Current Issue Study Guide

Topic: Renewable Energy For A Sustainable Future

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?

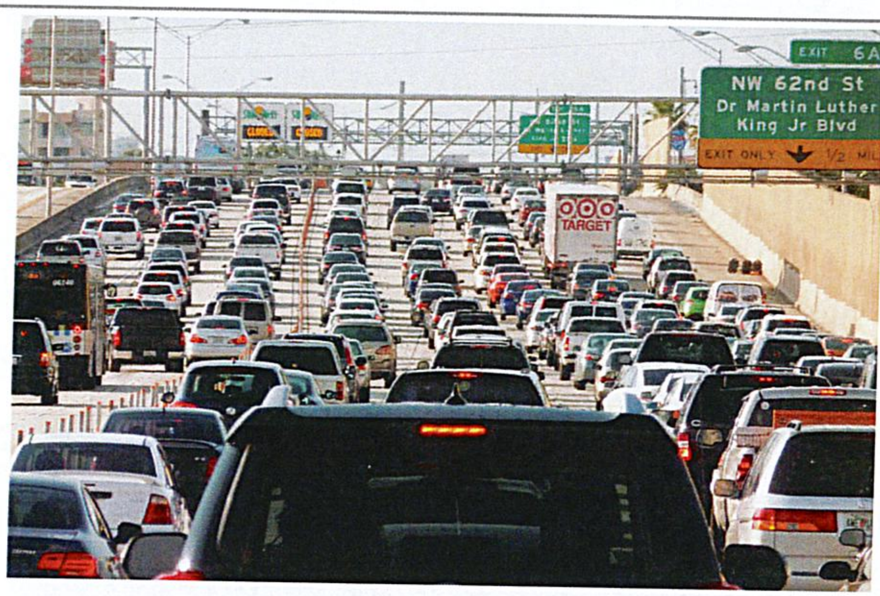
Energy is an interdisciplinary topic, and the concepts used to understand energy in the Earth system are fundamental to all disciplines of science. One cannot study physics or understand biomes, photosynthesis, fire, evolution, seismology, chemical reactions, or genetics without considering energy. Everything 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).

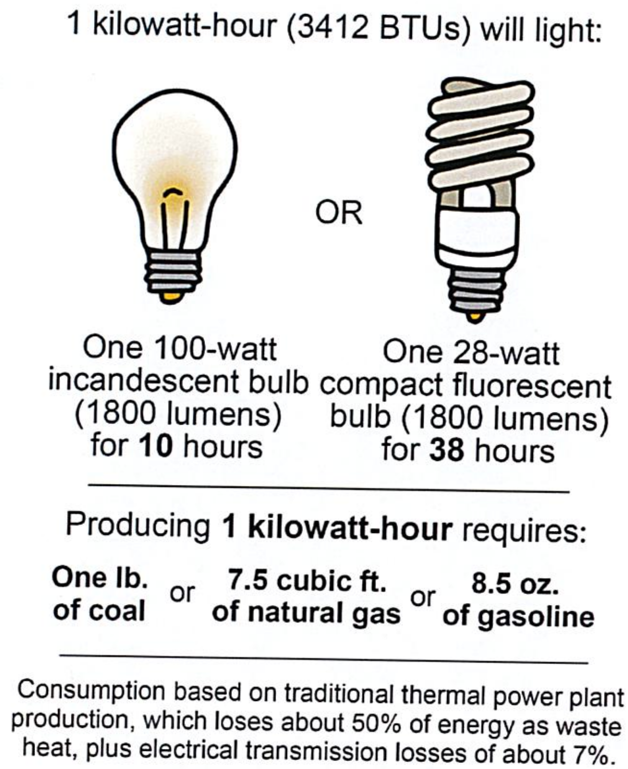
What do different units of energy mean?

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.

