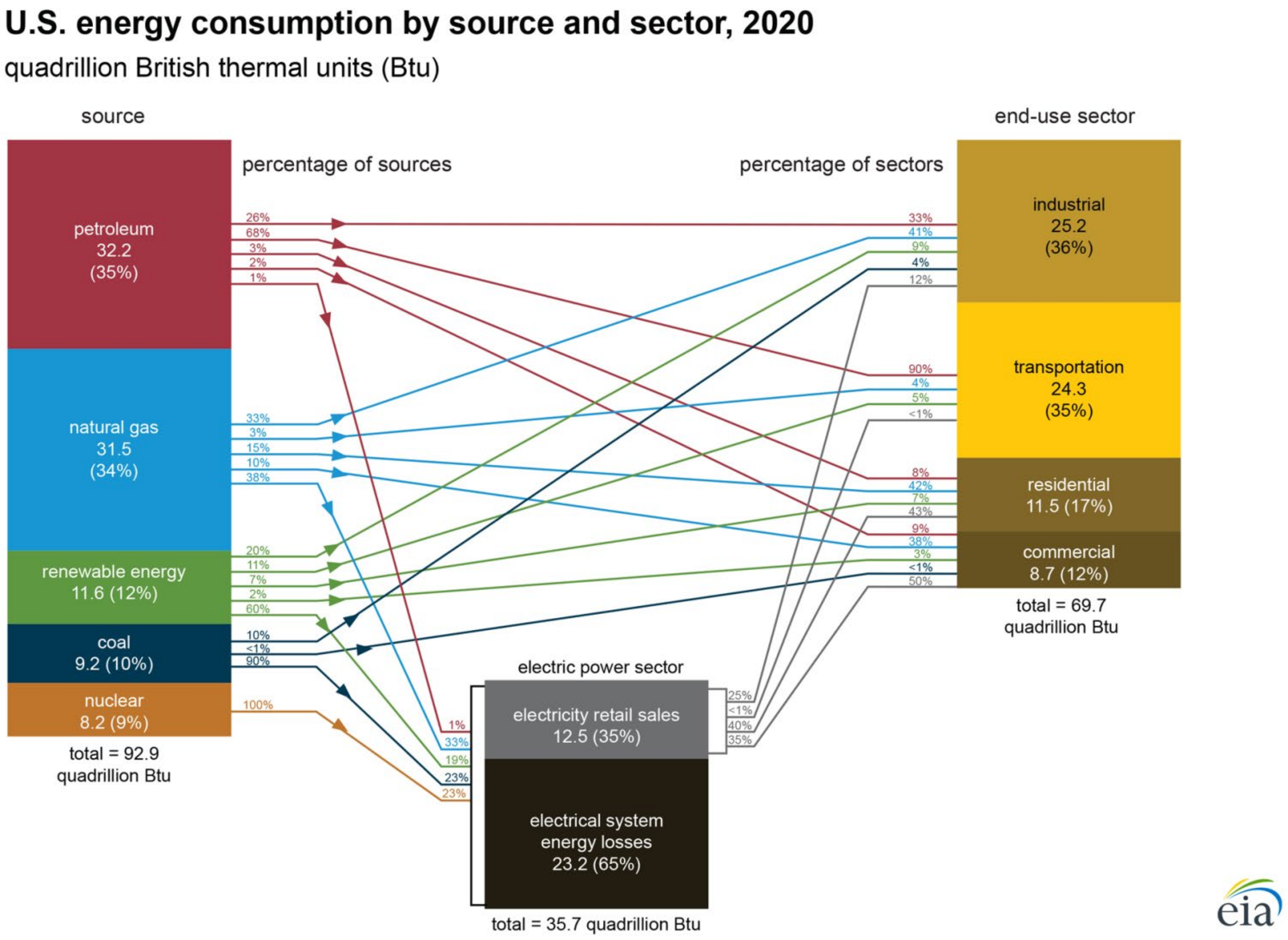


Examples of uses and sources of 1 kWh. 1kWh will light a 100-watt incandescent lighbulb for 10 hours and one 28-watt compact fluorescent bulb for 38 hours. Producing 1kWh requires one pound of coal or 7.5 cubic feet of natural gas or 8.5 ounces of gasoline. About 50% of energy used is lost as waste and 7% is lost in transmission. Image modified from original by Jim Houghton, published in The Teacher-Friendly Guide to the Geology of the Southeastern U.S., 2nd ed., edited by Andrielle N. Swaby, Mark D. Lucas, and Robert M. Ross (published by the Paleontological Research Institution) (CC BY-NC-SA 4.0 license).

How do we look at energy in the Earth system?

The Energy Information Administration (EIA) categorizes energy as coming from one of five sources: petroleum, natural gas, coal, renewable energy (for example, wind or hydroelectric), and nuclear electric power. The EIA categorizes energy as being used in one of four energy sectors: transportation, industrial, electric power, and residential and commercial). 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.



US energy production sources and use sectors for 2020. Petroleum (35%) and natural gas (34%) provide more energy than other sources. Most petroleum (68%) is used for transportation, whereas natural gas is used to produce electricity (38%) and in the industrial sector (38%). More energy is used to generate electricity than for any other use, and electricity is generated by all five major energy sources. Nuclear is unique among sources in that all of the energy it generates goes to a single sector (electricity). Image modified from"U.S. energy consumption by source and sector" by US Energy Information Administration.

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 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.

Energy Literacy Principles*

Each principle of energy literacy is defined by a set of fundamental concepts. Keeping these energy principles in mind when we teach others about energy can help us to place our own energy consumption in context and understand its effect on the Earth system.

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.

**Principles from "Energy Literacy: Energy Principles and Fundamental Concepts for Energy Education," the US Office of Energy Efficiency & Renewable Energy.*

Fossil fuels

Fossil fuels—oil, natural gas, and coal—are made of the preserved organic remains of ancient organisms. Organic matter is only preserved when its rate of accumulation is higher than the rate of its decay. This most often happens when the oxygen supply is so low that aerobic bacteria (oxygen-loving bacteria) cannot thrive, which greatly slows the breakdown of organic matter. When organic matter does not break down, over time it will be incorporated into buried sediment. After burial, the organic material is compacted and heated with the rest of the rock, eventually transforming it 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. Coal is formed when preserved plant matter is buried, compacted, and heated. The largest coal beds were swampy environments where fallen forest trees and leaves were buried in stagnant muds. Petroleum and natural gas originate deep underground through a slow process that involves the heating of sedimentary rocks that contain an abundance of organic matter. The largest oil and gas reserves were at one time nutrient-rich seas with abundant surface phytoplankton and organic-rich bottom sediments.

Oil and natural gas

Oil and natural 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 to the bottom of large water bodies in vast numbers. 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 at which organic matter sinks and becomes buried in muddy sediments. Under such conditions, organic matter may accumulate enough to make up several percent or more of the deposited sediment.

Oil and gas reservoirs

Oil and gas that form in rocks under the Earth's surface are under pressure. Therefore, they will move gradually upward to areas of lower pressure through tiny connections between pore spaces and natural fractures in rocks.

A rock layer that forms a reservoir for oil or gas must be permeable. Fluids and gas (such as water, oil, and natural gas) can move through permeable rocks, or rocks that have enough connected fractures or space between grains to form pathways for the movement of fluids and gas. Sandstone, limestone, and fractured rocks are generally permeable.

In order for a permeable rock layer to be a viable reservoir, it must also be covered by an impermeable barrier that blocks the movement of oil or gas upward out of the reservoir rock and towards the surface. Often, this barrier is formed by impermeable rock layers. Impermeable rocks are made up of tightly packed or poorly sorted particles with very little space between them. Thus, these rock layers do not have enough space for liquids and gases to travel through, and the rock layers can form a cap that traps natural gas and oil below the surface. Folds ("arches") or faults in impermeable rock layers are common barriers under which oil reservoirs form.

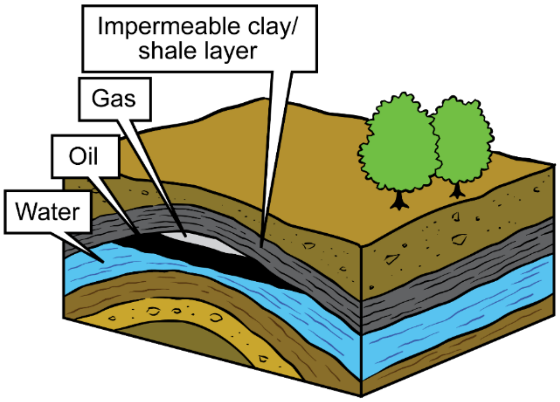


Diagram of an oil and gas reservoir. In this image, natural gas and fluids (water and oil) have accumulated in a layer of permeable reservoir rock, where they are separated by density (gas is lightest, water densest). An impermeable clay or shale layer that has been folded serves as a barrier to further movement of fluids and gas upward toward the surface. Image modified from original by Jim Houghton, published in The Teacher-Friendly Guide to the Geology of the Southeastern U.S., 2nd ed., edited by Andrielle N. Swaby, Mark D. Lucas, and Robert M. Ross (published by the Paleontological Research Institution) (CC BY-NC-SA 4.0 license).

Oil shale or shale oil?

It is unfortunate that two terms that sound as similar as "shale oil" and "oil shale" are actually quite different kinds of fossil fuel resources.

Oil shale is rock that contains an immature, waxy, solid organic material known as kerogen. Kerogen is not actually oil. Kerogen must be artificially heated to convert it into synthetic oil or a hydrocarbon gas. Thus, the whole rock layer, which may or may not technically be shale, must be mined and/or processed (possibly in place) to produce synthetic oil.

In contrast, shale oil is mature oil trapped in the original shale rock in which it formed. In this case, the source rock is also the reservoir rock, because it is so impermeable that the oil never escaped. This type of rock may be fractured (e.g., by hydraulic fracturing, discussed below) to provide pathways for the oil to escape.

A piece of oil shale from the New Albany shale of Indiana. Photo by James St. John (flickr, Creative Commons Attribution 2.0 Generic license, image resized).

Natural asphalt

Natural asphalt or bitumen deposits are oil reservoirs that have lost most of their lighter hydrocarbons, so they have become viscous, like tar. Oil that trickles out at the Earth’s surface is known as a "seep." Natural seeps of crude oil and natural gas were known to Native Americans and used in medicines before European colonization. Early European settlers used surface petroleum for medical purposes, greasing wagon wheels, softening leather, and caulking log cabins. Small local distilleries produced kerosene for lamps by the 1850s. The most famous natural asphalt seeps in the United States are the La Brea Tar Pits in Los Angeles, California.

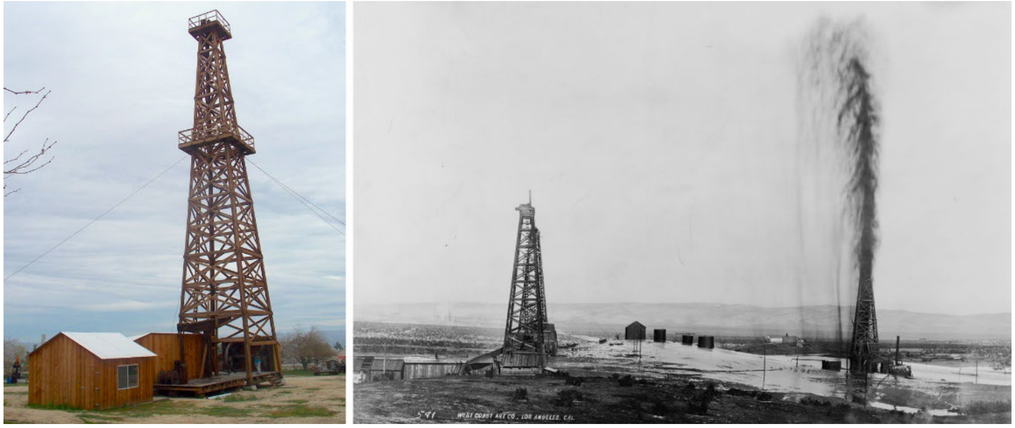
Natural asphalt seeps (tar pits) in California. ***Left:*** *Bubbles in a tar pit in La Brea, Los Angeles, California. Photo by Daniel Schwen (Wikimedia Commons, Creative Commons Attribution license 2.5 Generic license, image cropped).* ***Right:*** *Asphalt seep in Carpinteria, Califronia. Photo by Ipab (Wikimedia Commons, Creative Commons Attribution-Share Alike 4.0 International license, image cropped and resized).*

Oil drilling

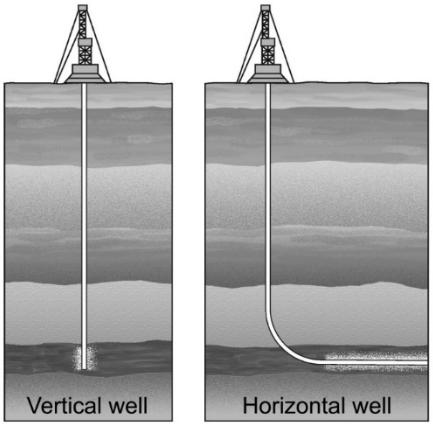
Conventional wells

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.

Gushers were an icon of oil exploration during the late 19th and early 20th centuries. These occurred when highly pressurized reservoirs were breached by simple drilling techniques. Oil or gas would travel up the borehole at a tremendous speed, pushing the drill bit out and spewing out into the air. Although iconic, gushers were extremely dangerous and wasteful. As well as spewing thousands of barrels of oil onto the landscape, they were responsible for the destruction of life and equipment. The advent of specialized blowout prevention valves in the 1920s enabled workers to prevent gushers and to regain control of blown wells. Today, this equipment is standard in both on- and offshore oil drilling.



Historical oil derricks (derricks are the tower-like structures). ***Left:*** *Wooden derrick built ca. 1917 preserved at the West Kern Oil Museum in California. Photo by Konrad Summers (Wikimedia Commons, Creative Commons Attribution-Share Alike 2.0 Generic license, image resized and cropped).* ***Right:*** *An oil field in California ca. 1910 with a gusher spewing oil on the right. Photo by West Coast Art Co. (from the Library of Congress Prints and Photographs Online Catalog, no known restrictions on publication).*



Diagrams of oil wells. ***Left:*** *A conventional vertical well.* ***Right:*** *A horizontal well. Hydraulic fracturing may be carried out along horizontal wells running for 1.6 kilometers (1 mile) or more along layers with oil or gas trapped in pore spaces. Image modified from original by Jim Houghton, published in The Teacher-Friendly Guide to the Geology of the Southeastern U.S., 2nd ed., edited by Andrielle N. Swaby, Mark D. Lucas, and Robert M. Ross (published by the Paleontological Research Institution) (CC BY-NC-SA 4.0 license).*

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.

Offshore drilling follows much the same process as onshore drilling but utilizes a mobile offshore drilling unit (MODU) to dig the well. There are several different types of MODUs, including submersible units that sit on the sea floor, drilling ships, and specialized rigs that operate from atop floating barges.

Pumpjacks at oil wells in the Bakken Formation, North Dakota. In these modern oil wells, the derricks used to drill the wells have been removed. Photo by USGS (public domain).

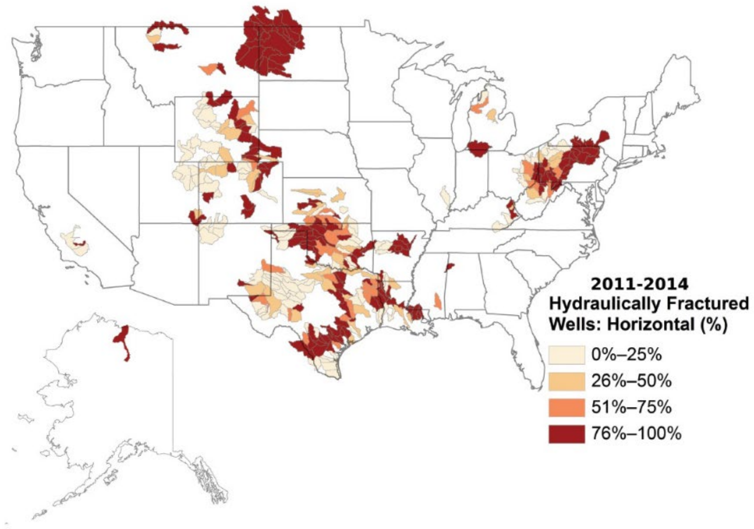
Hydraulic fracturing ("fracking")

Devonian-aged shales are the major source rock for petroleum and natural gas. Because the shales are not permeable, gas production occurs where the rocks are naturally fractured or where rocks are intentionally fractured using a process called hydraulic fracturing. When source rocks with low permeability—also known as "tight" layers—are fractured beneath the surface, gas and oil trapped within them are released.

Devonian Solsville Shale Member, Marcellus Shale Formation, New York. The Marcellus Shale is a gas-producing shale that occurs primarily in New York, Ohio, Pennsylvania, and West Virginia. It is exploited for gas in some regions using hydraulic fracturing. Photo by James St. John (flickr, Creative Commons Attribution 2.0 Generic license, image cropped and resized).

Hydraulic fracturing uses horizontal wells drilled along the source rock layer. Most horizontal wells are drilled where the source rock is about 100–150 meters (330–490 feet) thick. The source rocks are fractured using high volumes of fracking fluid (frac fluid) flushed through the well at high pressure. The frac fluid is made up of water mixed with gel, sand, and chemicals. The gel increases the viscosity of the fluid. The thousands of tiny fractures created by the fluid are held open by the small grains of sand.

Chemicals are added to the frac fluid to increase the recovery of fossil fuels. One type of chemical is "slickwater," which is used to reduce friction. "Slickwater, high-volume hydraulic fracturing"—often shortened to "hydraulic fracturing" or simply "fracking"—has greatly increased the accessibility of fossil fuel resources and the production rate of oil and gas.



Percentage of hydraulically fractured (horizontally drilled) wells in oil and gas producing areas of the United Sates. Map by the USGS.

Fracking has been controversial, in large part because of associated impacts. For example, fracking and other oil and gas extraction activities create large quantities of wastewater that contain salts and other contaminants. This wastewater may include frac fluid and produced water. Produced water is water that is pumped out of the ground along with oil or gas. This contaminated water must be treated, reused, or contained.

One method of wastewater containment is the use of injection wells. Injection wells are used to pump wastewater deep underground. Underground disposal of wastewater using injection wells has caused powerful earthquakes in some areas of the US that have experienced few powerful earthquakes before. Induced earthquakes (earthquakes caused by human activity) are especially a problem where buildings and other infrastructure have not been built to withstand shaking.

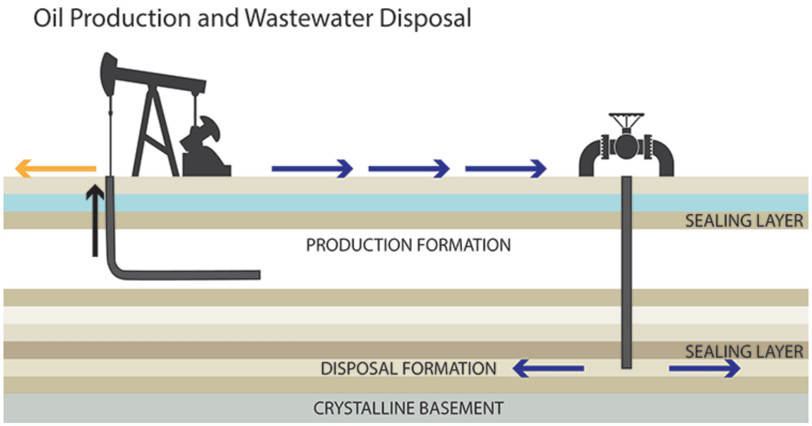
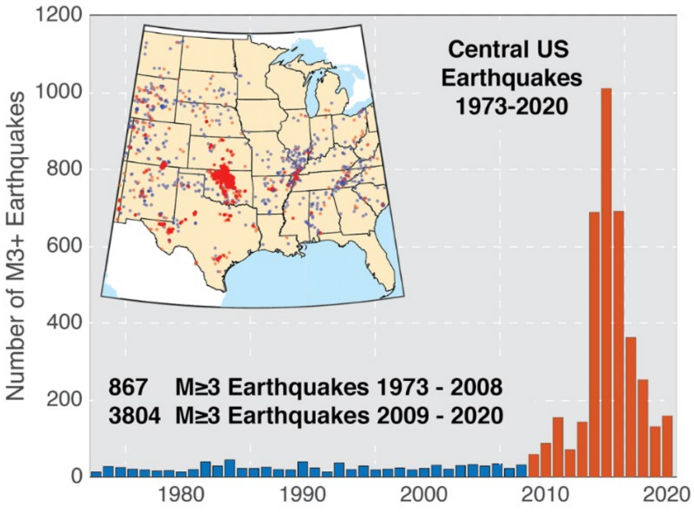


Diagram showing pumping of oil (left) and injection of wastewater into a well (right). Note that wastewater is injected deep underground beneath a sealing layer of impermeable rock. Source: USGS (public domain).