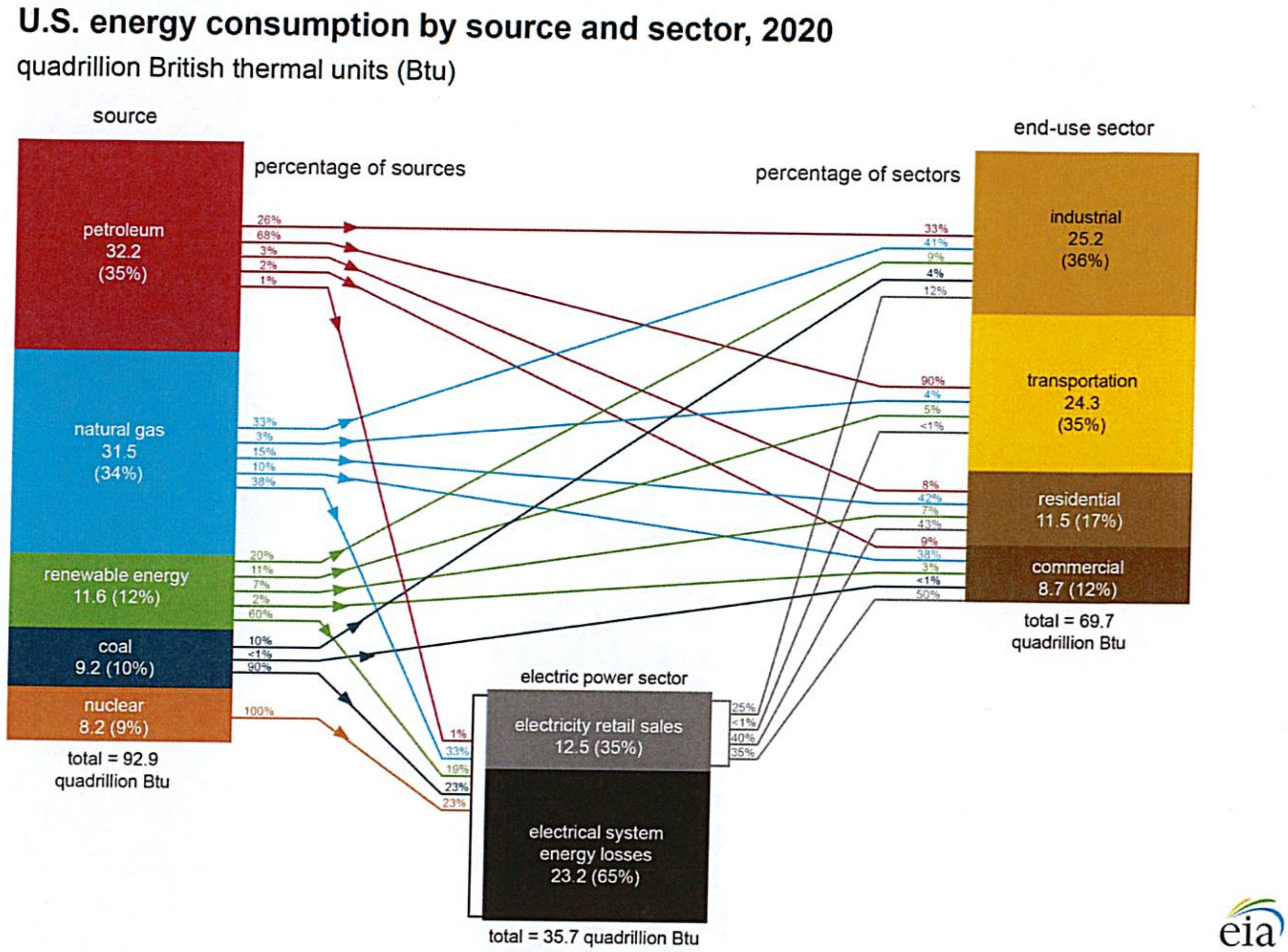


Examples of uses and sources of 1 kWh. 1kWh will light a 100-watt incandescent lighbulb for 10 hours and one 28-watt compact fluorescent bulb for 38 hours. Producing 1kWh requires one pound of coal or 7.5 cubic feet of natural gas or 8.5 ounces of gasoline. About 50% of energy used is lost as waste and 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.

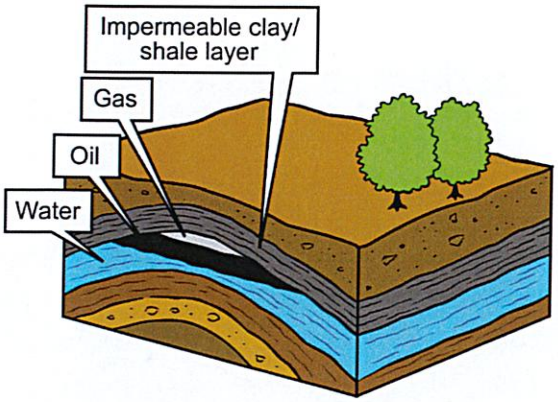


Diagram of an oil and gas reservoir. In this image, natural gas and fluids (water and oil) have accumulated in a layer of permeable reservoir rock, where they are separated by density (gas is lightest, water densest). An impermeable clay or shale layer that has been folded serves as a barrier to further 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.

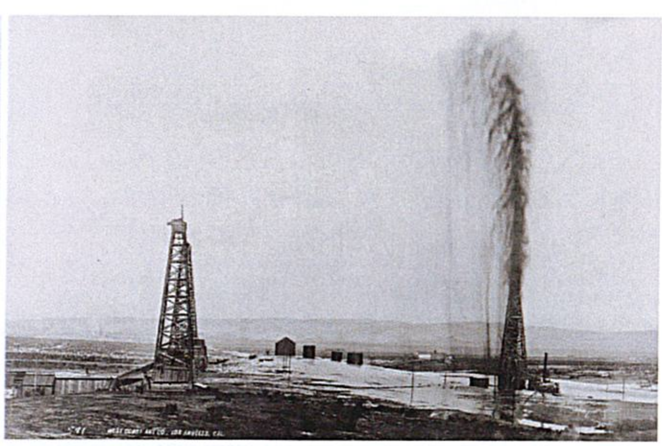
Natural asphalt seeps (tar pits) in California. ***Left:*** *Bubbles in a tar pit in La Brea, Los Angeles, California. Photo by Daniel Schwen (Wikimedia Commons, Creative Commons Attribution license 2.5 Generic license, image cropped).* ***Right:*** *Asphalt seep in Carpinteria, Califronia. Photo by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

Oil drilling

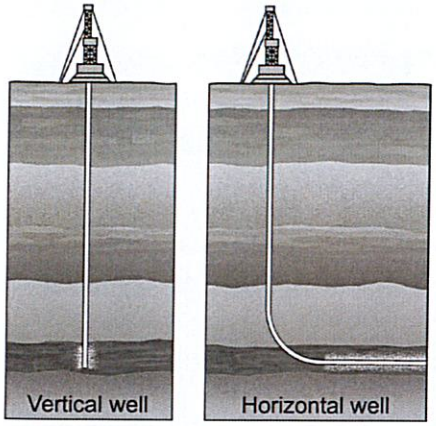
Conventional wells

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).

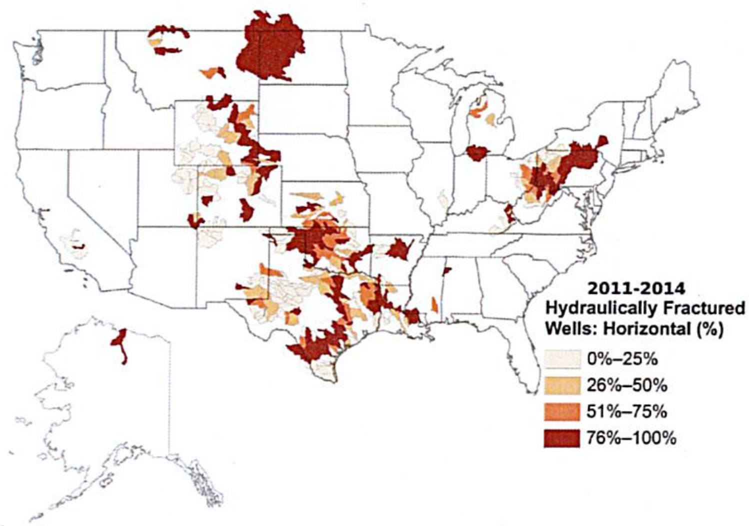
Hydraulic fracturing ("fracking")

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.