Original description from the USGS: "Annual number of earthquakes with a magnitude of 3.0 or larger in the central and eastern United States, 1973–2020. The long-term rate of approximately 25 earthquakes per year increased sharply starting around 2009." Source: [USGS (public domain)](#).

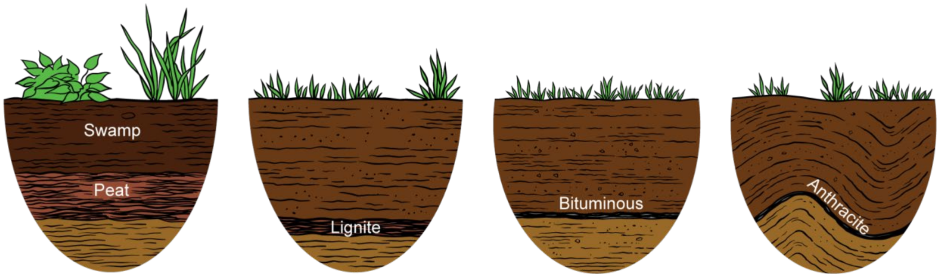


Coal

How does coal form?

Coal ultimately comes from organic matter from land plants. Leaves, wood, and other plant matter accumulate on the ground as plants die or shed parts. If these structures do not rapidly decay, they may form peat, an accumulation of partially decayed plant matter. The peat may then be buried by additional organic matter and sediment. As the peat is buried more and more deeply by additional layers of sediment and organic matter, pressure from the overlying sediments builds, squeezing and compressing the peat into coal.

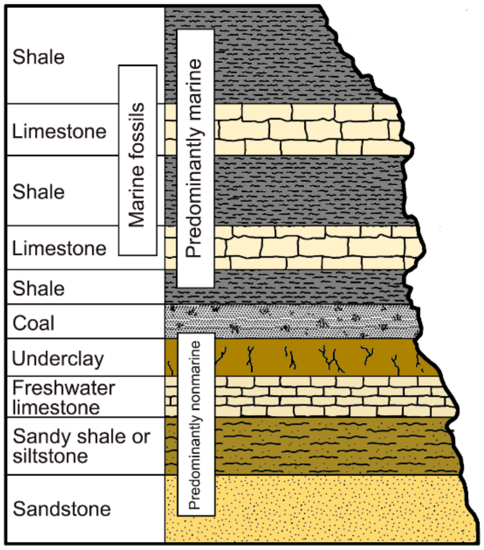
Over time, the coal may become more carbon rich as water and other components are squeezed out. Peat may become lignite, bituminous, and eventually anthracite coal. By the time a peat bed has been turned into a layer of anthracite, they layer is one-tenth of its original thickness and is up to 95% carbon. Anthracite has the fewest pollutants of the four types of coal, because it has the highest amount of pure carbon.



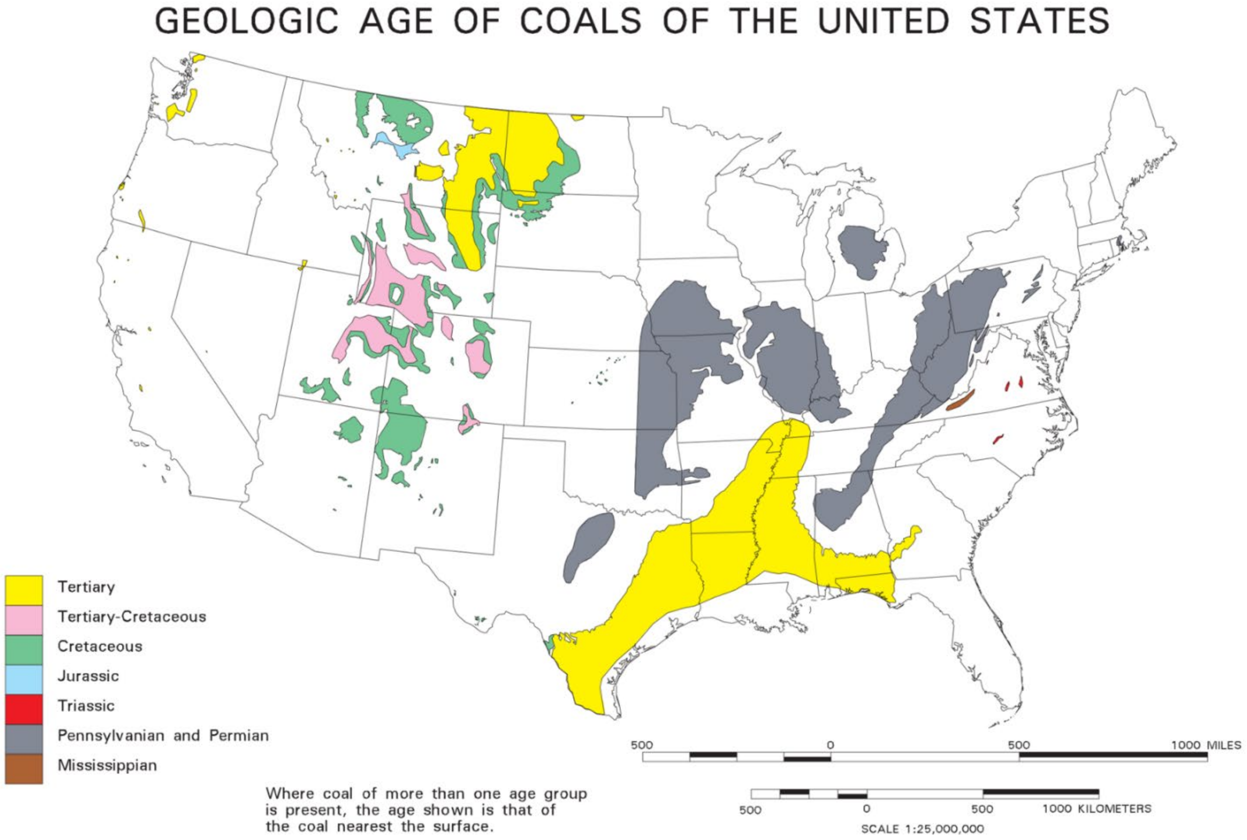
Stages in the formation of coal, from left to right: Peat is buried beneath a swamp. Through compaction and loss of water, it forms lignite. Through further compression, the coal transforms into bituminous coal and finally anthracite coal. Image modified from original by Jim Houghton, published in The Teacher-Friendly Guide to the Geology of the Southeastern U.S., 2nd ed., edited by Andrielle N. Swaby, Mark D. Lucas, and Robert M. Ross (published by the Paleontological Research Institution) ([CC BY-NC-SA 4.0](#) license).

When did coal form?

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. These plant formed thick forests ("coal swamps") that were dominated by large trees. Coals deposited during the Pennsylvanian period occur in repeated successions of sedimentary rock layers known as cyclothems, which are alternating sequences of marine and non-marine sedimentary rocks. Carboniferous cyclothems formed due to repeated sea level changes caused by the growth and melting of continental glaciers on the supercontinent Gondwana from about 330 to 260 million years ago.



An example of a cyclothem, alternating sequences of marine and nonmarine sedimentary rocks characterized by their light and dark colors. Image modified from original by Wade Greenberg-Brand (after image from Levin, 2006, The Earth Through Time, 8th ed.), published in The Teacher-Friendly Guide to the Geology of the Southeastern U.S., 2nd ed., edited by Andrielle N. Swaby, Mark D. Lucas, and Robert M. Ross (published by the Paleontological Research Institution) (CC BY-NC-SA 4.0 license).



Coal deposits and the ages of coals in the contiguous US. The Tertiary period is the former name for the time interval now split into the Paleogene and Neogene periods. Source: USGS Open-File Report 96-92, digital compilation by John Tully.

Thick coal deposits are not found in coastal deposits and deltas that formed during earlier times even though geologic and climatic conditions were similar. This is because the plants that made up the coastal swamp forests that produced enough biomass to form large peat deposits had not yet evolved. Plants had only just begun to spread on to land and evolve vascular tissue during the Silurian period. Diversification and evolution of plants during the Devonian was rapid. As forests evolved and increased in size in the late Devonian and Carboniferous, significant quantities of organic matter were produced on land for the first time. The Carboniferous is not the only time period during which large coal deposits formed. Coals are also known from the Mesozoic and Cenozoic eras.

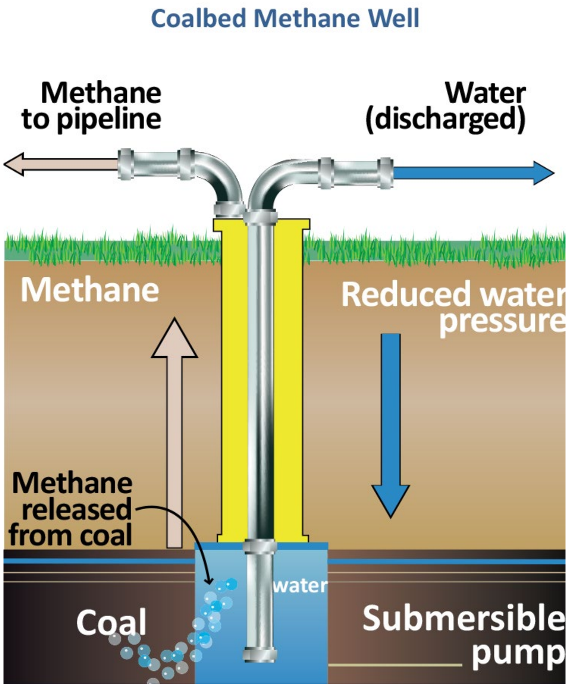
During the Carboniferous, burial of enormous quantities of terrestrial organic matter took carbon dioxide (CO_2) out of the atmosphere. CO_2 concentrations decreased to the point that global cooling led to the growth of continental glaciers. Today, we are enacting the same process in reverse. In only a few hundred years, we have released carbon dioxide that took millions of years to be buried into the atmosphere.

Coalbed methane

Since about 1980, large reserves of natural gas have been exploited in tandem with coal seams. This gas, called coalbed methane, is a byproduct of the process of coalification (coal formation). During coal mining, coal seams (deposits) have long been vented, in part because of the potential build-up of methane (CH_4, the primary gas in "natural gas") released from fissures around the coal. Methane is a safety hazard in subsurface mines. The build-up of methane in mine shafts can cause explosions if the gas is ignited; an ignition source could be a spark, for example.

Methods have been developed to trap coalbed methane so that it can be used as an energy source. Water saturates fractures in some coal seams, making these seams aquifers. (An aquifer is a water-bearing, permeable rock formation that is capable of providing water in usable amounts to springs or wells.) If there is sufficient water pressure in a coal seam aquifer, methane within the coal fractures may be trapped in the coal. To extract coalbed methane, water is removed from the coal using a well. Removing water reduces the water pressure in the coal, allowing the trapped methane to escape. The gas moves out of the coal towards areas of lower pressure. As the methane moves into the well, it is separated from the water and captured.

Production rates for coalbed methane climbed steeply beginning in the early 1990s, and peaked in about 2008, when about a tenth of the country's yearly natural gas production came from coalbed methane. In recent years, it has declined as shale gas methane production has increased. Coalbed methane still accounts for over 5% of US methane production.



The use of a well to relieve water pressure in a coal seam, allowing the methane to escape. As water is pumped out of the coal seam, the water pressure is lowered, allowing gas to escape. The gas is captured in a separate pipe as in bubbles up in the water at the bottom of the well. *[Diagram from "Fossil energy research benefits: Coalbed methane" US Department of Energy Office of Fossil Energy](#).*

Renewable energy

Renewable energy is obtained from sources that are virtually inexhaustible and that replenish over small time scales relative to human life spans. Examples of renewable energy are biomass, geothermal, hydroelectric, solar, and wind. Several of these sources are covered in more detail below:

Solar panels, Colorado. Photo by Jessica K. Robertson, USGS (public domain).

Bioethanol and biomass plants

Biomass resources are organic materials that are burned to generate energy. Areas such as forestry, agriculture, and urban waste management generate hundreds of thousands of tons of biomass materials. These include oils that come from plants (soybeans and canola), as well as biomass from sugar production (sugarcane, sugar beets, and sorghum), starchy crops (grains like rice and corn), wood and wood byproducts, and certain types of municipal waste.

Geothermal energy

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, like the Basin and Range of the western US, Iceland (part of the mid-Atlantic ridge), Japan (an area of subduction), and Hawaii and Yellowstone (areas with hot spots).

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 butane becomes steam, which is used to power the turbine.

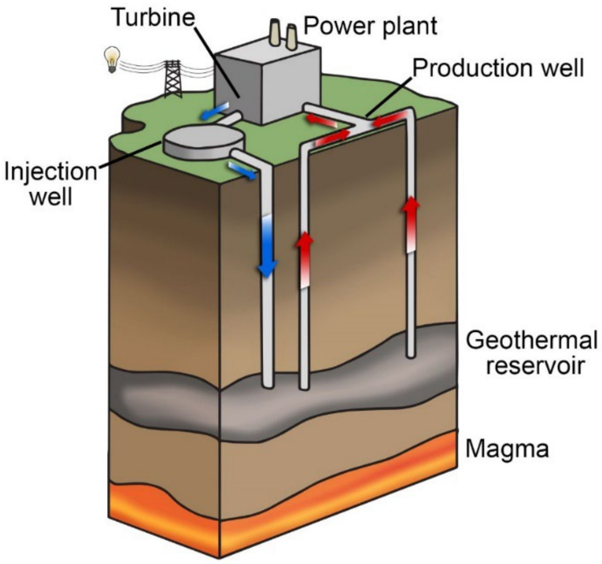


Diagram of a geothermal plant. Image modified from original by Wade Greenberg-Brand, published in The Teacher-Friendly Guide to the Geology of the Northwest Central US, edited by Mark D. Lucas, Robert M. Ross, and Andrielle N. Swaby (published by the Paleontological Research Institution, 2015) (CC BY-NC-SA 4.0 license).

Hydroelectricity

Hydroelectricity uses the gravitational force of falling or rushing water to rotate turbines that convert the water's force into energy. Generating hydroelectric power requires the building of dams.

Pickwick Landing Dam on the Tennessee River, Hardin County, Tennessee, 1939. Photo by the Tennessee Valley Authority (K-1850, flickr, Creative Commons Attribution 2.0 Generic license, image resized).

Wind energy

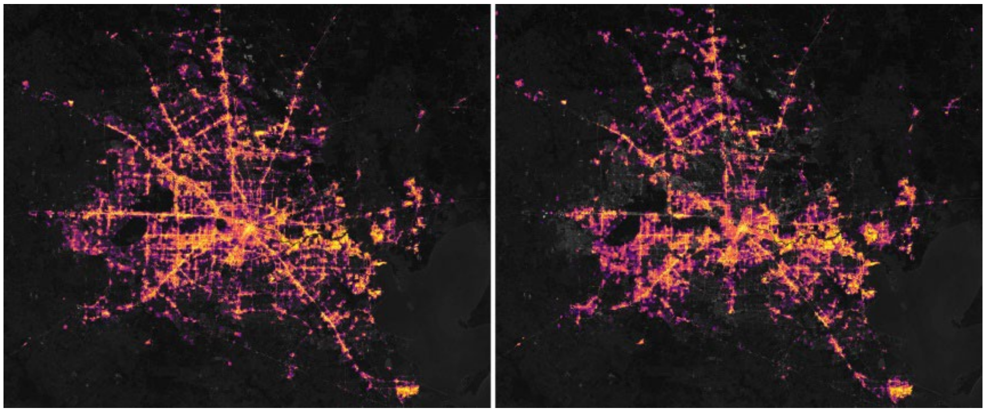
Economically useful wind energy depends on steady high winds. Variation in wind speed is in large part influenced by the shape and elevation of the land surface. For example, higher elevations tend to have higher wind speeds, and flat areas can allow winds to pick up speed without interruption; thus 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.

Some regions may have locally high wind speeds that can support strategically placed wind farms. 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.

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 the need for energy for cooling. At the same time, projected increases in the number of severe weather events—hurricanes, floods, tornados, winter storms, and other extreme weather—will continue to have a significant effect on energy infrastructure like power grids.

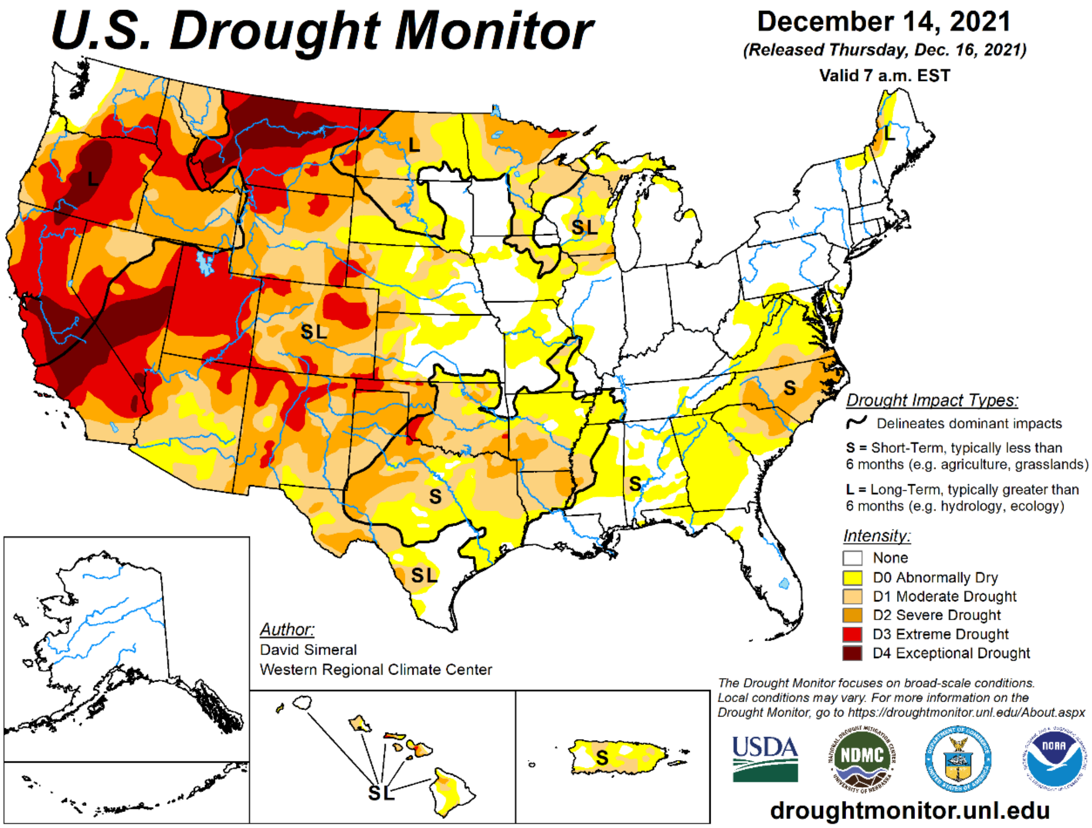
When severe winter storms hit Texas in early 2021, the state's power grid was overwhelmed by high energy demand combined with a lack of engineering for winter conditions and isolation from the power grid in the rest of the US. Power to many buildings was purposely shut off to keep the grid from failing. An estimated 1.4 million customers lost power in Houston alone.



The photos above show nighttime lights in Houston before the storms (February 7, left) and following the storms (February 16, right). *Photos from NASA Earth Observatory ("Extreme winter weather causes U.S. blackouts," February 17, 2021)*.

Drought and water shortages are already affecting energy production and supply. For example, drought conditions affecting the western US in 2021 caused reservoir levels to drop and, in some cases, water supplies to dry up for entire communities, like Mendocino Village, California. The hydroelectric plant on Lake Oroville, a reservoir in northern California, had to be shut down because lake levels fell too low to sustain power generation. These types of disruptions affect us both locally and nationally, are diverse in nature, and will require equally diverse solutions.

Satellite images of Lake Oroville, a reservoir in northern California. ***Left:*** *At capacity (highest level), June 2019.* ***Right:*** *At a much lower water level due to drought, June 2021. In August 2021, the Edward Hyatt Power Plant, a hydroelectric plant on Lake Oroville, was shut down because water levels were too low. Source: [USGS (public domain)](#).*



Drought conditions in the US, December 2021. Source: [David Simeral, US Drought Monitor Mitigation Center at the University of Nebraska, Lincoln](#).

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 are faced with a sort of "energy triage"; we need to consider which means of energy production and transport make the least impact. 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.

Adaptation

Adaptation—changing our habits of energy use and delivery—will 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 extraction, production, and usage—and improving infrastructure and delivery methods will go a long way toward decreasing the effects of climate change and increasing our energy security.

Some types of adaptation are grounded in the development of new technologies for energy production and energy efficiency, while others may be related to changes in behavior. 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 in which we use energy, allowing us to telecommute and changing the way we shop.

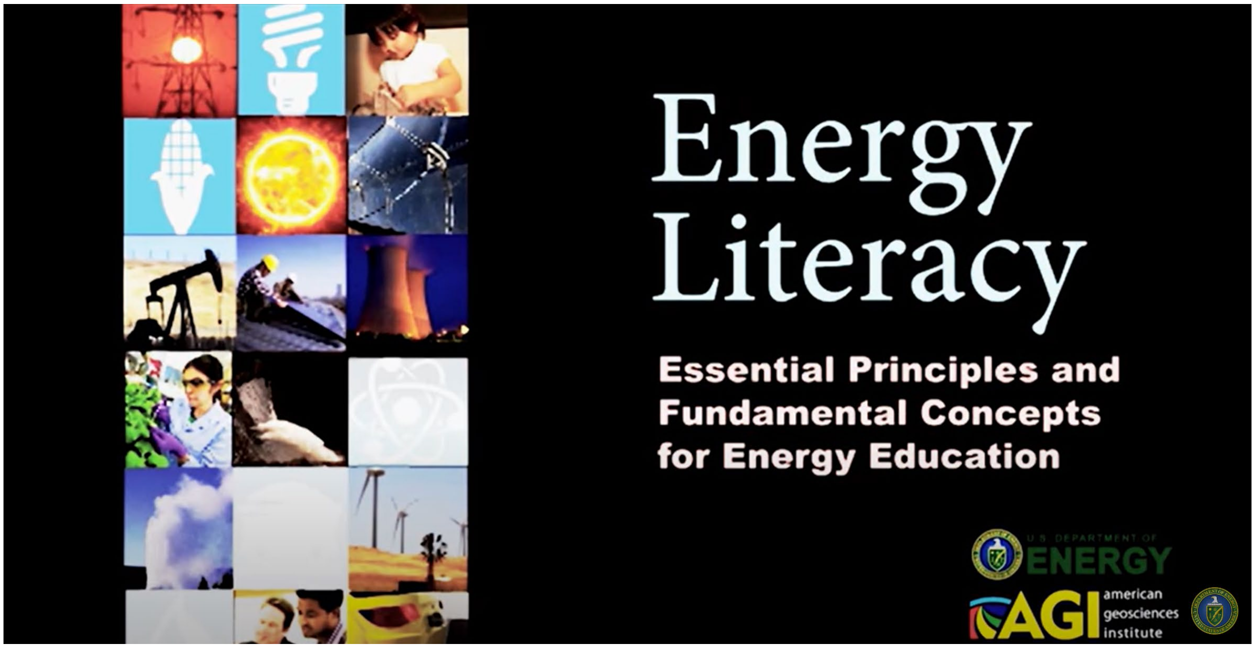
Key points to keep in mind regarding the future of energy

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.
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 ways in which our energy system changes, climate change will introduce both new risks and new opportunities.

Energy Decisions Video

US Department of Energy, 2015 – 5 minutes

https://youtu.be/9Wub1_Dk_Ok



Energy Literacy

Essential Principles and Fundamental Concepts for Energy Education

U.S. DEPARTMENT OF ENERGY

AGI american geosciences institute

Appendix

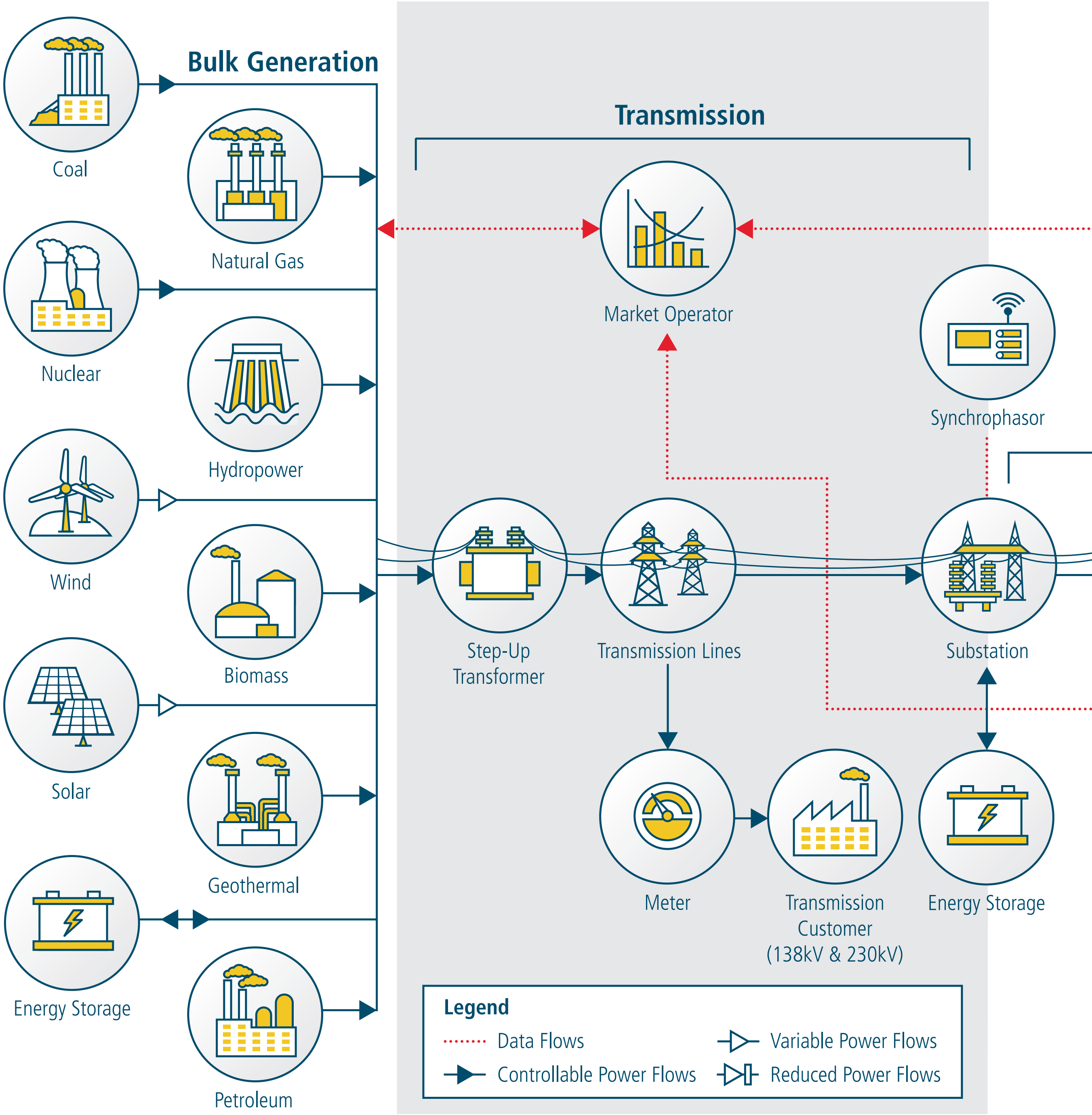
ELECTRICITY SYSTEM OVERVIEW

This appendix provides context for understanding the analysis and recommendations contained in the main body of the report. It is an overview of the Nation's existing electricity system, including its physical structure and elements, the history of its development, and major laws and jurisdictions governing its operation. It explores the Federal role in the resilience and security of the electric grid, and it describes the complex operations, business models, and market structures comprising the electricity system.

Elements of the Electricity System

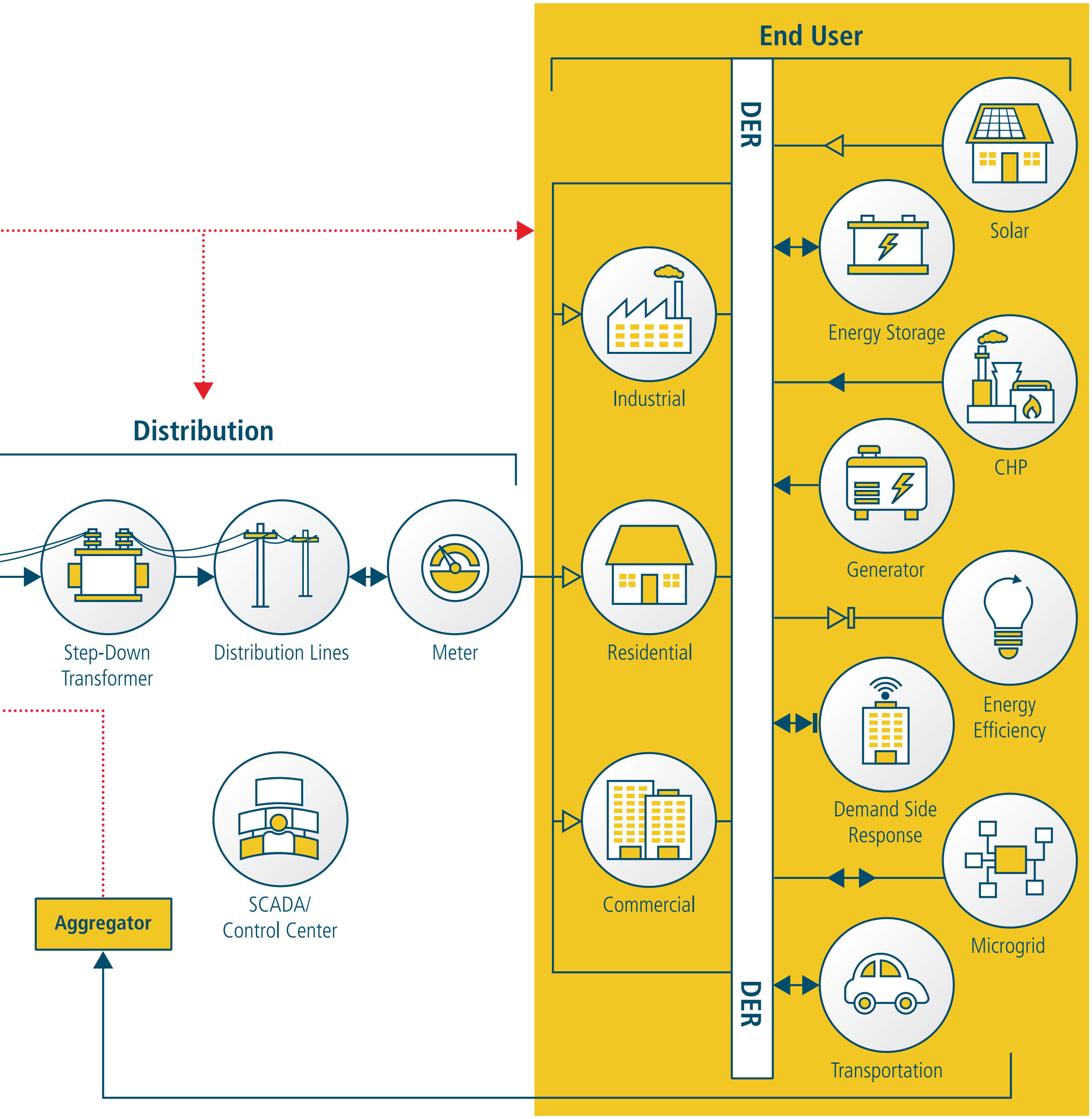
The U.S. electric power system is an immensely complex system-of-systems, comprising generation, transmission, and distribution subsystems and myriad institutions involved in its planning, operation, and oversight (Figure A-1). End use and distributed energy resources (DER) are also important parts of the electric power system.

Figure A-1. Schematic Representation of the U.S. Electric Power System



The electric power system comprises the following broad sets of systems: bulk generation, transmission, distribution, and end use (including DER).

Acronyms: combined heat and power (CHP), distributed energy resources (DER), kilovolts (kV), supervisory control and data acquisition (SCADA).


End User
DER
Solar
Energy Storage
Industrial
CHP
Distribution
Generator
Step-Down
Transformer
Distribution Lines
Meter
Residential
Energy
Efficiency
Demand Side
Response
Commercial
SCADA/
Control Center
Aggregator
Microgrid
DER
Transportation

Generation

Electricity generation accounts for the largest portion of U.S. primary energy use, using 80 percent of the Nation's domestically produced coal,[1] one-third of its natural gas, and nearly all of its nuclear and non-biomass renewable resource production. In 2014, 39 percent of the Nation's primary energy use was devoted to electricity generation, and electricity accounted for 18 percent of U.S. delivered energy.[2]

In 2014, there were over 6,500 operational power plants of at least 1 megawatt in the U.S. electric power system.[a, 3, 4] These power plants delivered nearly 3,764 billion kilowatt-hours (kWh) of power in 2014, supplying electricity to over 147 million residential, commercial, and industrial customers at an average price of $0.104/kWh for a total revenue from electricity sales of more than $393 billion.[5, 6, 7, 8]

The U.S. electricity generation portfolio is diverse and changes over time through the commercial market growth of specific generation technologies—often due to a confluence of policies, historic events, fuel cost, and technology advancement. Today, coal and natural gas each provide roughly one-third of total U.S. generation; nuclear provides 20 percent; hydroelectric and wind provide roughly 5 percent each; and other resources, including solar and biomass, contribute less than 2 percent each.[9] However, there are major generation mix differences between regions (Figure A-2).[10]

The availability of primary energy resources, like coal and natural gas, and renewable energy resources, like wind and solar, differs widely across the country (Figure A-3). This dispersed resource availability influences the regional generation mixes.

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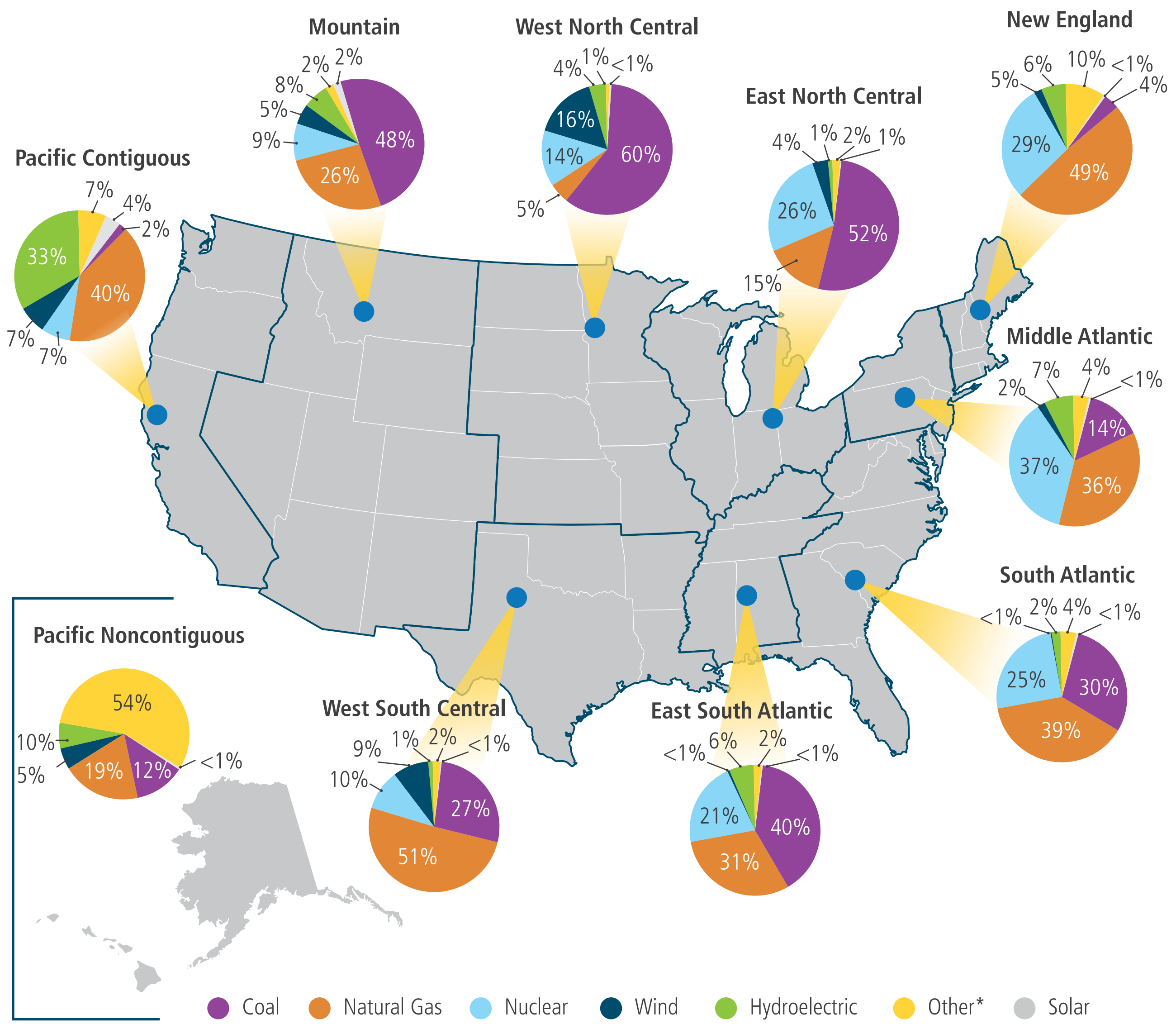
[a] A megawatt is a thousand kilowatts. A kilowatt is a unit of power output commonly used in the electricity industry. A kilowatt-hour (kWh) is a related unit of energy (the amount of power provided times the number of hours that it is provided). Electricity is usually billed by the kWh. An average American home uses roughly 11,000 kWh per year. Source: "How Much Electricity Does an American Home Use?" Energy Information Administration, Frequently Asked Questions, last modified October 18, 2016, https://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3.

Figure A-2. Electric Power Regional Fuel Mixes, 2015[11, 12]

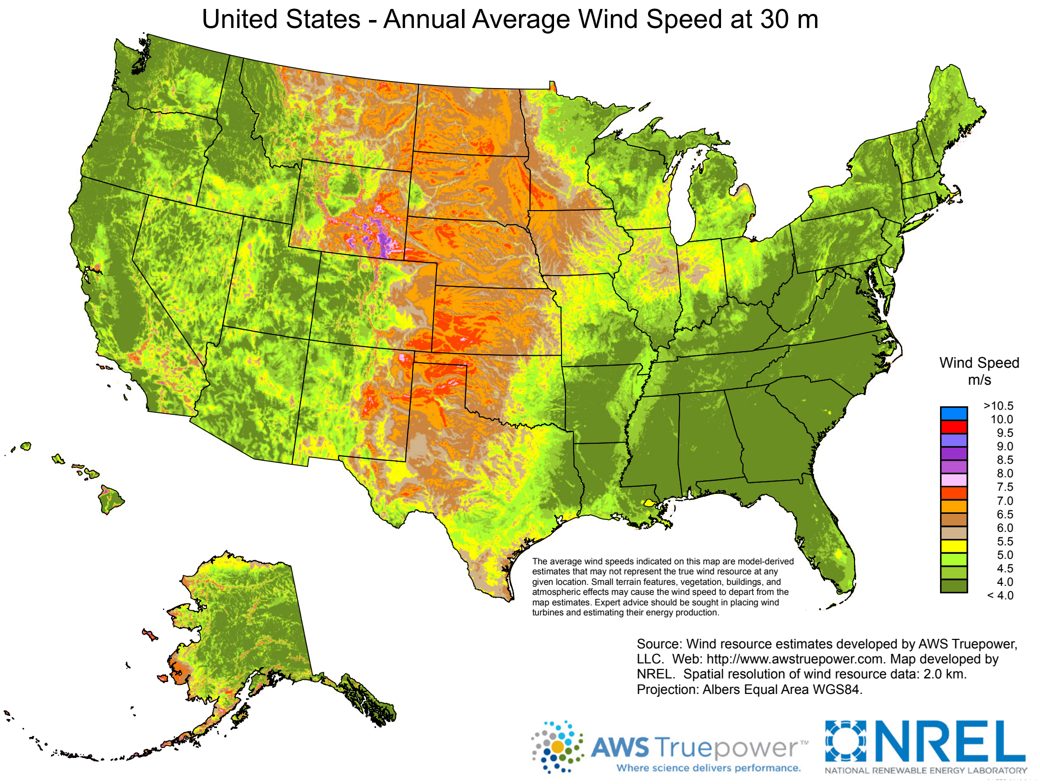


*Includes the following Energy Information Administration fuel type designations: Distillate Petroleum, Geothermal, Biogenic Municipal Solid Waste and Landfill Gas, Other Gases, Other Renewables, Other (including nonbiogenic municipal solid waste), Petroleum Coke, Residual Petroleum, Waste Coal, Waste Oil, and Wood and Wood Waste.

Note: Sum of components may not add to 100% due to independent rounding.