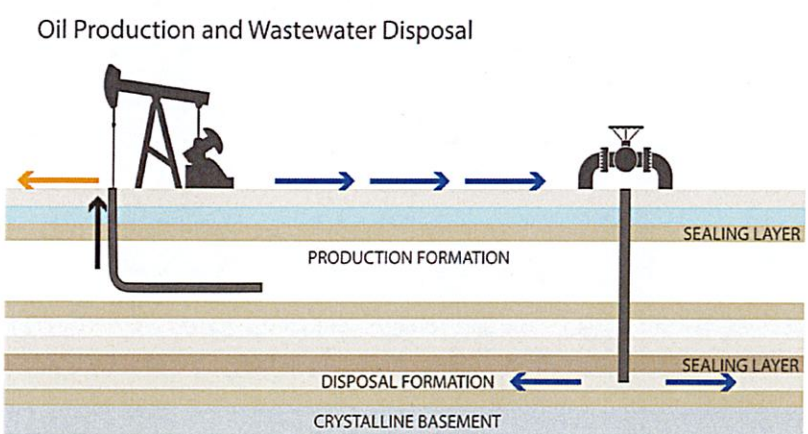
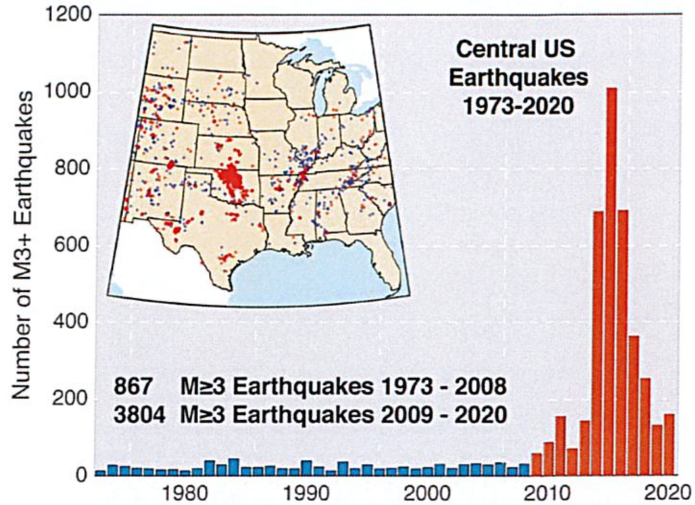


Diagram showing pumping of oil (left) and injection of wastewater into a well (right). Note that wastewater is injected deep underground beneath a sealing layer of impermeable rock. [Source: USGS (public domain)](#).

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).

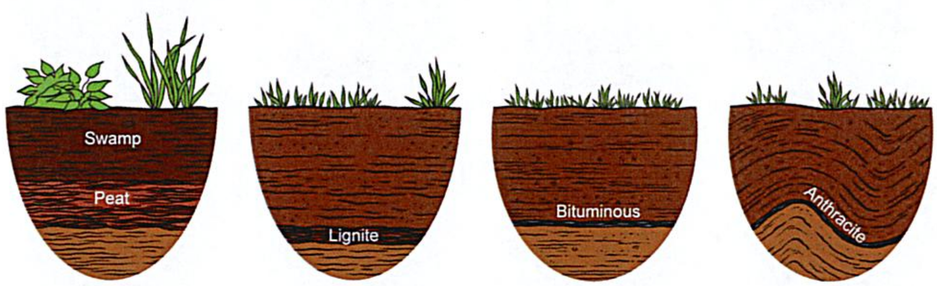


Coal

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.

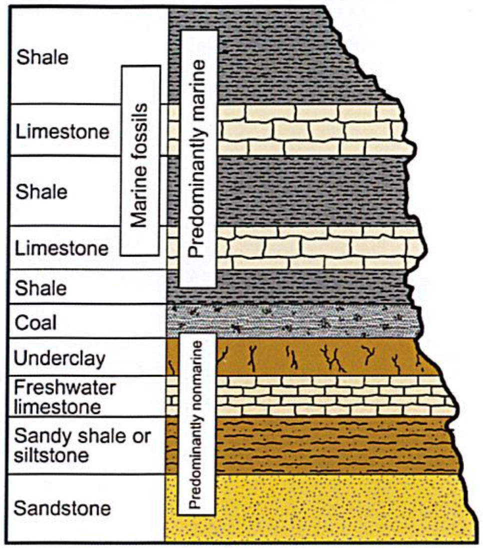
Over time, the coal may become more carbon rich as water and other components are squeezed out. Peat may become lignite, bituminous, and eventually anthracite coal. By the time a peat bed has been turned into a layer of anthracite, they layer is one-tenth of its original thickness and is up to 95% carbon.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



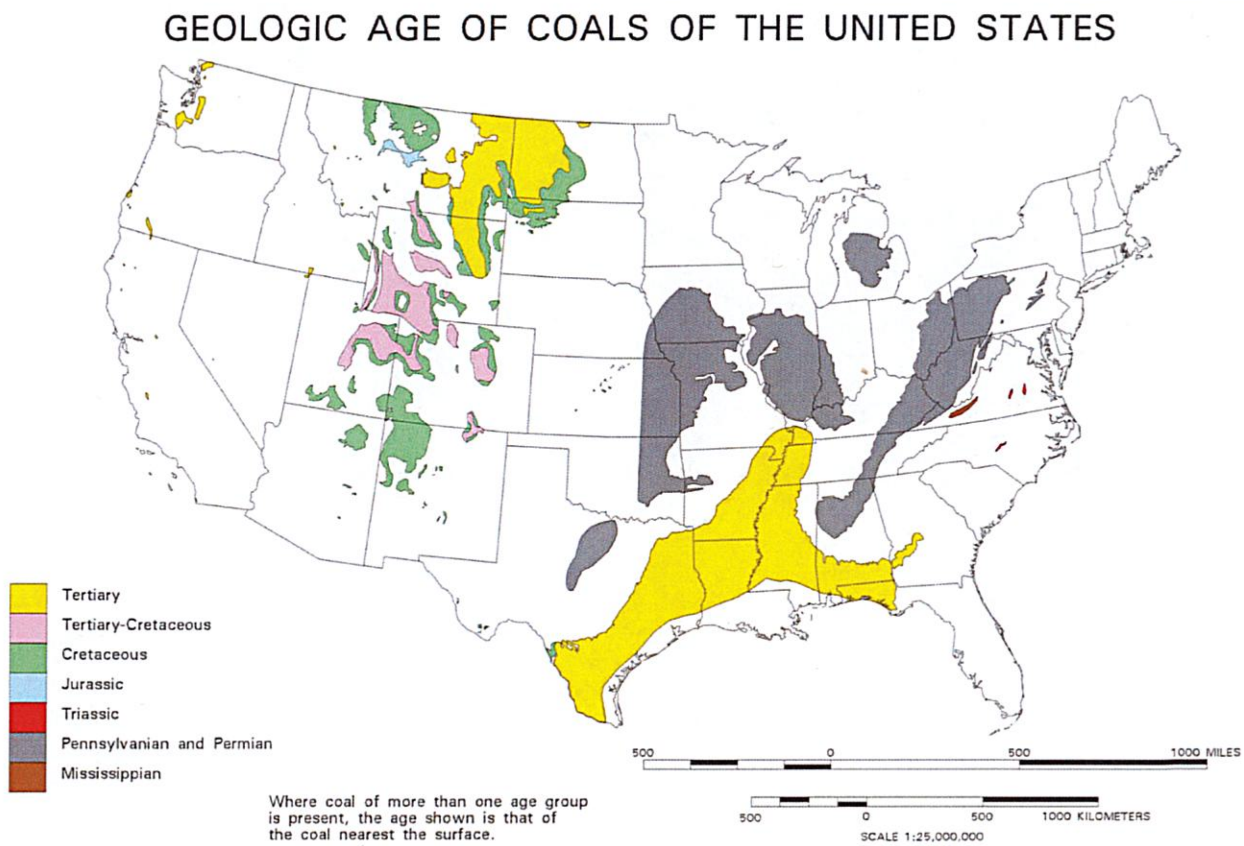
Stages in the formation of coal, from left to right: Peat is buried beneath a swamp. Through compaction and loss of water, it forms lignite. Through further compression, the coal transforms into bituminous coal and finally anthracite coal. Image modified from original by Jim Houghton, published in The 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.