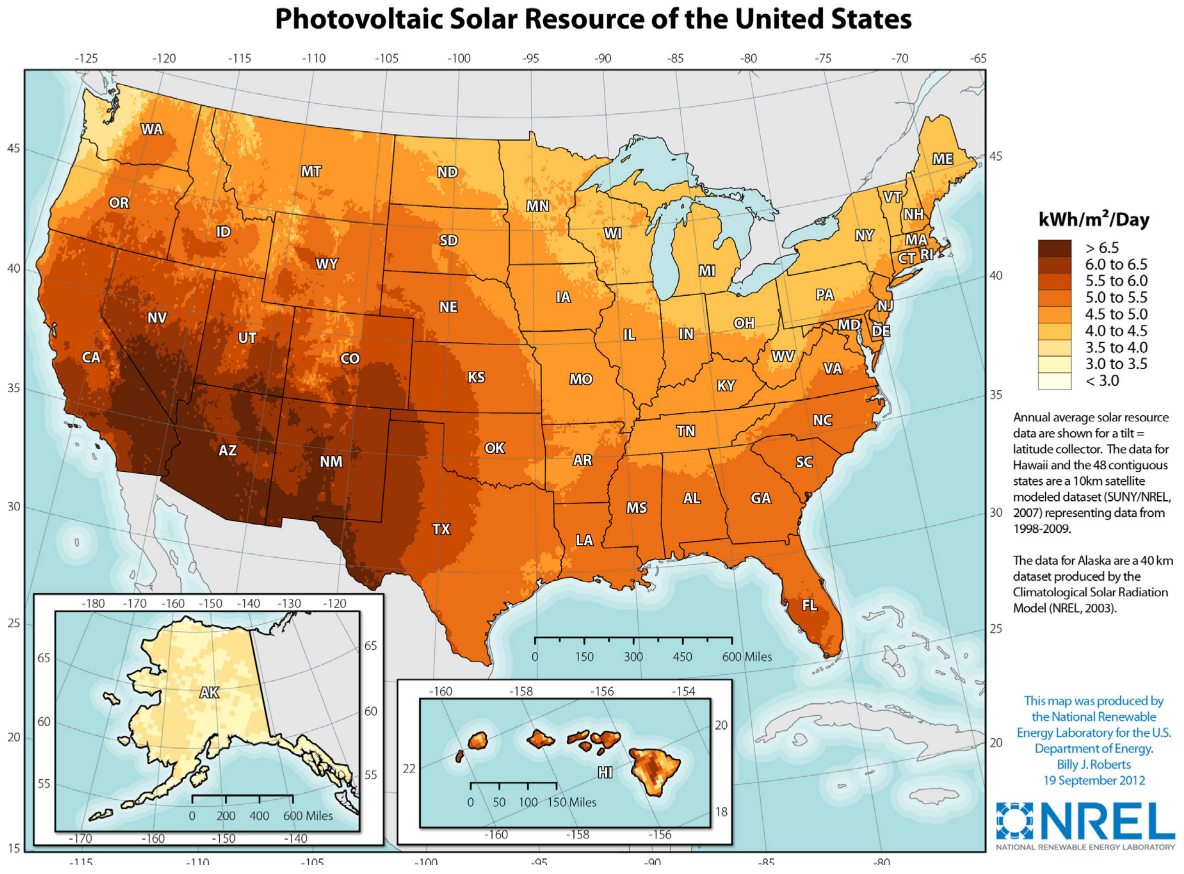
The U.S. electricity industry relies on a diverse set of generation resources with strong regional variations. As of 2015, coal fuels the majority of electricity generation in the Mountain, West North Central, East North Central, and East South Central regions. Coal is also a significant resource for the South Atlantic and West South Central regions, though both have sizable natural gas generation as well, and the South Atlantic region includes substantial shares of nuclear. The Pacific Contiguous and New England regions are predominately natural gas, with significant contributions of hydroelectric and nuclear, respectively. The Middle Atlantic is the only region that is predominately nuclear, and the Pacific Noncontiguous region is the only region in which fuel oil represents more than a few percentage points of total generation, where it constitutes nearly half of all generation.

Figure A-3. Wind and Solar Energy Resource Maps for the United States[13,14]



The average wind speeds indicated on this map are model-derived estimates that may not represent the true wind resource at any given location. Small terrain features, vegetation, buildings, and atmospheric effects may cause the wind speed to depart from the map estimates. Expert advice should be sought in placing wind turbines and estimating their energy production.

Source: Wind resource estimates developed by AWS Truepower, LLC. Web: http://www.awstruepower.com. Map developed by NREL. Spatial resolution of wind resource data: 2.0 km. Projection: Albers Equal Area WGS84.



Annual average solar resource data are shown for a tilt = latitude collector. The data for Hawaii and the 48 contiguous states are a 10km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2009.

The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy. Billy J. Roberts 19 September 2012

Energy resource availability varies widely across the United States. Wind and solar energy resources are concentrated in the Midwest and Southwest regions of the United States.

Transmission

The U.S. transmission network includes the power lines that link electric power generators to each other and to local electric companies. The transmission network in the 48 contiguous states is composed of approximately 697,000 circuit-miles[b] of power lines and 21,500 substations operating at voltages of 100 kilovolts (kV)[c] and above.[15] Of this, 240,000 circuit-miles are considered high voltage, operating at or above 230 kV (Figure A-4).[16] A substation is a critical node within the electric power system and is composed of transformers, circuit breakers, and other control equipment. Distribution substations are located at the intersection of the bulk electric system and local distribution systems.

The vast majority of transmission lines operate with alternating current (AC). With commonly used technology, system operators cannot specifically control the flow of electricity over the AC grid; electricity flows from generation to demand through many paths simultaneously, following the path of least electrical resistance. A limited number of transmission lines are operated using direct current (DC). Unlike AC transmission lines, the power flows on DC lines are controllable. However, their physical characteristics make them cost-effective only for special purposes, such as moving large amounts of power over very long distances.[17]

Electricity moved through transmission and distribution systems faces electrical resistance and other conversion losses. Losses from resistance and conversion amount to 5 to 6 percent of the total electricity that enters the system at the power plant.[18]

Each transmission line has a physical limit to the amount of power that can be moved at any time, which depends on the conditions of the power system. Within one market or utility control area, physical limits of system assets are the primary drivers of power price differences in different parts of the system.

Distribution System

The role of the large generators and transmission lines that comprise the bulk electric system is to reliably provide sufficient power to distribution substations. In turn, the distribution system is responsible for delivering power when and where customers need it while meeting minimum standards for reliability and power quality.[19] Power quality refers to the absence of perturbations in the voltage and flow of electricity that could damage end-use equipment or reduce the quality of end-use services.[20]

Before delivery to a customer, electric power travels over the high-voltage transmission network (at hundreds of kilovolts) to a distribution substation where a transformer reduces the voltage before the electricity moves along the distribution system (at tens of kilovolts). Several primary distribution feeder circuits, connected by an array of switches at the distribution bus, emanate from the substation and pass through one or more additional transformers before reaching the secondary circuit that ultimately serves the customer. One or more additional transformers reduce the voltage further to an appropriate level before arriving at the end-use customer's meter.[d, 21]

An emerging role of the distribution system is to host a wide array of distributed energy generation, storage, and demand-management technologies. Though some distributed energy technologies—like campus-sized combined heat and power—have existed for decades, rapid cost declines in solar, energy storage, and power electronic technologies, coupled with supportive policies, have led to a rapid proliferation of new devices and, at times, new challenges and opportunities for the planning and operation of distribution systems.

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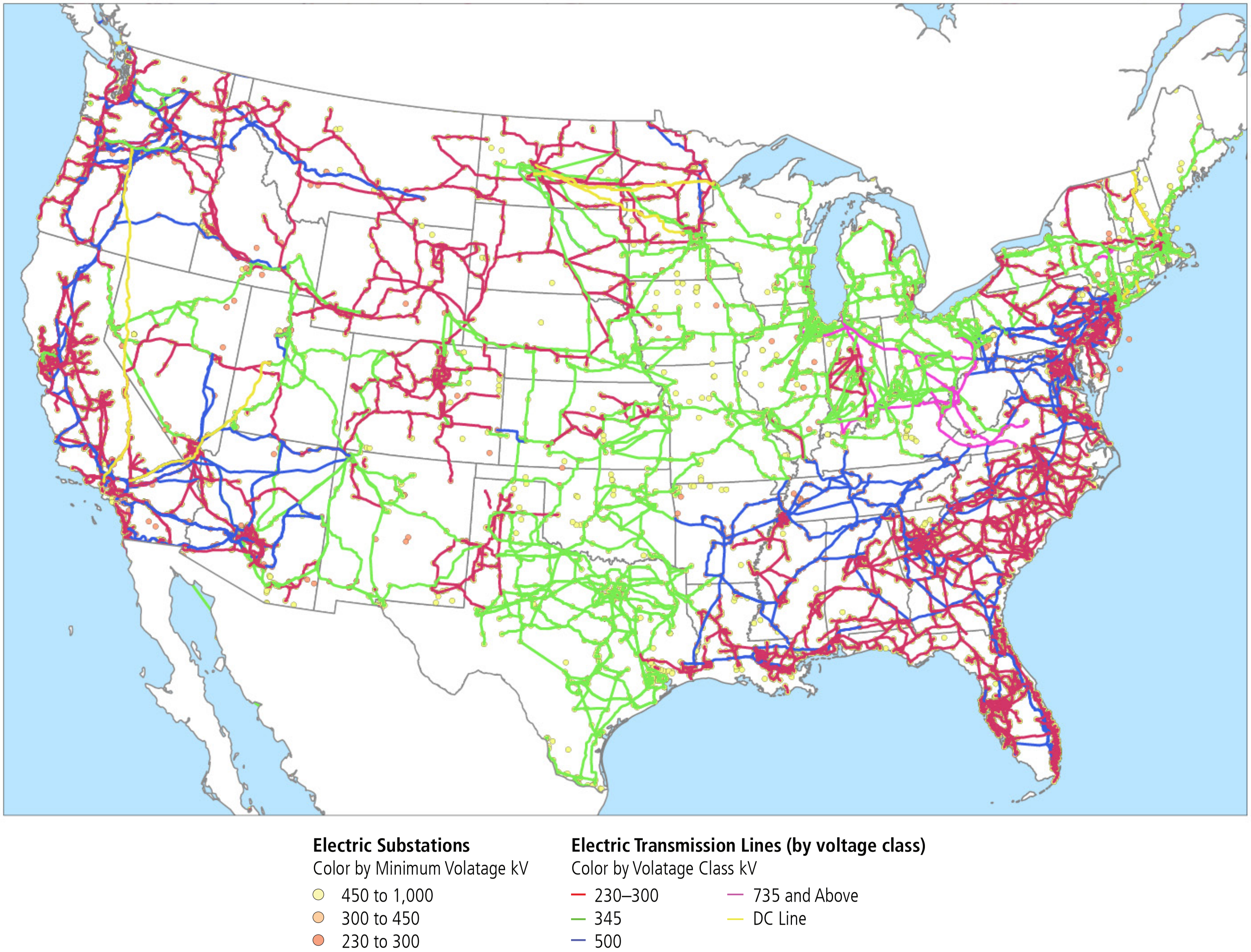
[b] A circuit-mile is 1 mile of one circuit of transmission line. Two individual 20-mile lines would be equivalent to 40 circuit-miles. One 20-mile double-circuit section would also be equivalent to 40 circuit-miles.

[c] A kilovolt (kV) is a commonly used unit of electrical "force" in the electricity industry. Electricity at higher voltages moves with less loss; however, system components able to manage high voltage are costly, and high voltages can be dangerous. Lower voltage is used in distribution systems to manage costs on system equipment and for safety.

[d] Most residential and commercial customers in the United States receive two 120-volt (V) connections. Most household plugs provide 120 V, while large appliances like dryers and ovens often combine the two 120-V connections into a single 240-V supply.

Figure A-4. High-Voltage Transmission Network and Substations of the 48 Contiguous States, 2015[22]



The transmission network comprises approximately 697,000 circuit-miles—of which roughly 240,000 miles operate at or above 230 kV—and 21,500 substations operating at voltages of 100 kV and above.[23, 24, 25]

Distributed Energy Resources (DER)

DER constitute a broad range of technologies that can significantly impact how much, and when, electricity is demanded from the grid. Though definitions of DER vary widely, the term is used in the Quadrennial Energy Review (QER) to refer to technologies such as distributed generation (DG), distributed storage, and demand-side management resources, including energy efficiency. Given the multiple definitions and understandings of the term DER, the QER will use DER to refer to the full range of these technologies and will delineate specific technologies where only some are relevant. Current and projected market penetration of DG is shown in Table A-1.

DER technologies can be located on a utility's distribution system or at the premises of an end-use customer. They differ with respect to several attributes, though a key differentiator is their level of controllability from a grid management perspective. Certain DER, such as energy efficiency or rooftop solar photovoltaic, impact total load but may not be directly controlled by grid operators. Other DER, such as DR or controllable distributed energy storage, can be more directly managed and called upon by grid operators when needed.

Table A-1. Current and Projected Distributed Generation Market Penetration, 2015 and 2040[26]

Resource	Total Generation (GWh)		% of Total Utility Generation	
	2015	2040	2015	2040
Combined Heat and Power (CHP)	166,946	246,896	4.2%	5.2%
Rooftop Solar PV	13,453	64,485	0.3%	1.4%
Distributed Wind	637	1,643	0.0%	0.0%
Other DG	4,298	4,298	0.1%	0.1%
Total Distributed Generation	185,334	317,323	4.7%	6.7%
Total Utility-Scale Generation	**3,947,520**	**4,745,441**		

Other DG includes small-scale hydropower; biomass combustion or co-firing in combustion systems; solid waste incineration or waste-to-energy; and fuel cells fired by natural gas, biogas, or biomass. Backup generators (for emergency power) are not included here because generation data are limited, and these generators are not used in normal grid operation.

Acronyms: distributed generation (DG); gigawatt-hours (GWh); photovoltaic (PV).

End Use

Electricity end-use infrastructure includes physical components that use, require, or convert electricity to provide products or services to consumers. Since the first time the electric light bulb lit up New York City, nearly all parts of the United States have gained access to electricity.[e] In that time, the proliferation of novel and unanticipated uses of electricity has placed electricity at the center of everyday life and established it as the engine for the modern economy.

Today, the residential and commercial sectors each consume about the same share of total electricity—38 percent and 36 percent, respectively—with the industrial sector accounting for an additional 26 percent of electricity demand.[27, 28] Cumulatively, electricity sales to end-use customers in the United States generated approximately $393 billion in 2014.[29, 30] Moving forward, new technologies, from automated thermostats to electric vehicles, are changing the way consumers use electricity.

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[e] There are thousands of households in Indian lands that still do not have access to electricity.

Electricity is a high-quality energy source available at a relatively low price. However, many low-income Americans struggle to afford their monthly electricity bills.[31] Nationally, average monthly residential bills in 2015 were $114.[32]

Brief History of the U.S. Electricity Industry

The U.S. electricity system represents one of the greatest technological achievements in the modern era. The complexity of the modern electricity industry is the result of a complicated history.

The Beginning of the Electricity Industry

The U.S. electricity industry began in 1882 when Thomas Edison developed the first electricity distribution system. Edison designed Pearl Street Station to produce and distribute electricity to multiple customers in the New York Financial District and to sell lighting services provided by his newly invented light bulbs.[33]

Early utilities distributed power over low-voltage DC lines. These lines could not move electricity far from where it was produced, which limited utility service to areas only about a mile from the generator. Multiple generators and dedicated distribution lines were required to serve a larger area. The limited reach of distribution lines and the lack of regulation of utilities resulted in the co-location of multiple independent utilities and competition for customers where multiple distribution lines overlapped.[34, 35]

In 1896, AC generation emerged as a competitor to DC when Westinghouse Electric developed a hydropower generation station at Niagara Falls, New York, and transmitted power 20 miles to Buffalo, New York.[36] At the voltage levels used at that time, AC has better electrical characteristics for moving power over long distances. This technological development—and related business models—allowed a single utility to broaden the geographic extent of its customers and sources of revenue. A wave of consolidation followed, where small, isolated DC systems were converted to AC and interconnected with larger systems. Interconnecting with other systems and serving more customers allowed operators to take advantage of the diversity of customer demand, deliver better economies of scale, and provide lower prices than competitors.[37]

A move toward today's system of regulatory oversight occurred around the turn of the century. With the industry consolidation of the late 1890s came public concern over lack of competition and the potential for large utilities to exert a monopoly power over prices.[38] In 1898, a prominent electricity industry leader and Thomas Edison's former chief financial strategist, Samuel Insull, called for utility regulation that granted exclusive franchises in exchange for regulated rates and profits in order to create a stable financial environment that would foster increased investments and electricity access.[39] Insull claimed that such regulation was needed because utilities are natural monopolies, meaning that a single firm can deliver a service at a lower total cost than multiple firms through economies of scale and avoidance of wasteful duplication (e.g., multiple distribution substations and circuits belonging to different companies serving a single area).

In 1907, Wisconsin became the first state to regulate electric utilities, and by 1914, 43 states had followed.[40, 41] The general form of utility regulation that was established by the Wisconsin legislature in 1907 endures today and is called the "state regulatory compact."

This compact allowed electric utilities to operate as distribution monopolies with the sole right to provide retail service to all customers within a given franchise area—as well as an obligation to do so. Those monopolies were allowed an opportunity to earn a fair rate of return on their investments. Some municipal governments across the country created their own utilities, owned and governed by the local government, as an alternative to investor-owned, regulated utilities.[42, f]

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[f] Other types of publicly owned electric utilities, besides those owned by municipal governments, include utilities organized around states, public utility districts, and irrigation districts. The term "public power" is often used to refer to electricity utilities operated by any of these political subdivisions.

The State Regulatory Compact

The "state regulatory compact" evolved as a concept "to characterize the set of mutual rights, obligations, and benefits that exist between the utility and society."[g] It is not a binding agreement. Under this "compact," a utility typically is given exclusive access to a designated—or franchised—service territory and is allowed to recover its prudent costs (as determined by the regulator) plus a reasonable rate of return on its investments. In return, the utility must fulfill its service obligation of providing universal access within its territory. The "regulatory compact" applies to for-profit, monopoly investor-owned utilities that are regulated by the government. The compact is less relevant to public power and cooperative utilities, which are nonprofit entities governed by a locally elected or appointed governing body and are assumed to inherently have their customers' best interests in mind. Regulators strive to set rates such that the utility has the opportunity to be fully compensated for fulfilling its service obligation. While not technically part of the "compact," customers also have a role to play in this arrangement: they give up their freedom of choice over service providers and agree to pay a rate that, at times, may be higher than the market rate in exchange for government protection from monopoly pricing. In effect, utilities have the opportunity to recover their costs, and, if successful, their investors are provided a level of earnings; customers are provided non-discriminatory, affordable service; and the regulator ensures that rates are adequately set such that the aforementioned benefits materialize.

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[g] Karl McDermott, *Cost-of-Service Regulation in the Investor-Owned Electric Utility Industry: A History of Adaptation* (Washington, DC: Edison Electric Institute, 2012), http://www.eei.org/issuesandpolicy/stateregulation/Documents/COSR_history_final.pdf.

In the early 1900s, states regulated nearly all of the activities of electric utilities—generation, transmission, and distribution.[43] However, a 1927 Supreme Court case[44] held that state regulation of wholesale power sales by a utility in one state to a utility in a neighboring state was precluded by the commerce clause of the U.S. Constitution.[45] These transactions were left unregulated as Congress had the authority to regulate, but no Federal agency existed to do so.[46]

The 1935 Federal Power Act (FPA) addressed the regulatory gap by providing the Federal Power Commission (FPC, eventually renamed the Federal Energy Regulatory Commission, or FERC)[h] with authority to regulate "the transmission of electric energy in interstate commerce" and "the sale of electric energy at wholesale in interstate commerce."[47, 48] The FPA left regulation of generation, distribution, and intrastate commerce to states and localities.[49] Federal regulation was to extend "only to those matters which are not subject to regulation by the States."[50] FERC was given jurisdiction over all facilities used for the transmission or wholesale trade of electricity in interstate commerce and was charged with ensuring that corresponding rates are "just and reasonable, and not unduly discriminatory or preferential."[51, 52]

Federal Investments in Rural Electrification

Urban areas were the first areas to attract utility investment. The higher density of potential customers in urban areas made these areas more cost-effective to serve. By the 1930s, most urban areas were electrified, while sparsely populated rural areas generally lagged far behind. The Great Depression and widespread floods and drought in the Great Plains during the 1930s led to a wave of significant Federal initiatives to develop the power potential of the Nation's water resources.

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[h] The Federal Power Commission was created in 1920 by the Federal Water Power Act to encourage the development of hydroelectric generation facilities.

One example of Federal efforts to capture the benefits of the Nation's water resources is the Tennessee Valley Authority (TVA). TVA was created in 1933 as a federally owned corporation to provide economic development through provision of electricity, flood control, and other programs to the rural Tennessee Valley area. To this day, TVA maintains a portfolio of generation and transmission assets to sell wholesale electricity to public power and cooperatives within its territory. Federal law grants first preference for this electricity to public power and cooperative utilities.

Congress passed the Rural Electrification Act in 1936, which encouraged electrification of areas unserved by investor-owned utilities (IOUs) and public power utilities. The act authorized rural electric cooperatives to receive Federal financing support and preferential sales from federally owned generation. The Bonneville Power Administration was created in 1937 to deliver and sell electric power from federally owned dams in the Pacific Northwest.[53] Increased Federal investment in hydropower followed through the 1940s, and by the 1960s, rural electrification was largely complete.[54]

Federally Owned Utilities

There are five Federal electric utilities: Tennessee Valley Authority (TVA), Bonneville Power Administration (BPA), Southeastern Power Administration (SEPA), Southwestern Power Administration (SWPA), and Western Area Power Administration (WAPA). TVA is an independent government corporation, while BPA, SEPA, SWPA, and WAPA are separate and distinct entities within the Department of Energy. Starting with BPA in 1937, followed by SEPA, SWPA, and WAPA, Congress established the Power Marketing Administrations (PMAs) to distribute and sell electricity from a network of more than 130 federally built hydroelectric dams.

The PMAs don't own or manage the power they sell but, in many cases, maintain the transmission infrastructure to distribute the low-cost electricity to public power and rural cooperative utilities, in addition to some direct sales to large industrial customers. The electricity-generating facilities are primarily owned and operated by the Department of the Interior's Bureau of Reclamation, the Army Corps of Engineers, and the International Boundary and Water Commission.

BPA, WAPA, and SWPA collectively own and operate 33,700 miles of transmission lines, which are integrally linked with the transmission and distribution systems of utilities in 20 states. Millions of consumers get electricity from the PMAs (usually indirectly, via their local utility), but a much larger number of consumers benefit from—and have a stake in—the continued efficient, effective operation of the PMAs and the transmission infrastructure they are building and maintaining.

TVA is a corporate agency of the United States that provides electricity for business customers and local power distributors, serving 9 million people in parts of seven southeastern states. TVA receives no taxpayer funding, deriving virtually all of its revenues from sales of electricity. In addition to operating and investing its revenues in its electric system, TVA provides flood control, navigation, and land management for the Tennessee River system and assists local power companies and state and local governments with economic development and job creation.

Electricity Industry Restructuring and Markets

As early as the 1920s, utilities sought operational efficiencies by coordinating generation dispatch and transmission planning across multiple utility territories. Coordination through cooperative power pools provided economies of scale and scope that ultimately lowered costs for all participant utilities. The principles of coordination pioneered in power pools later became the basis for the centrally organized electricity markets that exist today.[55]

Over time, economists and industry observers came to believe that the natural monopoly status that was the basis of so much of electricity industry regulation no longer applied to generation and instead only applied to the "wires" part of the system. While it would be economically wasteful for multiple companies to install overlapping and competing distribution and transmission lines, the generation and sale of electricity to retail customers could be organized as competitive activities.[56] To encourage fair and open competition, several states eventually restructured individual IOUs into separate companies that invested in either regulated or competitive parts of the industry.

Restructuring actions vary by region and by state, but they are typically characterized by the "unbundling" of ownership and regulation of electricity generation, transmission, distribution, and sales, with large variations in how restructuring is implemented across regions and states.

Congress took an early step toward reintroducing market competition in the generation sector in 1978 when it enacted the Public Utilities Regulatory Policies Act (PURPA).[57] PURPA required utilities to purchase power from qualifying non-utility generators at the utility's avoided cost. This led to a wave of investment in generation by non-utility companies.

A major step toward creating electric markets was Congress' enactment of the Energy Policy Act of 1992 (EPAct 1992), which provided FERC with limited authority to order transmission access for wholesale buyers in procuring wholesale electric supplies.[58, 59, 60] Subsequent FERC actions, including Order No. 888 and Order No. 889, created greater transmission access and facilitated the creation of competitive wholesale electricity markets. These FERC orders increased access to electricity supplies from other utilities for wholesale buyers, including public power and rural cooperative utilities.

Also in the 1990s, several states made regulatory changes introducing retail electric choice programs to allow some customers to choose an electricity provider other than their local utility, and to have electricity delivered over the wires of their local utility.[61] States that allow customer choice are sometimes called "deregulated states," a misnomer, as retail electricity providers and other parts of the industry remain highly regulated. By 1996, at least 41 states, including California, New York, and Texas, had or were considering ending utility monopolies and providing electricity service through retail competition.[62] Some states, notably in the Southeast and in western states besides California, did not embrace this wave of restructuring. In 2000 and 2001, California and the Pacific Northwest experienced severe electricity shortages and price spikes. This California electricity crisis left many states that had not yet implemented restructuring wary of pursuing such reforms. Today, 15 states allow retail electric choice for some or all customers, while 8 states have suspended it, including California, which suspended retail choice for residential customers after the energy crisis.[63]

The net result of these changes to jurisdictions, industry structure, and competitive markets is that the United States today has a patchwork of mechanisms governing the electricity industry and a diverse set of industry participants. Regulation of the industry continues to evolve as new technologies, policies, and business realities emerge.

Petroleum

What Is Petroleum?

Petroleum, often known as **oil**, is a **fossil fuel**. It is called a fossil fuel because it was formed from the remains of tiny sea plants and animals that died hundreds of millions of years ago, before dinosaurs lived. When the plants and animals died, they sank to the bottom of the oceans. They were buried by thousands of feet of sediment and sand that turned into rock.

Over time, this organic mixture was subjected to enormous pressure and heat as the layers increased. The mixture changed chemically, breaking down into compounds made of hydrogen and carbon atoms—**hydrocarbons**. Finally, an oil-saturated rock, much like a wet household sponge, was formed.

Not all organic material buried underground turns into oil. Certain geological conditions must exist within the rock formations for the transformations to occur. First, there must be a trap of non-porous rock that prevents the material from seeping out, and a seal (such as salt or clay) to keep the material from rising to the surface. Even under these conditions, only about two percent of the organic material is transformed into oil.

A typical petroleum reservoir is mostly sandstone or limestone in which oil is trapped. The oil in it may be as thin as gasoline or as thick as tar. It may be almost clear or black. Petroleum is called a **nonrenewable** energy source because it takes hundreds of millions of years to form. We cannot make more oil in a short time.

Petroleum at a Glance, 2021

Classification:
- nonrenewable

Major Uses:
- transportation, industry

U.S. Energy Consumption:
- 35.071 Q
- 36.06%

U.S. Energy Production:
- 23.239 Q
- 23.77%

Data: Energy Information Administration

History of Oil

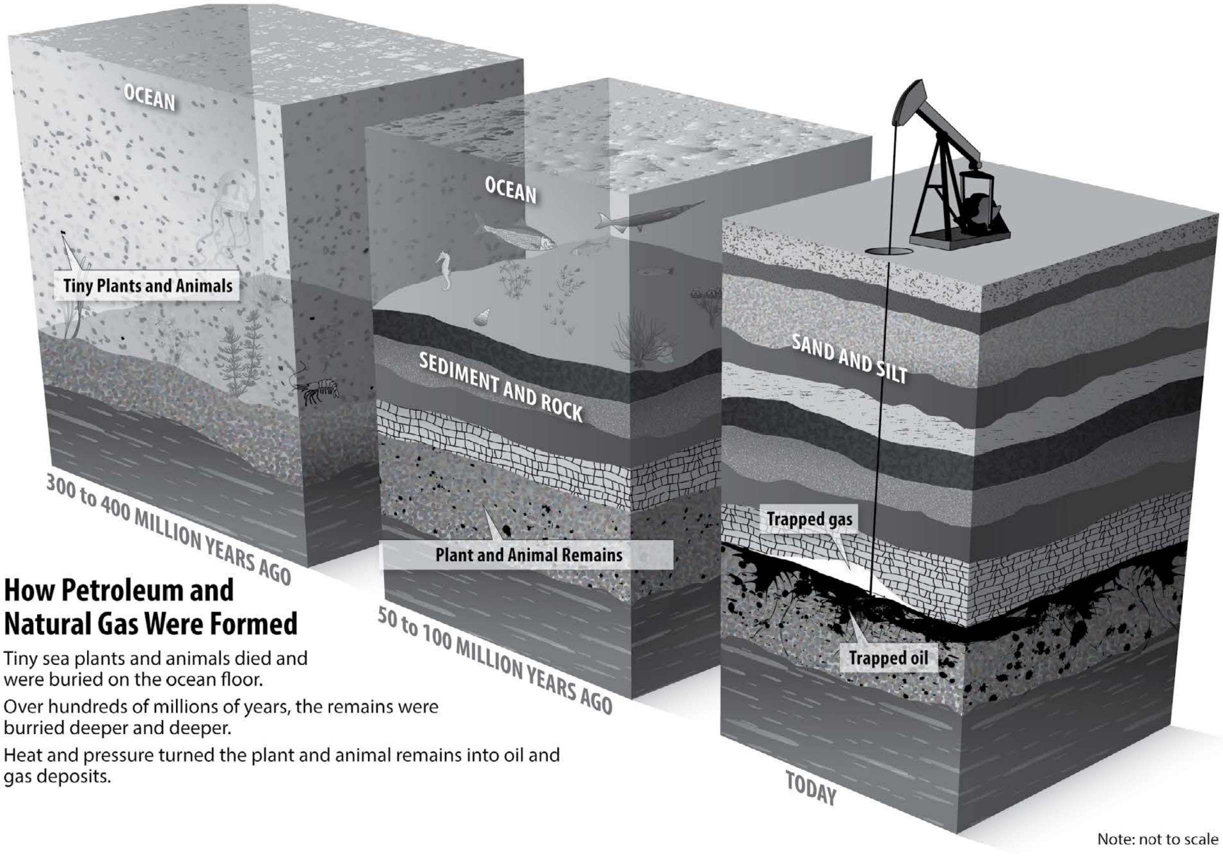
People have used naturally available **crude oil** for thousands of years. The ancient Chinese and Egyptians, for example, burned oil to produce light.

Before the 1850s, Americans often used whale oil for light. When whale oil became scarce, people began looking for other oil sources. In some places, oil seeped naturally to the surface of ponds and streams. People skimmed this oil and made it into **kerosene**. Kerosene was commonly used to light America's homes before the adoption of the electric light bulb.

As demand for kerosene grew, a group of businessmen hired Edwin Drake to drill for oil in Titusville, PA. After much hard work and slow progress, he discovered oil in 1859. Drake's well was 69.5 feet deep, very shallow compared to today's wells.

Drake refined the oil from his well into kerosene for lighting. **Gasoline** and other products made during refining were simply thrown away because people had no use for them.

In 1892, the horseless carriage, or automobile, solved this problem since it required gasoline. By 1920, there were nine million motor vehicles in this country and gas stations were opening everywhere.



How Petroleum and Natural Gas Were Formed

Tiny sea plants and animals died and were buried on the ocean floor.

Over hundreds of millions of years, the remains were burried deeper and deeper.

Heat and pressure turned the plant and animal remains into oil and gas deposits.

Note: not to scale

Petroleum

Producing Oil

Although research has improved the odds since Edwin Drake's days, petroleum exploration today is still a risky business. Geologists study underground rock formations to find areas that might yield oil. Even with advanced methods, only between 60 and 75 percent of exploratory wells find oil, depending on the region. Developmental wells fare much better; over 90 percent can find oil.

When the potential for oil production is found on shore, a petroleum company brings in a 50 to 100-foot **drilling rig** and raises a **derrick** that houses the drilling tools. Today's oil wells average over 6,000 feet deep and may sink below 20,000 feet. The average well might produce anywhere from 10-100 barrels of oil per day, depending how the well is drilled. However, some new wells can yield thousands of barrels per day.

To safeguard the environment, oil drilling and oil production are regulated by state and federal governments. Oil companies must get permission to explore for oil on new sites. Experts believe that much of our remaining oil reserves are on land owned by the Federal Government. Oil companies lease the land from the Federal Government, which, in return, receives rental payments for the mineral rights as well as percentage payments from each barrel of oil.

Texas produces more oil than any other state. The other top-producing states are New Mexico, North Dakota, Alaska, and Colorado. These five states account for 71 percent of all U.S. crude oil production. In all, 32 states produce petroleum.

From Well to Market

We cannot use crude oil exactly as it comes out of the ground. The process is a little more complicated than that. So, how does thick, black crude oil come out of the ground and eventually get into your car as a thin, amber-colored liquid called gasoline?

Oil's first stop after being pumped from a well is an oil refinery. A **refinery** is a plant where crude oil is processed. Sometimes, refineries are located near oil wells, but usually the crude oil has to be delivered to the refinery by ship, barge, pipeline, truck, or train.

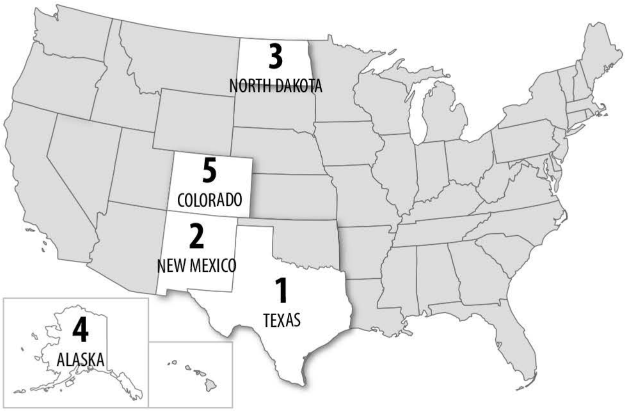
After the crude oil has reached the refinery, huge round tanks store the oil until it is ready to be processed. **Tank farms** are sites with many storage tanks.

An oil refinery cleans and separates the crude oil into various fuels and byproducts. The most important one is gasoline. Some other petroleum products are **diesel fuel**, heating oil, and jet fuel. Chemical processes in refineries can take 42 gallons in a barrel and actually create the equivalent of about 45 gallons of products.

Refineries use many different methods to make these products. One method is a heating process called **distillation**. Since oil products have different boiling points, molecule sizes, and densities, the end products can be distilled, or separated. For example, asphalts have a higher boiling point than gasoline, allowing the two to be separated.

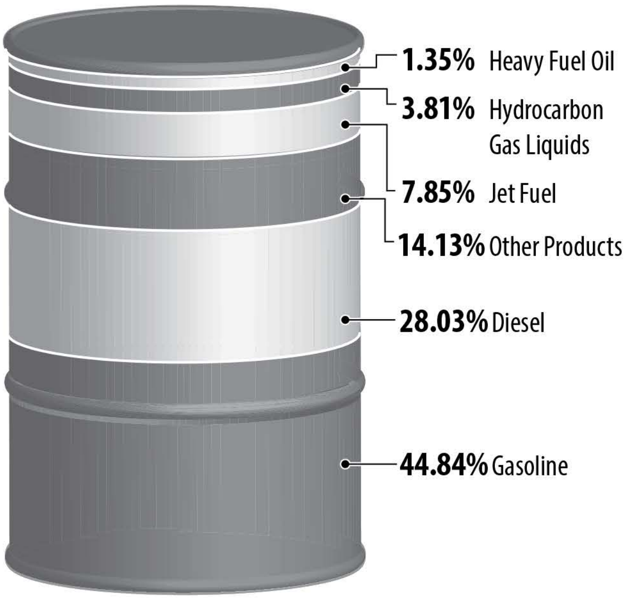
Refineries have another job; they remove contaminants from the oil. A refinery removes sulfur from gasoline, for example, to increase its efficiency and to reduce air pollution. Not all of the crude oil sent to a refinery is turned into product. A small percentage of the energy in the crude oil is used to operate the refinery facility.

Top Petroleum Producing States, 2021



Data: Energy Information Administration

Products Produced From a Barrel of Oil, 2021



Data: Energy Information Administration
*Total may not equal 100% due to independent rounding.

Shipping Oil Products

Pipelines are the safest and cheapest way to move large quantities of crude oil or refined petroleum across land. About 190,000 miles of small gathering lines and large trunk lines move crude oil from wells to refineries.

Pump stations, which are spaced 20 to 100 miles apart along the underground pipelines, keep the petroleum products moving at a speed of about five miles per hour. At this rate, it takes two to three weeks to move a shipment of gasoline from Houston, TX to New York City. Petroleum is transported over water via ship or tanker.

Distribution

Companies called **jobbers** handle the wholesale distribution of oil. They sell just about everything that comes out of a barrel of crude oil. Jobbers fill bulk orders for petroleum products from gasoline stations, industries, utility companies, farmers, and other consumers.

The retailer is the next link in the chain. A retailer may be a gasoline station or a home heating oil company. The last link is when you pump gasoline into your car, and the engine converts the gasoline's chemical energy into motion to move your car.

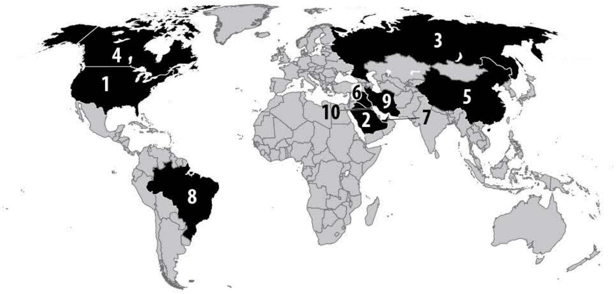
Demand for Oil

Since World War II, petroleum has been the leading source of energy consumed in the United States. Petroleum supplies about 35 percent of total U.S. energy demand. Natural gas supplies about 34 percent.

America uses about 20 million barrels of oil (about 895 million gallons) every day of the year. And experts say we will continue to use oil at these rates, especially for transportation, in the coming years.

Even now, we use about 52 percent more oil than we did in 1973, simply for transportation. This is true even though today's vehicles get almost twice as many miles per gallon as their 1970s counterparts, because there are almost twice as many vehicles on the road today than in 1973 when the first oil crisis hit the U.S. Today, about 70 percent of U.S. oil consumption is used for transportation.

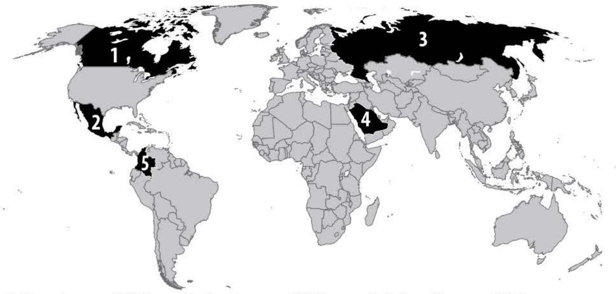
Top Oil-Producing Countries, 2021



1. United States
2. Saudi Arabia
3. Russia
4. Canada
5. China
6. Iraq
7. United Arab Emirates
8. Brazil
9. Iran
10. Kuwait

Data: Energy Information Administration

Top Sources of U.S. Imported Oil, 2021



1. Canada, non-OPEC
2. Mexico, non-OPEC
3. Russia, non-OPEC
4. Saudi Arabia, OPEC
5. Colombia, non-OPEC

Percentage of Total Imports from Non-OPEC Nations: 88.68%
Percentage of Total Imports from OPEC Nations: 11.32%

Data: Energy Information Administration

Imported Oil

The United States uses more petroleum than it produces. In 2021, we imported 43 percent of our crude oil supply from other countries.

Many Americans believe this dependence on imported petroleum is problematic and reduces America's energy security and the ability to withstand disruption of supply. We were first alerted to that reality in 1973 when a group of Arab countries stopped supplying oil (called an **oil embargo**) to the United States. These countries belonged to an international trade group called the Organization of Petroleum Exporting Countries, or **OPEC** for short. OPEC member countries often set production levels for petroleum. OPEC member nations include Saudi Arabia, Venezuela, United Arab Emirates, Iran, Iraq, Kuwait, and several others mostly in the Middle East and Africa. As a rule, the less oil they produce, the higher the price of oil on the world market.

The next shock came in 1978–1979 when the Iranian Revolution cut off oil production. Again, world oil prices increased. Other major price increases resulted from the Persian Gulf War in 1990–1991, and the September 11, 2001 terrorism attacks, and Hurricane Katrina in the Gulf of Mexico in 2005.

As many countries in the Middle East, North Africa, and Europe experience political change, petroleum prices may increase temporarily, resulting in higher prices for gasoline and other products. Many people believe that prices are less related to oil supply and more related to how petroleum is traded (bought and sold) as a commodity.

The U.S. continues to work to increase energy security and maintain domestic supplies of petroleum—including the purchase and storage of three months of supply in the Strategic Petroleum Reserve (SPR). Established in 1975, the SPR is only to be tapped during an energy emergency. The SPR was first tapped in 1991 during the first Persian Gulf War and has since been tapped following events like Hurricanes Rita and Katrina in 2005, the Libyan civil conflict in 2011, and the Ukraine-Russia Conflict of 2022.

The United States imports oil from both non-OPEC and OPEC countries. Today, we import more oil from Canada than any other country (51.22 percent), followed by Mexico (8.39 percent). The United States is a major consumer in the global energy economy, and access to petroleum resources continues to be a high priority for providing the energy resources needed for transportation and making many of our consumer goods and products. As countries like China and India grow, their demand for petroleum and petroleum products increases as well. Global demand for oil continues.

There are steps we can take to help ensure our energy security and reduce the impact of high oil prices. Some experts believe the most important step is to decrease our demand for oil through increased conservation, reducing the oil we use, and increasing the efficiency of our vehicles and transportation.

Some people believe we should increase oil production in the United States, which might include areas like the Arctic National Wildlife Refuge (ANWR) in northern Alaska and offshore. Others say we should increase our use of other transportation options like electricity. Many people agree that the United States must increase production from domestic sources, increase efficiency, and continue development of non-petroleum transportation fuels.