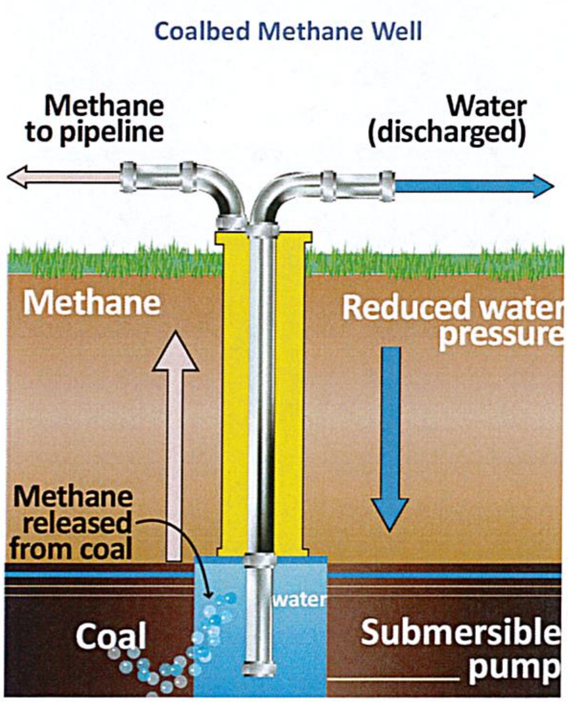
Thick coal deposits are not found in coastal deposits and deltas that formed during earlier times even though geologic and climatic conditions were similar. This is because the plants that made up the coastal swamp forests that produced enough biomass to form large peat deposits had not yet evolved. 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.

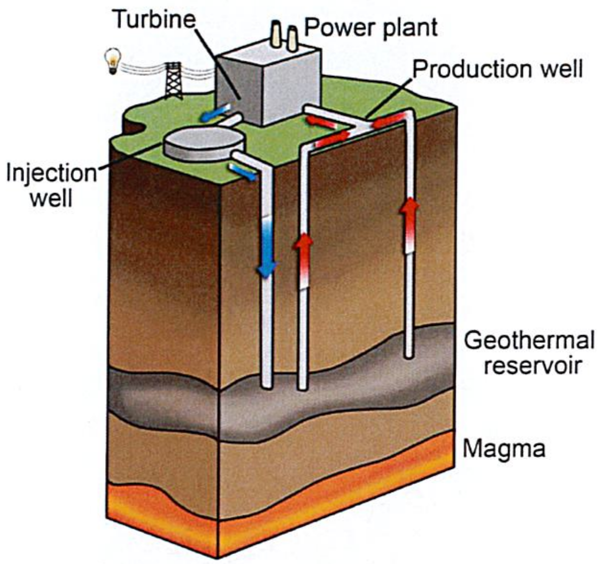


Diagram of a geothermal plant. Image modified from original by Wade Greenberg-Brand, published in The Teacher-Friendly Guide to the Geology of the Northwest Central US, edited by Mark D. Lucas, Robert M. Ross, and Andrielle N. Swaby (published by the Paleontological Research Institution, 2015) (CC BY-NC-SA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

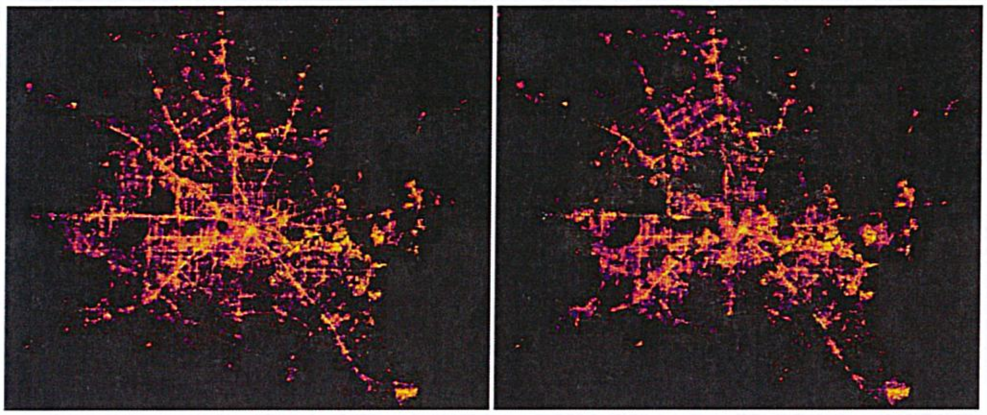
Economically useful wind energy depends on steady high winds. Variation in wind speed is in large part influenced by the shape and elevation of the land surface. For example, higher elevations tend to have higher wind speeds, and flat areas can allow winds to pick up speed without interruption; thus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

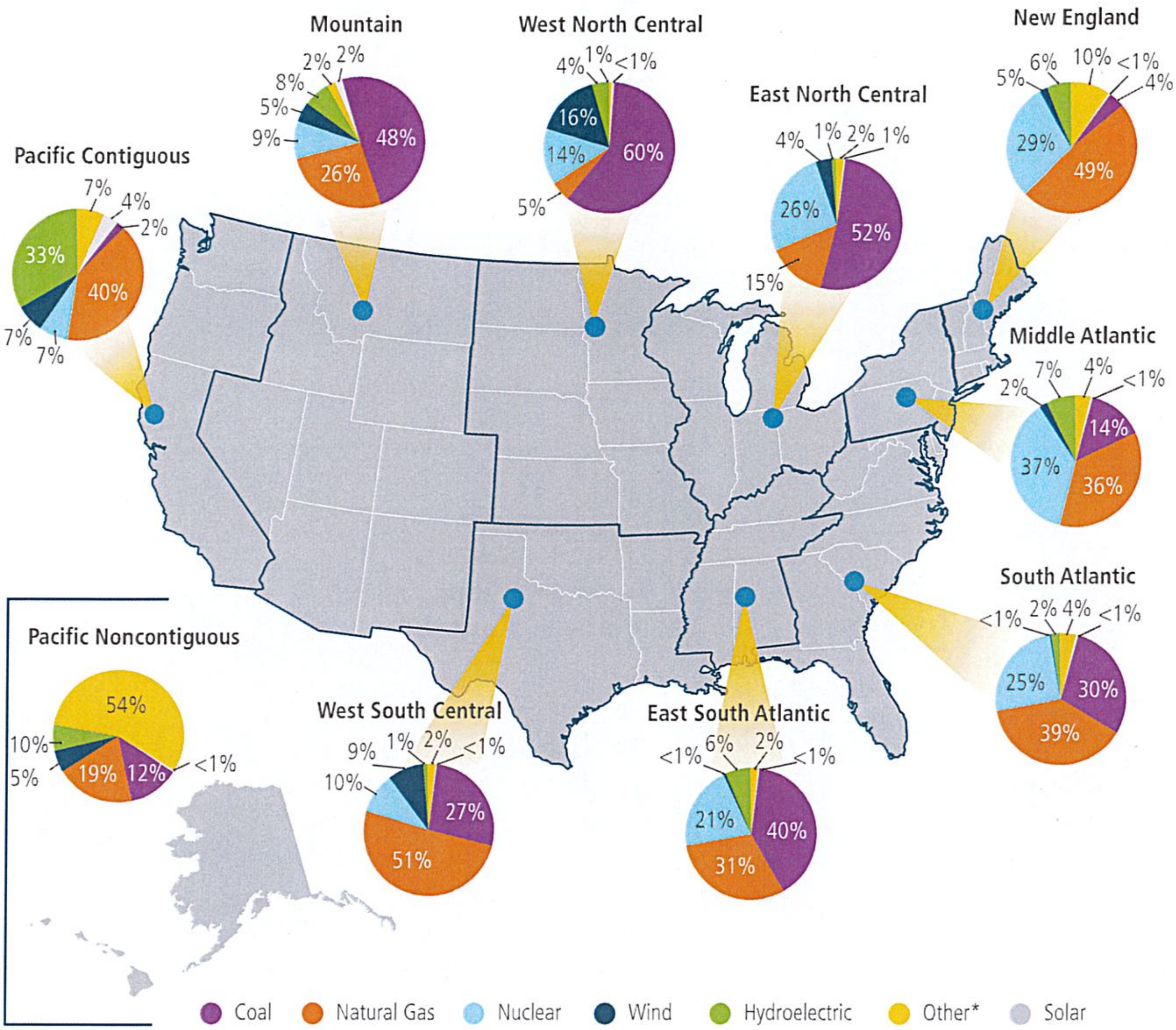
When severe winter storms hit Texas in early 2021, the state's power grid was overwhelmed by high energy demand combined with a lack of engineering for winter conditions and isolation from the power grid in the rest of the US. Power to many buildings was purposely shut off to keep the grid from failing.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