Offshore Oil Reserves

There are rich deposits of petroleum and natural gas on the **outer continental shelf (OCS)**, especially off the Pacific coasts of California and Alaska and in the Gulf of Mexico. Thirty basins have been identified that could contain enormous oil and gas reserves. It is estimated that 30 percent of undiscovered U.S. gas and oil reserves are contained in the OCS.

Today, there are thousands of drilling platforms, servicing thousands of wells. OCS production supplies approximately 3 percent of the nation's natural gas production and 15 percent of its oil production. Most of the active wells are in the central and western Gulf of Mexico, with additional wells off the coast of California.

Although there are no producing wells in other areas, there is believed to be significant oil potential in the Beaufort Sea off Alaska, as well as natural gas potential in the eastern Gulf of Mexico and in certain basins off the Atlantic Coast.

The Bureau of Ocean Energy Management (BOEM), part of the U.S. Department of the Interior (DOI), grants permission to use offshore lands through lease sales. After companies pay for a lease, they apply for BOEM permits to develop energy resources from the lease. A lease is generally 9 square miles. Offshore petroleum exploration and production have been ongoing in the central and western portions of the Gulf of Mexico. Until recently, the Pacific Coast, the eastern portion of the Gulf of Mexico, and parts of Alaska were restricted from new lease sales. However, those restrictions were lifted, and a few lease sales took place in 2020. In January of 2021, all new lease sales were paused in an effort to address climate concerns in the U.S., however new lease sales may be held again in 2023, per DOI.

Offshore Production

Offshore production is costly—many times more expensive than land-based production. To reach oil buried in shallow water, drilling platforms stand on stilt-like legs that are imbedded in the ocean floor. These huge platforms hold all the drilling equipment needed, as well as housing and storage areas for the work crews. Once the well has been drilled, the platforms also hold the production equipment.

Floating platforms are used for drilling in deeper waters. These self-propelled vessels are anchored to the ocean bottom with huge cables. Once the wells have been drilled from these platforms, the production equipment is lowered to the ocean floor and sealed to the well casings to prevent leakage. Wells have been drilled in 10,000 feet of water using these floating rigs.

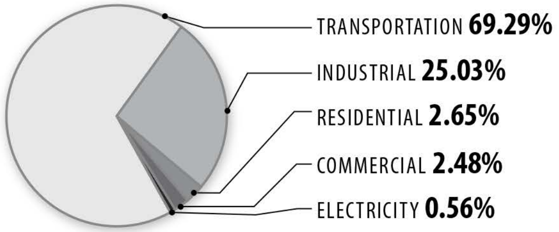
In 2010, the Macondo (Deepwater Horizon) well accident released oil into the Gulf of Mexico for several months. The companies involved in developing Macondo, the Coast Guard, and the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) quickly began work to determine the cause of the accident and to improve production and safety standards as a result.

Oil Prices

Most of the world moves on petroleum—gasoline for cars, jet fuel for planes, and diesel fuel for trucks. Then there are petroleum products needed to run factories and manufacture goods. That's why the price of oil is so important. In 1998, the average price of a barrel of oil dropped as low as $11 a barrel; in the spring and summer of 2008, the price shot up to over $130 a barrel, the highest price in history. The average price at the end of 2019 was just about $57 a barrel.

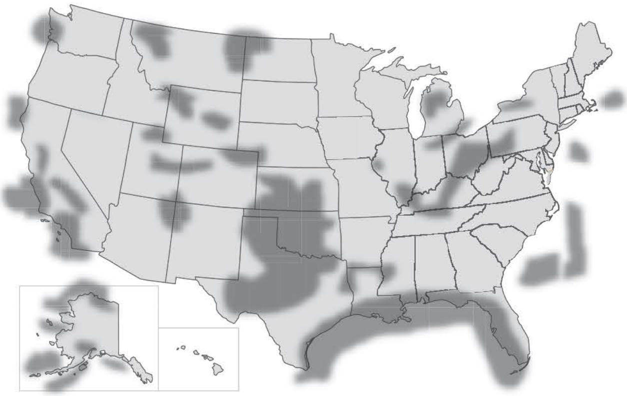
In early 2020, the coronavirus pandemic set up the perfect storm for plummeting oil prices. By mid-April, a combination of decreased demand from the pandemic and excess oil from unadjusted production led to a glut on the market. Producers were running out of places to store oil. The price of one barrel of West Texas Intermediate (WTI) oil was negative, meaning producers were paying buyers to take oil. Russia, Saudi Arabia, and other OPEC countries agreed to reduce the amount of oil produced in May, but prices dropped below $20 per barrel. In 2021, prices averaged much higher at $71 per barrel.

U.S. Petroleum Consumption by Sector, 2021



Data: Energy Information Administration
*Total may not equal 100% due to independent rounding.

U.S. Oil and Gas Basins



Data: Energy Information Administration

Low oil prices are good for the consumer and the economy, acting as a check on inflation. The oil industry, however, does not prosper during periods of low oil prices. Oil industry workers lose their jobs, many small wells are permanently sealed, and the exploration for new oil sources drops off. Low oil prices have another side effect. People use more petroleum products when crude oil is cheap. They buy bigger cars and drive more miles. Urban air quality suffers.

Oil and the Environment

In the United States, we use more petroleum than any other energy source. Petroleum products—gasoline, fertilizers, plastics, medicines—have brought untold benefits to Americans and the rest of the world. We depend on these products, and, as consumers, we demand them. However, petroleum production, distribution, and consumption can contribute to air and water pollution.

Drilling for and transporting oil can endanger wildlife and the environment if it spills into rivers or oceans. Leaking underground storage tanks can pollute groundwater and create noxious fumes. Processing oil at the refinery can contribute to air and water pollution. Burning gasoline to fuel our cars contributes to air pollution. Even the careless disposal of waste oil drained from the family car can pollute rivers and lakes.

Many advances have been made in protecting the environment since the passage of the Clean Air Act in 1970. Refineries must curb emissions and monitor water quality. Fuels have been reformulated to burn cleaner, reducing the levels of lead, nitrogen oxide, carbon monoxide, and hydrocarbons released into the air.

Despite regulations and advances, using petroleum-based fuels and creating products from petroleum still emit greenhouse gases that impact the environment. Continued dependence on petroleum presents an ongoing challenge. The future must balance the demand for petroleum products with protection of the global environment.

Coal

Coal at a Glance, 2021

Classification:	**Major Uses:**
•nonrenewable	•electricity, industry
U.S. Energy Consumption:	**U.S. Energy Production:**
•10.547 Q	•11.621 Q
•10.85%	•11.88%

Data: Energy Information Administration

What Is Coal?

Coal is a **fossil fuel** created from the remains of plants that lived and died about 100 to 400 million years ago when parts of the Earth were covered with huge swampy forests. Coal is classified as a **nonrenewable** energy source because it takes millions of years to form.

The energy we get from coal today comes from the energy that plants absorbed from the sun millions of years ago. All living plants store solar energy through a process known as **photosynthesis**. When plants die, this energy is usually released as the plants decay. Under conditions favorable to coal formation, however, the decay process is interrupted, preventing the release of the stored solar energy. The energy is locked into the coal.

Millions to hundreds of millions of years ago, plants that fell to the bottom of the swamp began to decay as layers of dirt and water were piled on top. Heat and pressure from these layers caused a chemical change to occur, eventually creating coal over time.

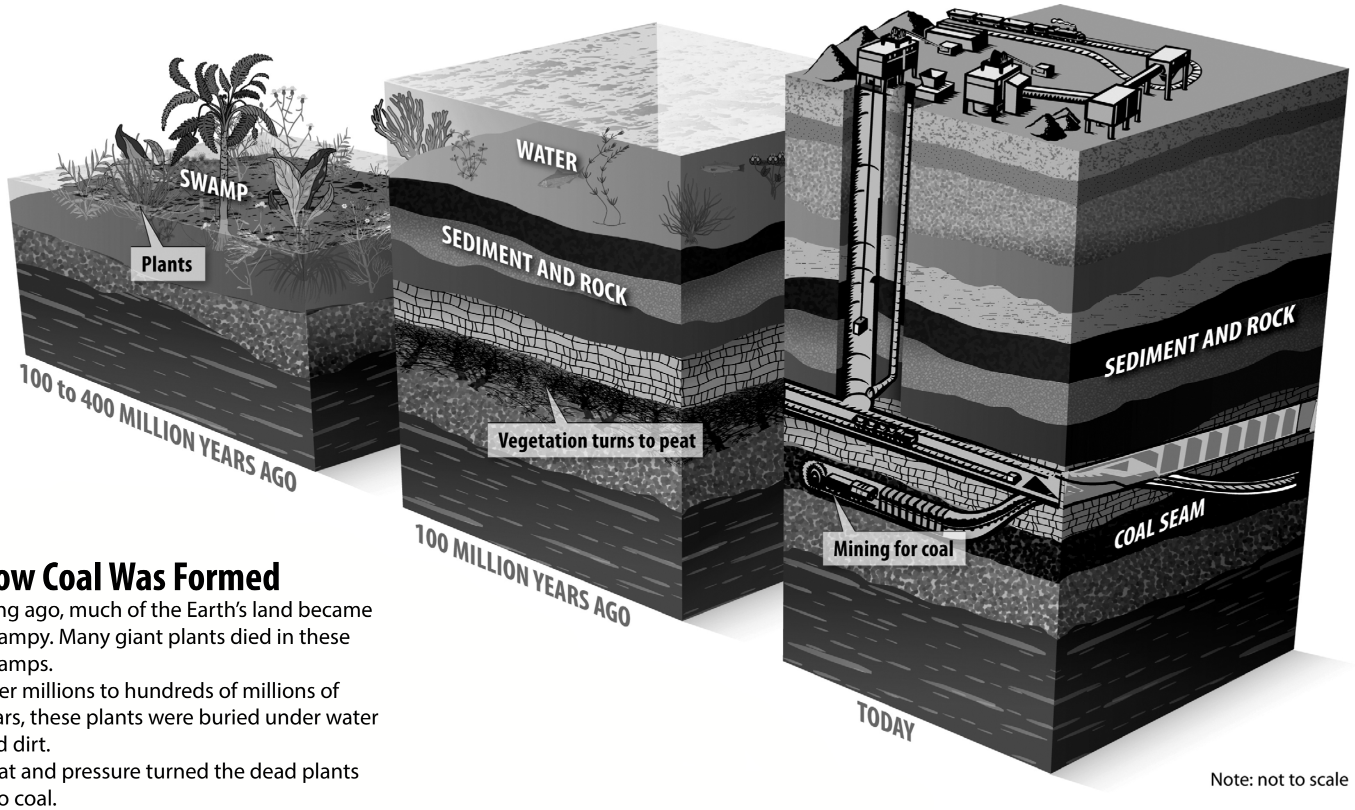
Seams of coal—ranging in thickness from a fraction of an inch to hundreds of feet—may represent hundreds or thousands of years of plant growth. One seam, the seven-foot thick Pittsburgh seam, may represent 2,000 years of rapid plant growth. One acre of this seam contains about 14,000 tons of coal.

History of Coal in America

Native Americans used coal long before the first settlers arrived in the New World. Hopi Indians, who lived in what is now Arizona, used coal to bake the pottery they made from clay. European settlers discovered coal in North America during the first half of the 1600s. They used very little at first. Instead, they relied on water wheels and wood to power colonial industries.

Coal became a powerhouse by the 1800s. People used coal to manufacture goods and to power steamships and railroad engines. By the American Civil War, people also used coal to make iron and steel. And by the end of the 1800s, people even used coal to make electricity.

When America entered the 1900s, coal was the energy mainstay for the nation's businesses and industries. Coal stayed America's number-one energy source until the demand for petroleum products pushed petroleum to the front. Automobiles needed gasoline. Trains switched from coal power to diesel fuel. Even homes that used to be heated by coal turned to oil or natural gas furnaces instead.



How Coal Was Formed

Long ago, much of the Earth's land became swampy. Many giant plants died in these swamps.

Over millions to hundreds of millions of years, these plants were buried under water and dirt.

Heat and pressure turned the dead plants into coal.

Note: not to scale

Coal

Coal production reached its low point in 1961. Since 1970, coal production reached high points during which coal production was up by as much as 48%. Today, coal supplies about 11 percent of the nation's total energy needs, mostly for electricity production, and has seen an overall decline in recent years due to the increased use of natural gas and renewables.

Coal Mining

There are two ways to remove coal from the ground, surface and underground mining. **Surface mining** is used when a coal seam is relatively close to the surface, usually within 200 feet. The first step in surface mining is to remove and store the soil and rock covering the coal, called the **overburden**. Workers use a variety of equipment—draglines, power shovels, bulldozers, and front-end loaders—to expose the coal seam for mining.

After surface mining, workers replace the overburden, grade it, cover it with topsoil, and fertilize and seed the area. This land reclamation is required by law and helps restore the biological balance of the area and prevent erosion. The land can then be used for croplands, wildlife habitats, recreation, or sites for commercial development.

About 63 percent of the nation's coal is obtained through surface mining. Surface mining is typically much less expensive than underground mining. With new technologies, surface mining productivity has more than doubled since 1970.

Underground (or deep) mining is used when the coal seam is buried several hundred feet below the surface. In underground mining, workers and machinery go down a vertical shaft or a slanted tunnel called a slope to remove the coal. Mine shafts may be as deep as 1,000 feet.

One method of underground mining is called **room-and-pillar mining**. With this method, much of the coal must be left behind to support the mine's roofs and walls. Sometimes as much as half the coal is left behind in large column formations to keep the mine from collapsing.

A more efficient and safer underground mining method, called **longwall mining**, uses a specially shielded machine that allows a mined-out area to collapse in a controlled manner. This method is called longwall mining because huge blocks of coal up to several hundred feet wide can be removed.

Processing and Transporting Coal

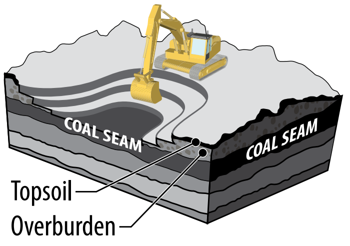
After coal comes out of the ground, it typically goes on a conveyor belt to a preparation plant that is located at the mining site. The plant cleans and processes coal to remove dirt, rock, ash, sulfur, and other impurities, increasing the heating value of the coal.

After the coal is mined and processed, it is ready to go to market. It is very important to consider transportation when comparing coal with other energy sources because sometimes transporting the coal can cost more than mining it.

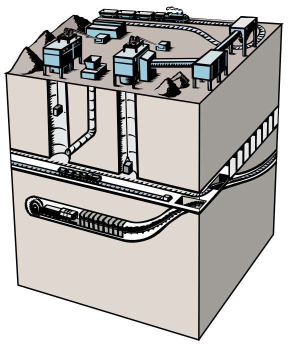
Underground pipelines can easily move petroleum and natural gas to market. But that's not so for coal. Huge trains transport more than two-thirds of U.S. coal for some or all of its journey to market.

It is cheaper to transport coal on river barges, but this option is not always available. Coal can also be moved by trucks and conveyors if the coal mine is close by. Ideally, coal-fired **power plants** are built near coal mines to minimize transportation costs.

Surface Mining



Deep Mining



Types of Coal

Coal is classified into four main types, depending on the amount of carbon, oxygen, and hydrogen present. The higher the carbon content, the more energy the coal contains.

Lignite is the lowest rank of coal, with a **heating value** of 4,000 to 8,300 **British thermal units** (Btu) per pound. Lignite is crumbly and has high moisture content. Most lignite mined in the United States comes from Texas. Lignite is mainly used to produce electricity. It contains 25 to 35 percent carbon. About nine percent of the coal mined in 2020 in the U.S. was lignite.

Subbituminous coal typically contains less heating value (8,300 to 13,000 Btu per pound) than bituminous coal and more moisture. It contains 35 to 45 percent carbon. In 2020, 46 percent of the coal mined in the U.S. was subbituminous.

Bituminous coal was formed by added heat and pressure on lignite. Made of many tiny layers, bituminous coal looks smooth and sometimes shiny. It is the most abundant type of coal found in the United States and has two to three times the heating value of lignite. Bituminous coal contains 11,000 to 15,500 Btu per pound. Bituminous coal is used to generate electricity and is an important fuel for the steel and iron industries. It contains 45 to 86 percent carbon. In 2020, 44 percent of the coal mined in the U.S. was bituminous coal.

Anthracite was created where additional pressure combined with very high temperature inside the Earth. It is deep black and looks almost metallic due to its glossy surface. It is found primarily in 11 northeastern counties of Pennsylvania. Like bituminous coal, anthracite coal is a big energy producer, containing nearly 15,000 Btu per pound. It contains 86 to 97 percent carbon. Less than one percent of coal mined in 2020 in the U.S. was anthracite.

Coal Reserves

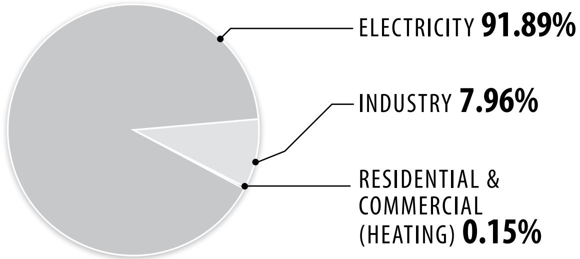
When scientists estimate how much coal, petroleum, natural gas, or other energy sources there are in the United States, they use the term **reserves**. Reserves are deposits that can be harvested using today's methods and technology.

Experts estimate that the United States has over 250 billion tons of recoverable coal reserves. If we continue to use coal at the same rate as we do today, we will have enough coal to last over 400 years. This vast amount of coal makes the United States the world leader in known coal reserves.

Where is all this coal located? Coal reserves can be found in 31 states. Montana has the most coal—about 74 billion mineable tons. Coal is also found in large quantities in Wyoming, West Virginia, Pennsylvania, Illinois, North Dakota, Ohio, and Kentucky. Western coal generally contains less sulfur than eastern coal.

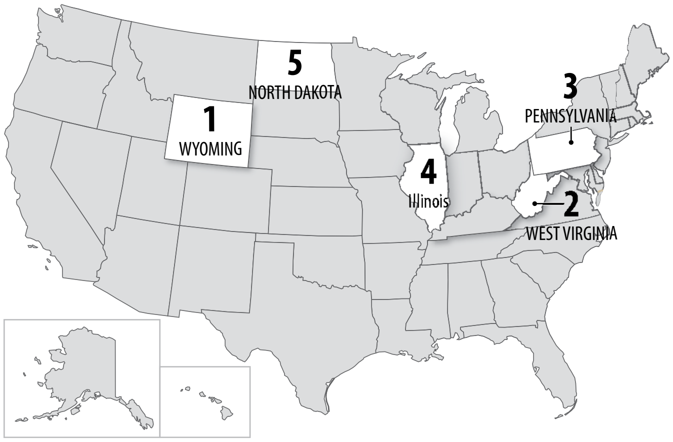
The Federal Government is by far the largest owner of the nation's coalbeds. The Bureau of Land Management leases over 570 million acres of coal bed mineral estates to landowners. Most of these leases are found in Western states.

U.S. Coal Consumption by Sector, 2021



Data: Energy Information Administration

Top Coal Producing States, 2020



Data: Energy Information Administration

Coal Production

Coal production is the amount of coal mined and taken to market. Where does mining take place in the United States? Today, coal is mined in 21 states. More coal is mined in western states than in eastern states, a marked change from the past when most coal came from eastern underground mines.

In the 1950s and 1960s, the East mined approximately 95 percent of the coal produced in the U.S. As of the early 1970s, the amount of coal produced by western mines steadily increased. In 2020, the West provided 61 percent of total production, and states east of the Mississippi River provided 39 percent.

Total U.S. coal production was 535 million short tons in 2020. The leading coal states are Wyoming, West Virginia, Pennsylvania, Illinois, and North Dakota. These five states produce over 71 percent of the coal in the U.S.

Some coal produced in the United States is exported to other countries. In 2021, foreign countries bought about 15.91 percent of all the coal produced in the U.S. The biggest foreign markets for U.S. coal are India, China, the Netherlands, Japan, South Korea, Brazil, and Canada.

How Coal Is Used

The main use of coal in the United States is to generate electricity. In 2021, 92 percent of all the coal in the United States was used for electricity production. Coal generates about 21.84 percent of the electricity used in the U.S. Other energy sources used to generate electricity include natural gas, uranium (nuclear power), hydropower, solar, and wind.

Another major use of coal is in iron and steelmaking. The iron industry uses coke ovens to melt iron ore. **Coke**, an almost pure carbon residue of coal, is used as a fuel in **smelting** metals. The United States has the finest coking coals in the world. These coals are shipped around the world for use in coke ovens. Coal is also used by other industries. The paper, brick, limestone, and cement industries all use coal to make products.

Coal is no longer a major energy source for heating American homes or other buildings. A very, very small amount of the coal produced in the U.S. today is used for heating. Coal furnaces, which were popular years ago, have largely been replaced by oil or gas furnaces or by electric heat pumps.

Coal and the Environment

As the effects of pollution became more noticeable, Americans decided it was time to balance the needs of industry and the environment.

Over a century ago, concern for the environment was not at the forefront of public attention. For years, smokestacks from electrical and industrial plants emitted pollutants into the air. Coal mining left some land areas barren and destroyed. Automobiles, coming on strong after World War II, contributed noxious gases to the air.

The Clean Air Act and the Clean Water Act require industries to reduce pollutants released into the air and the water. Laws also require companies to reclaim the land damaged by surface mining. Progress has been made toward cleaning and preserving the environment.

The coal industry's largest environmental challenge today is removing organic sulfur, a substance that is chemically bound to coal. All fossil fuels, such as coal, petroleum, and natural gas, contain sulfur. Low-sulfur coal produces fewer pollutants.

When these fuels are burned, the organic sulfur is released and combines with oxygen to form sulfur dioxide. Sulfur dioxide is an invisible gas that has been shown to have adverse effects on air quality.

The coal industry works to solve this problem. One method uses devices called **scrubbers** to remove the sulfur in coal smoke. Scrubbers are installed at coal-fired electric and industrial plants where a water and limestone mixture reacts with sulfur dioxide to form sludge. Scrubbers eliminate up to 98 percent of the sulfur dioxide. Utilities that burn coal spend millions of dollars to install these scrubbers.

The coal industry has made significant improvements in reducing sulfur emissions. Since 1989, coal-fired plants in the United States have lowered sulfur dioxide emissions per ton by two-thirds and have increased efficiency significantly by modernizing their plants.

Coal plants also recycle millions of tons of fly ash (a coal byproduct) into useful products such as road building materials, cement additives and, in some cases, pellets to be used in rebuilding oyster beds.

Carbon dioxide (CO_2) is released when coal is burned. CO_2 combines with other gases, such as those emitted from automobiles, to form a shield that allows the sun's light through the atmosphere but doesn't let the heat that is produced out of the atmosphere. This phenomenon is called the **greenhouse effect**. Without this greenhouse effect, the Earth would be too cold to support life. However, the use of combustible fuels like coal plays a major role in the changes in greenhouse gas levels in the Earth's atmosphere that are responsible for a change in the Earth's climate.

The scientific community agrees that the Earth is already experiencing a warming trend due to increased greenhouse gas concentrations. Long-term studies by scientists in many countries are being conducted to determine the effect of increased CO_2 and methane gas levels in the atmosphere and how these atmospheric concentrations affect the oceans, ice sheets, and ecosystems. Scientists are continually researching new technologies to help mitigate changes to the global climate.

Cleaner Coal Technology

Coal is the United States' most plentiful fossil fuel, but traditional methods of burning coal produce emissions that can reduce air and water quality. Using coal can help the United States achieve domestic energy security if we can develop methods to use coal that won't damage the environment.

The Clean Coal Technology Program is a government and industry funded program that began in 1986 in an effort to resolve U.S. and Canadian concern over **acid rain**. Clean coal technologies remove sulfur and nitrogen oxides before, during, and after coal is burned, or convert coal to a gas or liquid fuel. Clean coal technologies are also more efficient, using less coal to produce the same amount of electricity.

Fluidized Bed Combustor: One technique that cleans coal as it burns is a fluidized bed combustor. In this combustor, crushed coal is mixed with limestone and suspended on jets of air inside a boiler. The coal mixture floats in the boiler much like a boiling liquid. The limestone acts like a sponge by capturing 90 percent of the organic sulfur that is released when the coal is burned. The bubbling motion of the coal also enhances the burning process.

Combustion temperatures can be held to 1,500 degrees Fahrenheit, about half that of a conventional boiler. Since this temperature is below the threshold at which nitrogen pollutants form, a fluidized bed combustor keeps both sulfur and nitrogen oxides in check.

Coal Gasification: Another clean coal technology bypasses the conventional coal burning process altogether by converting coal into a gas. This method removes sulfur, nitrogen compounds, and particulates before the fuel is burned, making it as clean as natural gas.

Carbon Capture, Utilization, and Storage: Research and demonstration projects are underway around the U.S. and the world to capture carbon dioxide from power plants and use it or store it deep underground in geologic formations. Researchers are investigating the best ways to capture carbon dioxide, either before or after coal is combusted. The carbon dioxide will then be compressed, converting the gas to a liquid. It can then be utilized by industry or transported via pipeline to appropriate storage sites. Three different types of locations have been identified as being able to hold carbon dioxide: 1) deep saline formations, 2) oil and gas reservoirs that are near depletion or have been depleted, and 3) unmineable coal seams.

Natural Gas

What Is Natural Gas?

Natural gas is generally considered a **nonrenewable fossil fuel**. (*There are some renewable sources of methane, the main ingredient in natural gas, also discussed in this fact sheet.*) Natural gas is considered a fossil fuel because natural gas was formed from the remains of tiny sea animals and plants that died 300 to 400 million years ago.

When these tiny sea animals and plants died, they sank to the bottom of the oceans where they were buried by layers of sediment that turned into rock. Over the years, the layers of **sedimentary** rock became thousands of feet thick, subjecting the energy-rich plant and animal remains to enormous pressure. Most scientists believe that the pressure, combined with the heat of the Earth, changed this organic mixture into petroleum and natural gas. Eventually, concentrations of natural gas became trapped in the rock layers like a sponge traps water.

Raw natural gas is a mixture of different gases. The main ingredient is **methane**, a natural compound that is formed whenever plant and animal matter decays. By itself, methane is odorless, colorless, and tasteless. As a safety measure, natural gas companies add a chemical odorant called **mercaptan** (it smells like rotten eggs) so escaping gas can be detected. Natural gas should not be confused with gasoline, which is made from petroleum.

History of Natural Gas

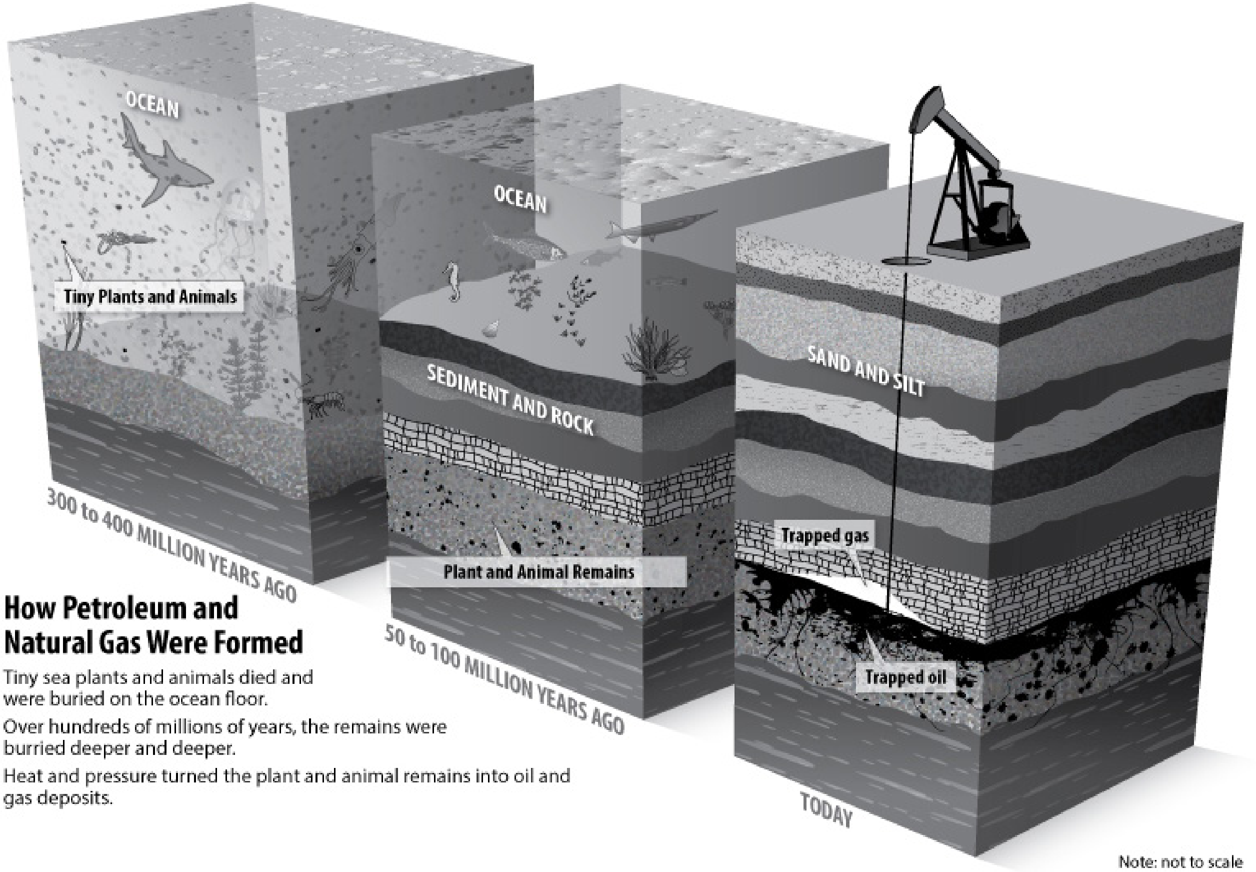
The ancient peoples of Greece, Persia, and India discovered natural gas many centuries ago. The people were mystified by the burning springs created when natural gas seeping from cracks in the ground was ignited by lightning. They sometimes built temples around these eternal flames so they could worship the mysterious fire.

About 2,500 years ago, the Chinese recognized that natural gas could be put to work. The Chinese piped the gas from shallow wells and burned it under large pans to evaporate seawater for the salt.

Natural gas was first used in America in 1816 to illuminate the streets of Baltimore with gas lamps. Lamplighters walked the streets at dusk to light the lamps.

Soon after, in 1821, William Hart dug the first successful American natural gas well in Fredonia, NY. His well was 27 feet deep, quite shallow compared to today's wells. The Fredonia Gas Light Company opened its doors in 1858 as the nation's first natural gas company.

By 1900, natural gas had been discovered in 17 states. In the past 40 years, the use of natural gas has grown. Today, natural gas accounts for over 29 percent of the energy we use.



How Petroleum and Natural Gas Were Formed

Tiny sea plants and animals died and were buried on the ocean floor.

Over hundreds of millions of years, the remains were burried deeper and deeper.

Heat and pressure turned the plant and animal remains into oil and gas deposits.

Natural Gas

Natural Gas at a Glance, 2016

Classification:
- nonrenewable

Major Uses:
- heating, industry, electricity

U.S. Energy Consumption:
- 28.455 Q
- 29.20%

U.S. Energy Production:
- 27.649 Q
- 32.83%

Data: Energy Information Administration

Producing Natural Gas

Natural gas can be difficult to find since it is usually trapped in **porous** rocks deep underground. Geologists use many methods to find natural gas deposits. They may look at surface rocks to find clues about underground formations. They may set off small explosions or drop heavy weights on the Earth's surface and record the sound waves as they bounce back from the sedimentary rock layers underground. They also may measure the gravitational pull of rock masses deep within the Earth.

If test results are promising, the scientists may recommend drilling to find the natural gas deposits. Natural gas wells average more than 8,600 feet deep and can cost hundreds of dollars per foot to drill, so it's important to choose sites carefully.

In the past few years, around 60 percent of the **exploratory wells** produced gas. The others came up dry. The odds are better for **developmental wells**—wells drilled on known gas fields. Over 90 percent of the developmental wells drilled recently yield gas. Natural gas can be found in pockets by itself or in petroleum deposits.

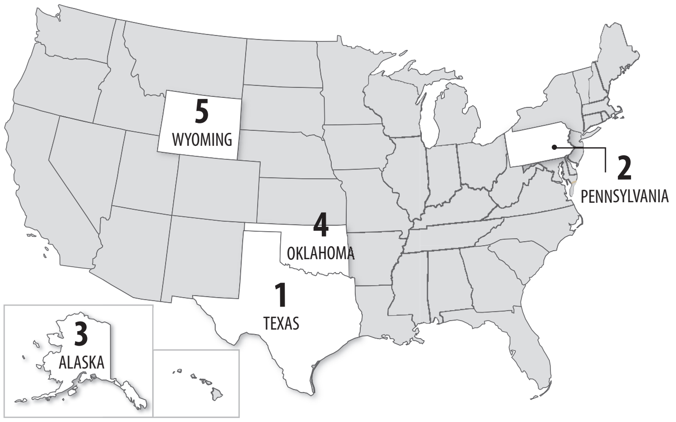
After natural gas comes out of the ground, it goes to a processing plant where it is cleaned of impurities and separated into its various components. Approximately 90 percent of natural gas is composed of methane, but it also contains other gases such as propane and butane.

Natural gas may also come from several other sources. One source is coalbed methane, natural gas found in seams of coal. Until recently, coalbed methane was just considered a safety hazard to miners, but now it is a valuable source of natural gas. Just under five percent of the total natural gas produced in the last few years came from coalbeds.

Another source of natural gas is the methane produced in landfills. Landfill gas is considered a renewable source of methane since it comes from decaying garbage. This **biogas** recovered from landfills is usually burned on the landfill site to generate electricity for the facility itself.

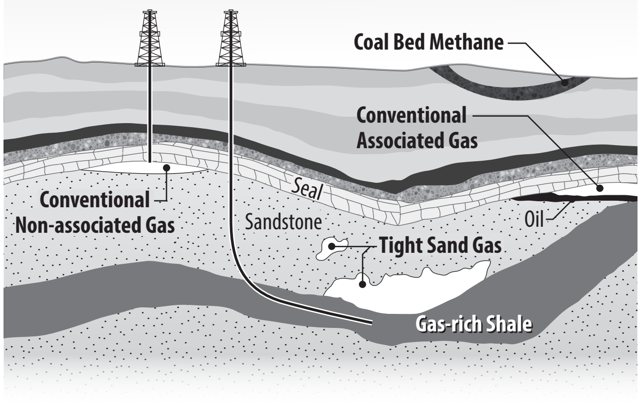
Today, natural gas is produced in 34 states, but the top five states—Texas, Pennsylvania, Alaska, Oklahoma, and Wyoming—produce 64 percent of the total. Natural gas is also produced offshore. A little more than five percent of U.S. natural gas comes from offshore wells. Altogether, the U.S. produces about one-fifth of the world's natural gas each year.

Top Natural Gas Producing States, 2016

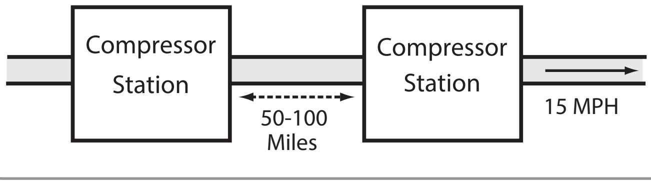


Data: Energy Information Administration

Locations of Natural Gas



Natural Gas Distribution System



Transporting and Storing Natural Gas

How does natural gas get to you? Usually by pipeline. Over two million miles of underground **pipelines** link natural gas wells to cleaning plants to major cities across the United States. Natural gas is sometimes transported thousands of miles by pipeline to its final destination.

A machine called a **compressor** increases the pressure of the gas, forcing the gas to move along the pipelines. Compressor stations, which are spaced about 50 to 100 miles apart, move the gas along the pipelines at about 15 miles per hour.

Some gas moved along this subterranean highway is temporarily stored in huge underground reservoirs. The underground reservoirs are typically filled in the summer so there will be enough natural gas during the winter heating season.

Eventually, the gas reaches the city gate of a local gas utility. The pressure is reduced and an odorant is added so leaking gas can be detected. Local gas companies use smaller pipes to carry gas the last few miles to homes and businesses. A gas meter measures the volume of gas a consumer uses.

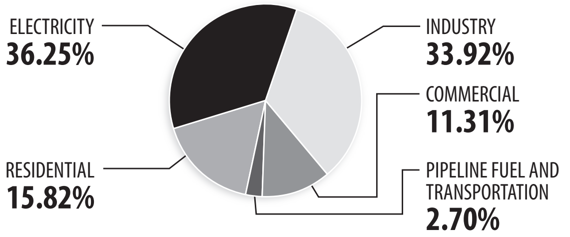
Natural Gas Use

Just about everyone in the United States uses natural gas. Natural gas ranks second in energy consumption, after petroleum. Over one-quarter of the energy we use in the United States comes from natural gas.

Industry uses a little more than one-third of the natural gas consumed in the U.S., mainly as a heat source to manufacture goods. Industry also uses natural gas as an ingredient in fertilizer, photographic film, ink, glue, paint, plastics, laundry detergent, and insect repellents. Synthetic rubber and man-made fibers like nylon also could not be made without the chemicals derived from natural gas.

Homes and businesses—the residential/commercial sector—consume a little more than one quarter of the natural gas in the country. A little less than half of homes use natural gas for heating. Many homes also use gas water heaters, stoves, and clothes dryers. Natural gas is used so often in homes because it is clean burning. Commercial use of natural gas is mostly for indoor space heating of stores, office buildings, schools, churches, and hospitals.

U.S. Natural Gas Consumption by Sector, 2016



Data: Energy Information Administration

Measuring Natural Gas

Gasoline is sold in gallons, coal in pounds, and wood in cords. Natural gas is sold in cubic feet. We can measure the heat contained in all these energy sources by one common unit of measure. The heat stored in a gallon of gasoline, a pound of coal, or a cubic foot of natural gas can all be measured in **British thermal units** or Btu.

One Btu is the amount of heat needed to raise the temperature of one pound of water one degree Fahrenheit. One candy bar (an energy source for the human body) has about 1,000 Btu. One cubic foot of natural gas has about 1,037 Btu. Natural gas is usually sold to pipeline companies in standard measurements of thousands of cubic feet (Mcf). One thousand cubic feet of natural gas would fit into a box that is 10 feet deep, 10 feet long, and 10 feet wide. Most residential customers are billed by the number of therms of natural gas they use each month. A therm is a measure of the thermal energy in the gas and is equal to about 98 cubic feet.

Just over 36 percent of natural gas consumed is used to make electricity. Until 2016, coal was the top fuel used to generate electricity in the U.S. However, in 2016, natural gas became the largest electricity producer. Natural gas power plants are cleaner than coal plants and can be brought on-line very quickly. Natural gas plants produce electricity more efficiently than new coal plants and produce it with fewer **emissions**. Many coal plants in the U.S. have, in fact, been converted to natural gas plants to meet the higher **EPA** air quality standards. Today, natural gas generates 34.03 percent of the electricity in the U.S.

Compressed natural gas is often used as a transportation fuel. Natural gas can be used in any vehicle that has been modified with a special carburetor and fuel tank. Natural gas is cleaner burning than gasoline, costs less, and has a higher octane (power boosting) rating. Today, over 150,000 vehicles run on natural gas in the United States.

Natural Gas Reserves

People in the energy industry use two special terms when they talk about how much natural gas there is—resources and reserves. Natural gas resources include all the deposits of gas that are still in the ground waiting to be tapped. Natural gas **reserves** are only those gas deposits that geologists know, or strongly believe, can be recovered given today's prices and drilling technology.

The United States has large reserves of natural gas. Most reserves are in the Gulf of Mexico and in the following states: Texas, Pennsylvania, Wyoming, Oklahoma, West Virginia, Colorado, Louisiana, New Mexico, Ohio, and Arkansas. If we continue to use natural gas at the same rate as we use it today, the United States has about a ninety year supply.

The U.S. natural gas proved reserves increased by almost 10 percent in 2014 to its highest level ever, 369 trillion cubic feet (Tcf). Starting in the late 1990s, proved reserves increased steadily almost every year due to improvements in shale gas exploration and production technologies. Currently the U.S. natural gas reserves total about 308 trillion cubic feet.

Natural Gas Prices

Since 1985, natural gas prices have been set by the market. The Federal Government sets the price of transportation for gas that crosses state lines. State public utility commissions will continue to regulate natural gas utility companies—just as they regulate electric utilities. These commissions regulate how much utilities may charge and monitor the utilities' policies.

How much does it cost to heat your home with natural gas? Compared to other energy sources, natural gas is an economical choice, though the price varies regionally. It is about two and a half times cheaper than fuel oil and three and a half times cheaper than electricity, both of which are common fuels used to heat U.S. homes.

Natural Gas and the Environment

All the fossil fuels—coal, petroleum, propane, and natural gas—release pollutants into the atmosphere when burned. The good news is that natural gas is the most environmentally friendly fossil fuel.

Burning natural gas produces less sulfur, carbon, and nitrogen than burning other fossil fuels. Natural gas also emits little ash particulate into the air when it is burned.

Like all fossil fuels, however, burning natural gas produces carbon dioxide, a greenhouse gas. The majority of scientists believe that increasing levels of carbon dioxide in the atmosphere, caused in large part by fossil fuel use, could have long-term effects on the global climate.

Future of Natural Gas

Shale Gas

Shale gas is natural gas that is trapped in shale formations. Shale is a common form of sedimentary rock. It is formed by the compaction of silt and clay-size mineral particles. Shale formations are found all over the world. The Energy Information Administration had projected that 53 percent of the U.S. natural gas would come from shale gas by 2040. However, in 2016, shale gas accounted for 52 percent of U.S. natural gas production, and those numbers continue to rise.