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

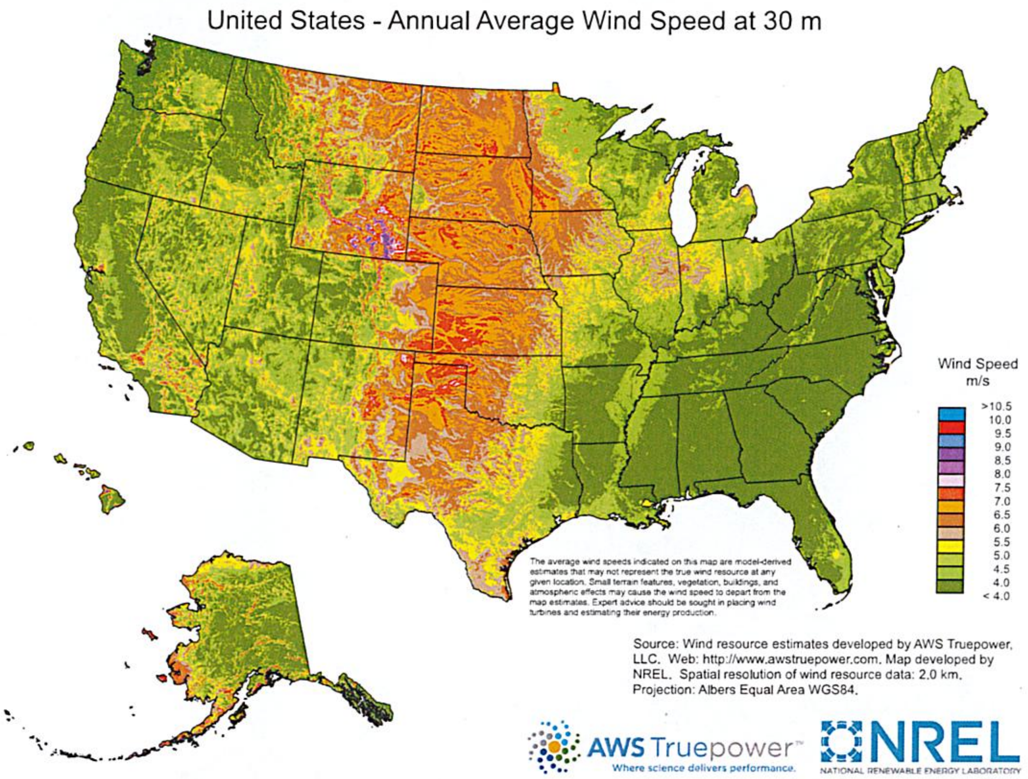


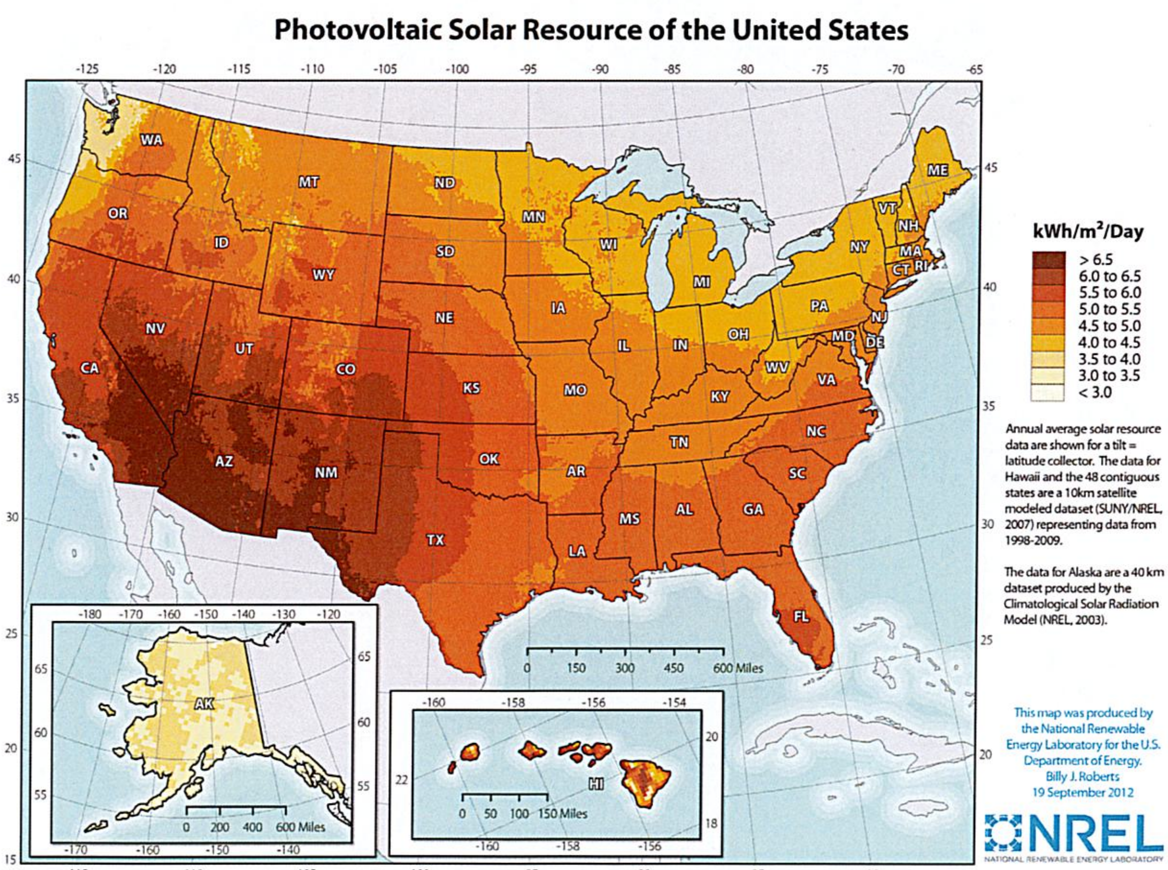
*Includes the following Energy Information Administration fuel type designations: Distillate Petroleum, Geothermal, Biogenic Municipal Solid Waste and Landfill Gas, Other Gases, Other Renewables, Other (including nonbiogenic municipal solid waste), Petroleum Coke, Residual Petroleum, Waste Coal, Waste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





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.

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.

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.

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:	Major Uses:
•nonrenewable	•transportation, industry
U.S. Energy Consumption:	**U.S. Energy Production:**
•35.071 Q	•23.239 Q
•36.06%	•23.77%

Data: Energy Information Administration

History of Oil

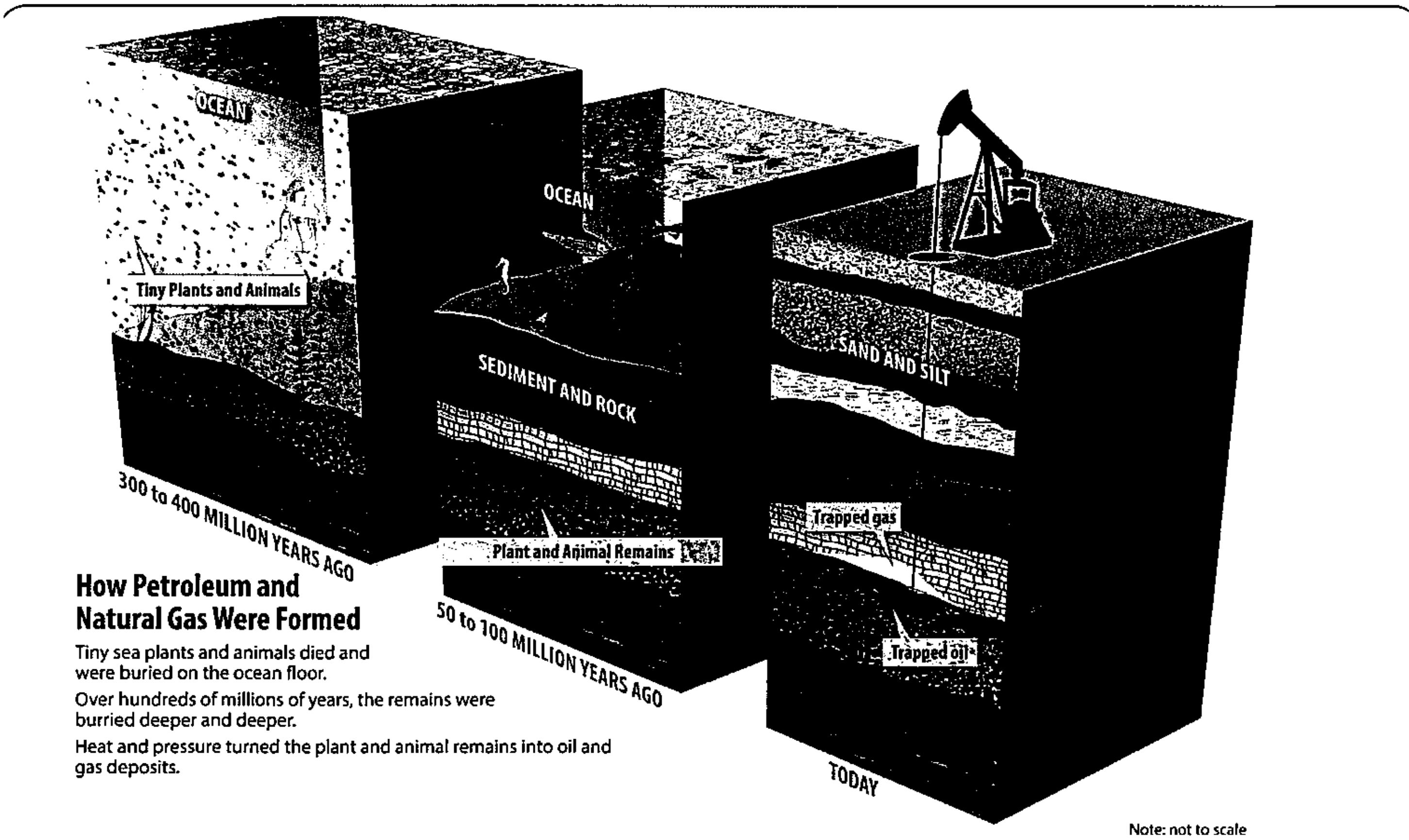
People have used naturally available **crude oil** for thousands of years. The ancient Chinese and Egyptians, for example, burned oil to produce light.