SHALE GAS PRODUCTION

Horizontal Drilling: A vertical well is drilled to the formation that has been identified as a natural gas reservoir. Then the drill bit can be turned up to a 90 degree angle so that the well parallels the natural gas reservoir. This allows the maximum amount of natural gas to be recovered.

Hydraulic Fracturing: Hydraulic fracturing, or "fracking," uses water, silica (sand), and chemical compounds piped several thousand feet below the Earth's surface, creating cracks or fissures in shale formations. This allows natural gas to be released and flow into the well. Hydraulic fracturing can be used along with horizontal drilling. Once the shale area is reached, the water, chemicals, and sand are pumped in to unlock the hydrocarbons in the shale.

BENEFITS AND CHALLENGES

There are benefits to natural gas development. When burned, it is cleaner than coal or oil, and releases fewer emissions. Advancements in drilling and fracturing techniques have made the extraction of shale gas possible to meet increasing demand for natural gas.

Development of natural gas from shale plays using hydraulic fracturing presents some challenges, including the need for access to water for use in the process, and the need to protect local drinking water and other natural resources. In some areas, development of shale gas brings drilling operations closer to local residential communities too, making land and homeowner cooperation and collaboration a high priority for companies engaged in development of these resources.

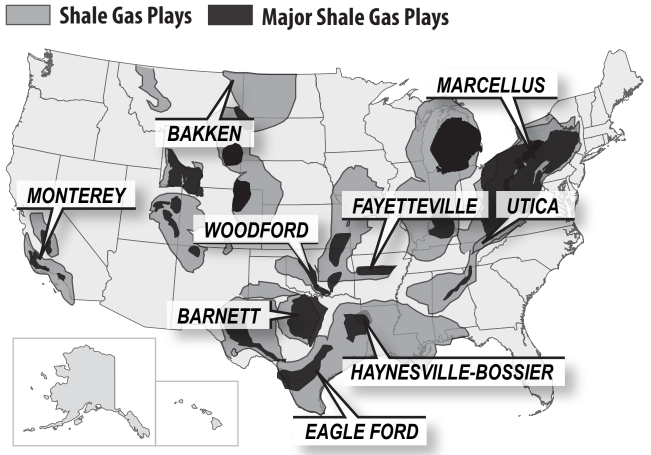
Continued technological innovations promise to make shale gas an important part of the United States' energy future.

Methane Hydrates

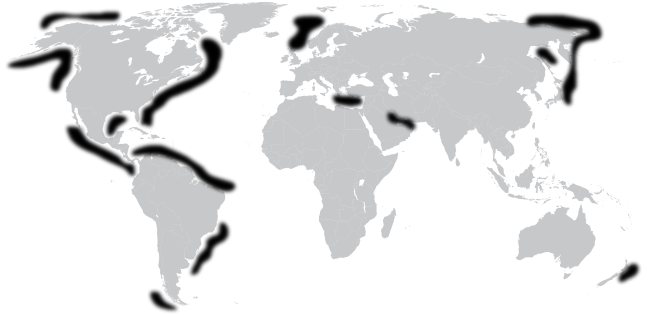
Buried in the sediments of the ocean floor is a reserve of methane so vast it could possibly fuel the entire world. In sediments on the ocean floor, tiny bacteria continuously break down the remains of sea animals and plants, producing methane gas. Under the enormous pressure and cold temperatures at the bottom of the sea, this methane gas dissolves and becomes locked in water molecules to form crystals. These crystals cement together the ocean sediments into solid layers—called **methane hydrates**—that can extend down into the sea floor.

Scientists also suspect that huge deposits of free methane gas are trapped beneath the hydrate layer. Researchers estimate there is more carbon trapped in hydrates than in all the fossil fuels; however, they aren't sure how to capture this methane. When a hydrate breaks down, it loses its solidity and turns to mush, causing major landslides and other disturbances to the ocean floor, as well as an increase in methane escaping into the atmosphere.

Location of Shale Gas Plays



Likely Methane Hydrate Deposits



Biogases

Depending on how the gas is obtained and used, methane from biogases can be classified as a natural gas. Biogases are fuel sources derived from plant and animal waste (see *Biomass*, page 10).

Today, we can drill shallow wells into landfills to recover the methane gas. Landfills are already required to collect methane gas as a safety measure. Typically, landfills collect the gas and burn it to get rid of it; but the gas can be put to work. In 2016, landfill gas generated 11.2 billion kilowatt-hours of electricity.

There are other ways to convert biomass into natural gas. One method converts aquatic plants, such as sea kelp, into methane gas. In the future, huge kelp farms could also produce renewable gas energy.

Liquefied Natural Gas

Another successful development has been the conversion of natural gas into a liquid. As a liquid, natural gas is called LNG, or **liquefied natural gas**. LNG is made by cooling natural gas to a temperature of -260°F. At that temperature, natural gas becomes a liquid and its volume is reduced 600 times. Liquefied natural gas is easier to store than the gaseous form since it takes up much less space. LNG is also easier to transport. People can put LNG in special tanks and transport it on trucks or ships. Today, more than 110 LNG facilities are operating in the United States.

Figure 1. Power infrastructure faces a variety of natural threats that can cause damage and disrupt the power system. Designing and siting power systems to minimize impacts from threats is important. *Photo from iStockphoto, 531920932*

Understanding Power System Threats and Impacts

Background

Understanding potential threats to a power system is an essential first step in supporting power sector resilience. It is important to assess both current and future threats, as well as the likelihood of these threats over time. Threats can be grouped in three categories, as highlighted below.

Natural threats resulting from acts of nature (e.g., severe weather, floods, earthquakes, hurricanes, and solar flares), as well as wildlife interactions with the power system (e.g., squirrels, snakes, or birds causing short circuits on distribution lines).

Technological threats resulting from failures of systems and structures (e.g., defects in materials or water line disruption).

Human-caused threats resulting from accidents (e.g., cutting an underground line) or from intentional actions of an adversary (e.g., cyberattacks or acts of terror).[1]

Identifying Threats

Threats can be identified through stakeholder processes and expert judgement, data sets, literature, and national planning documents and resources. Key experts and stakeholders to engage for threat identification and determination of likelihood of occurrence include:

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[1] https://training.fema.gov/programs/emischool/el361toolkit/glossary.htm

What is a Power System Threat?

Anything that can damage, destroy, or disrupt the power system is considered a threat. Threats can be natural, technological, or caused by human activity. Threats are not typically within the control of the power system planners and operators and can include wildfires, cyclones or typhoons, droughts, longer-term temperature changes, cyberattacks, and many others.

ministries and offices of energy, environment, and natural resources; meteorological agencies; utilities; power systems operators; risk assessment experts; and emergency managers. Examples of resources that could be reviewed to inform threat identification are outlined below:

- Existing threat and risk assessments
- Historical data related to disasters, extreme temperatures, and grid outages. Figure 1 shows an example of historical data being used to understand risks to the energy sector in the United States related to hurricanes.
- National planning documents across sectors with information and data related to threats to water quality, river systems, floodplain management, and geology, such as landslide areas and earthquakes
- Integrated resource plans
- Emergency plans
- Maps and geographic data
- Utility information.

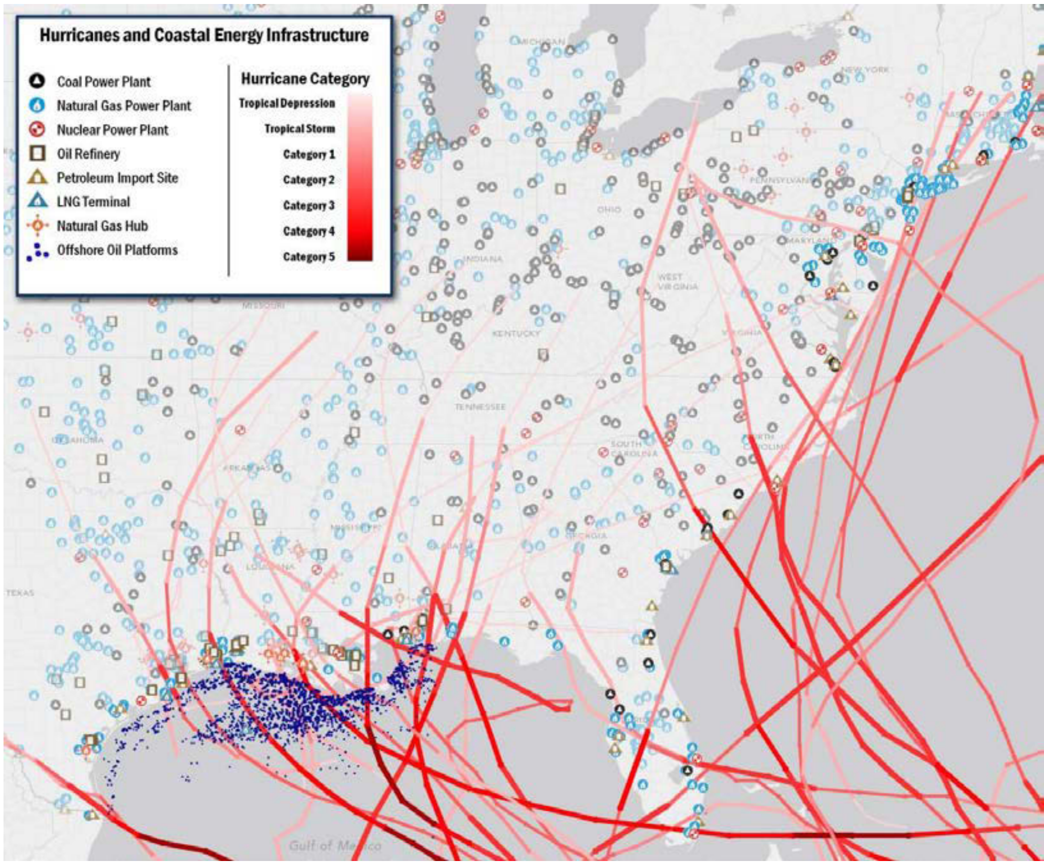

Figure 1. Historical data used to show storm tracks and coastal energy infrastructure in the United States. *https://www.energy.gov/sites/prod/files/2017/01/f34/2016%20DOE%20Climate%20Adaptation%20Plan_0.pdf*

Box 1 presents key questions that stakeholders can consider when working to identify threats to a power system.

Likelihood of Threat Occurrence

The likelihood of threat occurrence is another important step in assessing the vulnerability of power systems. Natural threats can be given a likelihood score based on historical threat data (e.g., disasters) and climate projections. Technological and human threats, which may be more dynamic than natural threats, may be given a score based on a more qualitative stakeholder

Box 1: Key Questions to Support Understanding of Threats to the Power System

1. What natural threats exist for your power sector, and how frequently do they occur?
2. How have power infrastructure systems been impacted by past threats (natural, technological, and human-caused) or system stresses?
3. Has critical power sector infrastructure ever gone offline or experienced reduced operability?
   - What threat caused this?
   - How many hours, days, or weeks was the infrastructure offline or not operational?
4. In the future, which threats and shocks are likely to increase (at the city, national, or multinational scale)?

interview process. Table 1 provides one framework for threat likelihood scoring as presented in the Power Sector Resilience Planning Guidebook.

Connecting Threats to Possible Power System Impacts

Natural, technological, and human-caused threats can have various impacts on electricity infrastructure and systems. Both chronic (e.g., temperature change) and acute events (e.g., storms and cyberattacks) can affect the demand, supply, and delivery of electricity. Impacts are highly localized (in terms of characteristics, severity, and variability), reflecting unique combinations of environmental factors and stressors in a specific location. Table 2 presents types of threats over the near- and long-term and potential impacts on generation, transmission, distribution, and demand.

Table 1. Scoring Framework for Threat Likelihood

Threat Likelihood Scores		Threshold Descriptions
Categorical	**Numerical**	
High	9	Accidents
Medium-High	7	More likely to occur than not.
Medium	5	May occur.
Low-Medium	3	Slightly elevated level of occurrence. Possible, but more likely not to occur.
Low	1	Very low probability of occurrence. An event has the potential to occur but is still very rare.

This fact sheet describes how natural, technological, and human-caused threats might impact the power sector across generation, transmission and distribution, and demand. In addition to direct system and infrastructure impacts, loss of power can affect other sectors (e.g., healthcare, education, and wastewater), as well as society and economic activity more broadly. While these impacts are not described in detail in this fact sheet, they are crucial in considering prioritization of resilience actions.

Power sector threats (including likelihood) and impacts assessed at the local or national level are essential inputs for performing a power-sector vulnerability

Natural, technological, and human-caused threats can have various impacts on electricity infrastructure and systems. A resilience action plan provides key power sector resilience actions designed to address power sector threats identified in a vulnerability assessment. *Photo from iStockphoto, 903206232*

Table 2. Threats and Potential Impacts on the Power Sector

Threats	Technologies/Sectors	Potential Impacts
Temperature Change	**Generation**	
	Biopower	Crop damage and increased irrigation demand
	Hydropower	Reduced generation capacity and operational changes
	Solar PV	Reduced generation capacity (e.g., higher heat can impact panel efficiency)
	Thermal technologies (coal, geothermal, natural gas, nuclear, concentrated solar power)	Reduced generation efficiency and capacity
	Transmission and distribution	Reduced transmission efficiency and capacity
	Demand	Increased demand for cooling
Water Availability and Temperature	**Generation**	
	Biopower	Decreased crop production
	Hydropower	Reduced generation capacity and operational changes
	Thermal technologies	Reduced generation capacity
Wind Speed Changes	**Generation**	
	Wind	Variations in generation capacity, making investments harder to pay back or generation harder to predict long-term
Sea Level Rise	**Generation**	
	Bioenergy	Physical damage to infrastructure and power disruption/loss—all generation technologies
	Hydropower	
	Solar PV	
	Thermal technologies	
	Wind	
Extreme Events (e.g., storms, short-term extreme heat events, floods, fires, and other natural disasters)	**Generation**	
	Bioenergy	Physical damage to infrastructure and fuel sources, and power disruption/loss—all generation technologies
	Hydropower	
	Solar PV	
	Thermal technologies	
	Wind	
	Transmission and distribution	Reduced transmission efficiency and capacity Reduced transmission efficiency and capacity
	Demand	Unpredictable changes to peak electricity demand
Technological	**Generation**	
	Bioenergy	Physical damage and power disruption/loss—all generation technologies
	Hydropower	
	Solar PV	
	Thermal technologies	
	Wind	
	Transmission and distribution	Physical damage and reduced transmission capacity
	Demand	Unpredictable demand
Human-caused (e.g., cyberattacks, accidents, and physical attacks/ malicious events)	**Generation**	
	Bioenergy	Physical damage and power disruption/loss—all generation technologies
	Hydropower	
	Solar PV	
	Thermal technologies	
	Wind	
	Transmission and distribution	Physical damage and reduced transmission capacity
	Demand	Unpredictable demand

Sources: Cox et al. (2017), WBCSD (2014).

Box 2: Identifying Threats to the Power Sector in the Lao PDR, and Planning for Resilience

USAID and NREL partnered with the government of the Lao PDR to perform a vulnerability assessment of the power sector and develop a resilience action plan. Key threats related to potential hydrological changes (and a large dependence on hydropower), wildfires, landslides, and flooding, among others. After undertaking a full vulnerability assessment process, key power sector resilience actions were identified to address these threats and related impacts. Selected actions are highlighted below. As can be seen, actions can relate to operational changes and planning, data collection, analysis, partnership across borders, and technology implementation, as well as other areas.

- Develop standard operating procedures and continuity-of-operation plans for extreme events—including staffing plans, prioritized repowering of networks, and agreements with neighboring countries;
- Develop climate projections and geospatial data for hydropower and other generation planning, and make these maps available publicly;
- Reduce dependence on hydropower through diversification of energy mix;
- Introduce flexibility solutions into power system operation;
- Establish protocol for data collection at all hydropower dams, including data types, collection frequency, and data format for sharing; and
- Develop incentive and enforcement structures to ensure that users and areas that are upstream from hydropower dams protect watersheds located upstream.

Source: Power Sector Resilience Action Plan for Lao PDR (forthcoming)

assessment. Box 2 describes a power-sector vulnerability assessment undertaken in the Lao People's Democratic Republic (PDR), supported by the U.S. Agency for International Development (USAID) and the National Renewable Energy Laboratory (NREL), that fed into a climate resilience action plan. For a full view of how threats and impacts are integrated with broader vulnerability assessment processes and power-sector resilience action plans, see: https://resilient-energy.org/guidebook, and learn more about power sector resilience at www.resilient-energy.org.

Resilient Energy Platform

The Resilient Energy Platform helps countries address power system vulnerabilities by providing strategic resources and direct country support, enabling planning and deployment of resilient energy solutions. This includes expertly curated reference materials, training materials, data, tools, and direct technical assistance in planning resilient, sustainable, and secure power systems. Ultimately, these resources enable decision makers to assess power sector vulnerabilities, identify resilience solutions, and make informed decisions to enhance energy sector resilience at all scales (including local, regional, and national). To learn more about the technical solutions highlighted in this fact sheet, visit the Resilient Energy Platform at https://resilient-energy.org/.

Resources

ADB (Asian Development Bank). *Climate Risk and Adaptation in the Electric Power Sector*. Manila, Philippines: Asian Development Bank. July 2012. https://www.adb.org/publications/climate-risk-and-adaptation-electric-power-sector.

Brown, Ray, Guillaume Prudent-Richard, and Katrina O'Mara. *Enhancing Power Sector Resilience: Emerging Practices to Manage Weather and Geological Risks.* World Bank IBRD & IDA. June 2016. https://openknowledge.worldbank.org/handle/10986/26382.

Cox, Sadie, Eliza Hotchkiss, Dan Bilello, Andrea Watson, Alison Holm, and Jennifer Leisch. *Bridging Climate Change Resilience and Mitigation in the Electricity Sector Through Renewable Energy and Energy Efficiency Emerging Climate Change and Development Topics for Energy Sector Transformation*. Golden, CO: NREL. NREL/TP-6A20-67040. November 2017. https://www.nrel.gov/docs/fy18osti/67040.pdf.

Cronin, Jennifer, Gabriel Anandarajah, and Olivier Dessens. "Climate change impacts on the energy system: a review of trends and gaps." *Climatic*

Change 151, no. 2 (November 2018): 79-93. https://link.springer.com/article/10.1007/s10584-018-2265-4.

DOE (U.S. Department of Energy). "U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather." Washington, D.C.: DOE. Last modified 2013. https://www.energy.gov/downloads/us-energy-sector-vulnerabilities-climate-change-and-extreme-weather.

Ebinger, Jane, and Walter Vergara. *Climate impacts on energy systems: key issues for energy sector adaptation*. Washington, D.C.: The World Bank. January 2011. http://documents.worldbank.org/curated/en/580481468331850839/Climate-impacts-on-energy-systems-key-issues-for-energy-sector-adaptation.

Hotchkiss, Eliza, Alex Dane, and Connie Komomua. "Resilience Roadmap." NREL. Last modified 2018. https://www.nrel.gov/resilience-planning-roadmap/.

Mission Support Center. *Cyber Threat and Vulnerability Analysis of the US Electric Sector*. Idaho National Laboratory: Mission Support Center. August 2016. https://www.energy.gov/sites/prod/files/2017/01/f34/Cyber%20Threat%20and%20Vulnerability%20Analysis%20of%20the%20U.S.%20Electric%20Sector.pdf.

Stout, Sherry, Nathan Lee, Sadie Cox, James Elsworth, and Jennifer Leisch. *Power Sector Resilience Planning Guidebook*. Golden, CO: NREL. NREL/TP-7A40-73489. June 2019. https://resilient-energy.org/guidebook.

UNDP (United Nations Development Programme). *Mapping Climate Change Vulnerability and Impact Scenarios: A Guidebook for Sub-National Planners*. November 2010. https://www.adaptationcommunity.net/?wpfb_dl=58.

USAID. 2016. Climate Vulnerability Assessment. https://www.climatelinks.org/resources/climate-vulnerability-assessment-annex-usaid-climate-resilient-development-framework.

WBCSD (World Business Council for Sustainable Development). "Building a Resilient Power Sector." Geneva: WBCSD. March 2014. https://www.wbcsd.org/Programs/Climate-and-Energy/Climate/Resources/Building-a-Resilient-Power-Sector.

Wilson, Rachel, and Bruce Biewald. *Best Practices in Electric Utility Integrated Resource Planning*. Synapse Energy Economics, Inc. June 2013. https://www.raponline.org/wp-content/uploads/2016/05/rapsynapse-wilson-biewald-bestpracticesinirp-2013-jun-21.pdf.

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The Resilient Energy Platform provides expertly curated resources, training, tools, and technical assistance to enhance power sector resilience. The Resilient Energy Platform is supported by the U.S. Agency for International Development.

The USAID-NREL Partnership addresses critical challenges to scaling up advanced energy systems through global tools and technical assistance, including the Renewable Energy Data Explorer, Greening the Grid, the International Jobs and Economic Development Impacts tool, and the Resilient Energy Platform. More information can be found at: **www.nrel.gov/usaid-partnership**.