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.

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.

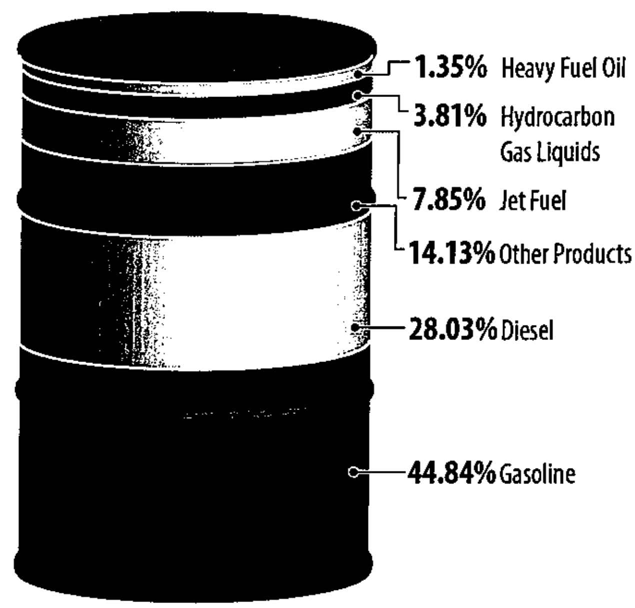
Refineries use many different methods to make these products. One method is a heating process called **distillation**. Since oil products have different boiling points, molecule sizes, and densities, the end products can be distilled, or separated. For example, asphalts have a higher boiling point than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

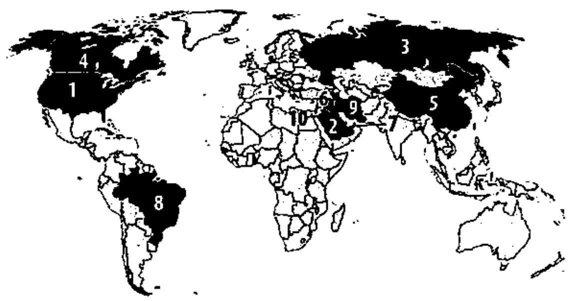
Demand for Oil

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.

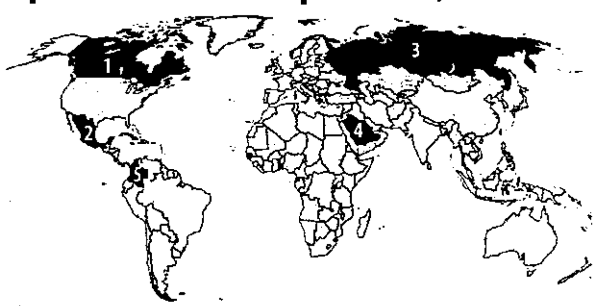
Top Oil-Producing Countries, 2021



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.

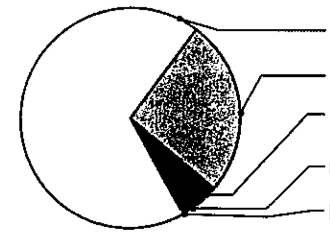
In 2010, the Macondo (Deepwater Horizon) well accident released oil into the Gulf of Mexico for several months. The companies involved in developing Macondo, the Coast Guard, and the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) quickly began work to determine the cause of the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

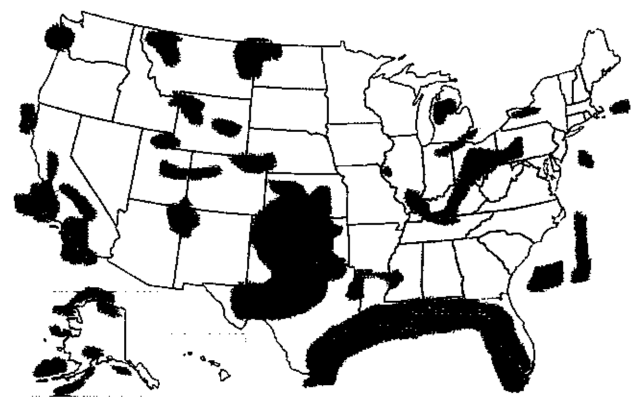
In early 2020, the coronavirus pandemic set up the perfect storm for plummeting oil prices. By mid-April, a combination of decreased demand from the pandemic and excess oil from unadjusted production led to a glut on the market. Producers were running out of places to store oil. The price of one barrel 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: •nonrenewable	**Major Uses:** •electricity, industry
U.S. Energy Consumption: •10.547 Q •10.85%	**U.S. Energy Production:** •11.621 Q •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.

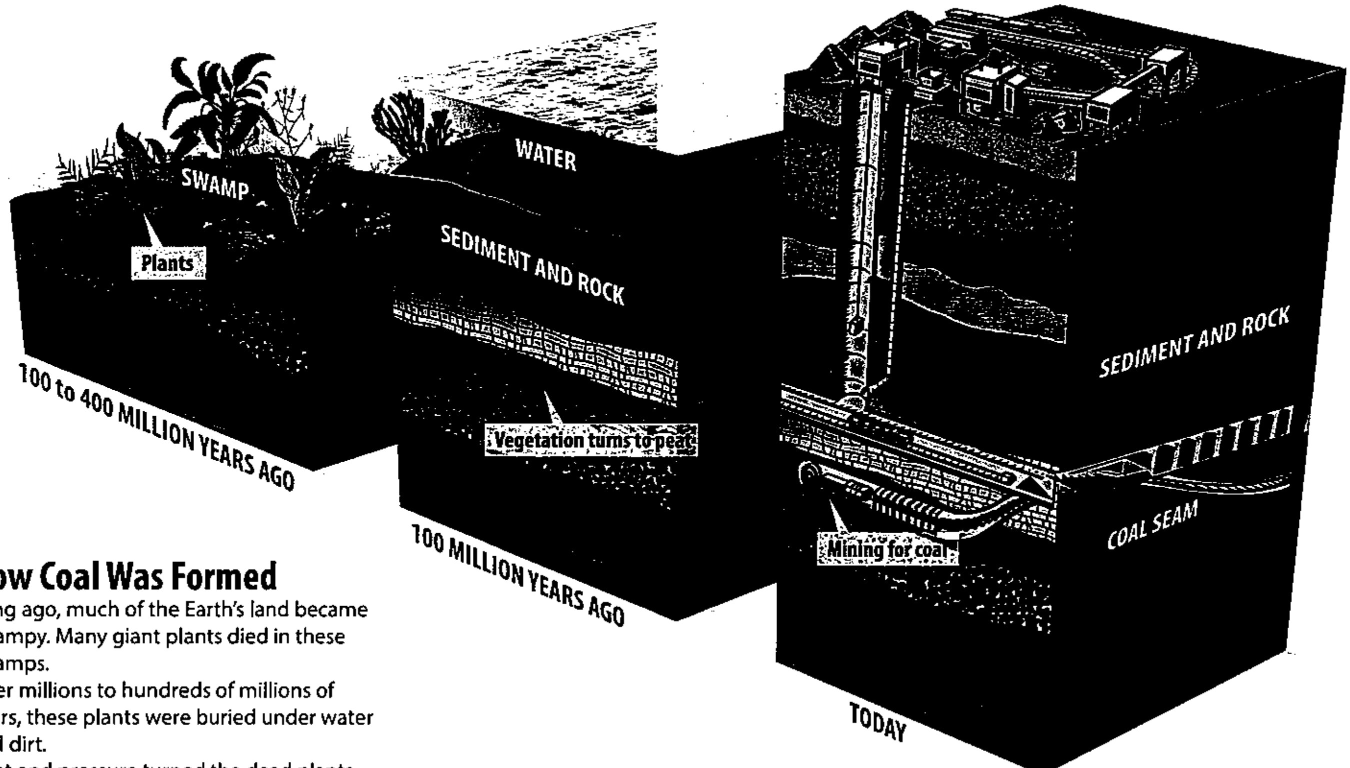
Seams of coal—ranging in thickness from a fraction of an inch to hundreds of feet—may represent hundreds or thousands of years of plant growth. One seam, the seven-foot thick Pittsburgh seam, may represent 2,000 years of rapid plant growth. One acre of this seam contains about 14,000 tons of coal.

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

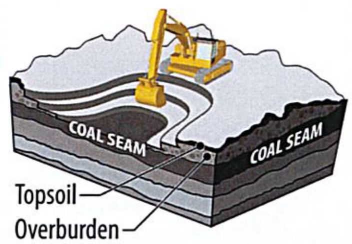
After coal comes out of the ground, it typically goes on a conveyor belt to a preparation plant that is located at the mining site. The plant cleans and processes coal to remove dirt, rock, ash, sulfur, and other impurities, increasing the heating value of the coal.

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.

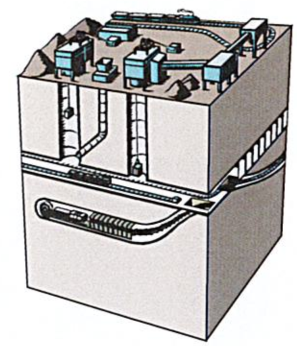
Underground pipelines can easily move petroleum and natural gas to market. But that's not so for coal. Huge trains transport more than two-thirds of U.S. coal for some or all of its journey to market.

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

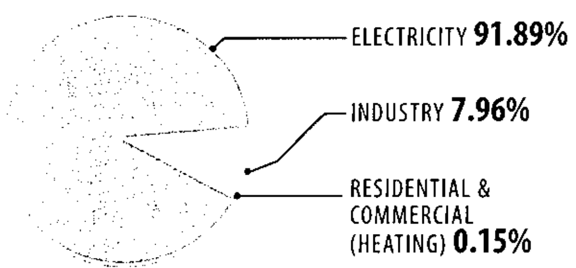
When scientists estimate how much coal, petroleum, natural gas, or other energy sources there are in the United States, they use the term **reserves.** Reserves are deposits that can be harvested using today's methods and technology.

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.

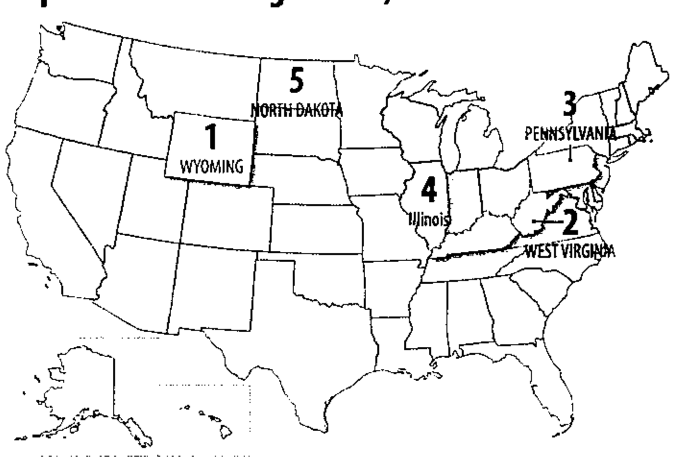
The Federal Government is by far the largest owner of the nation's coalbeds. The Bureau of Land Management leases over 570 million acres of coal bed mineral estates to landowners. Most of these leases are found in Western states.

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

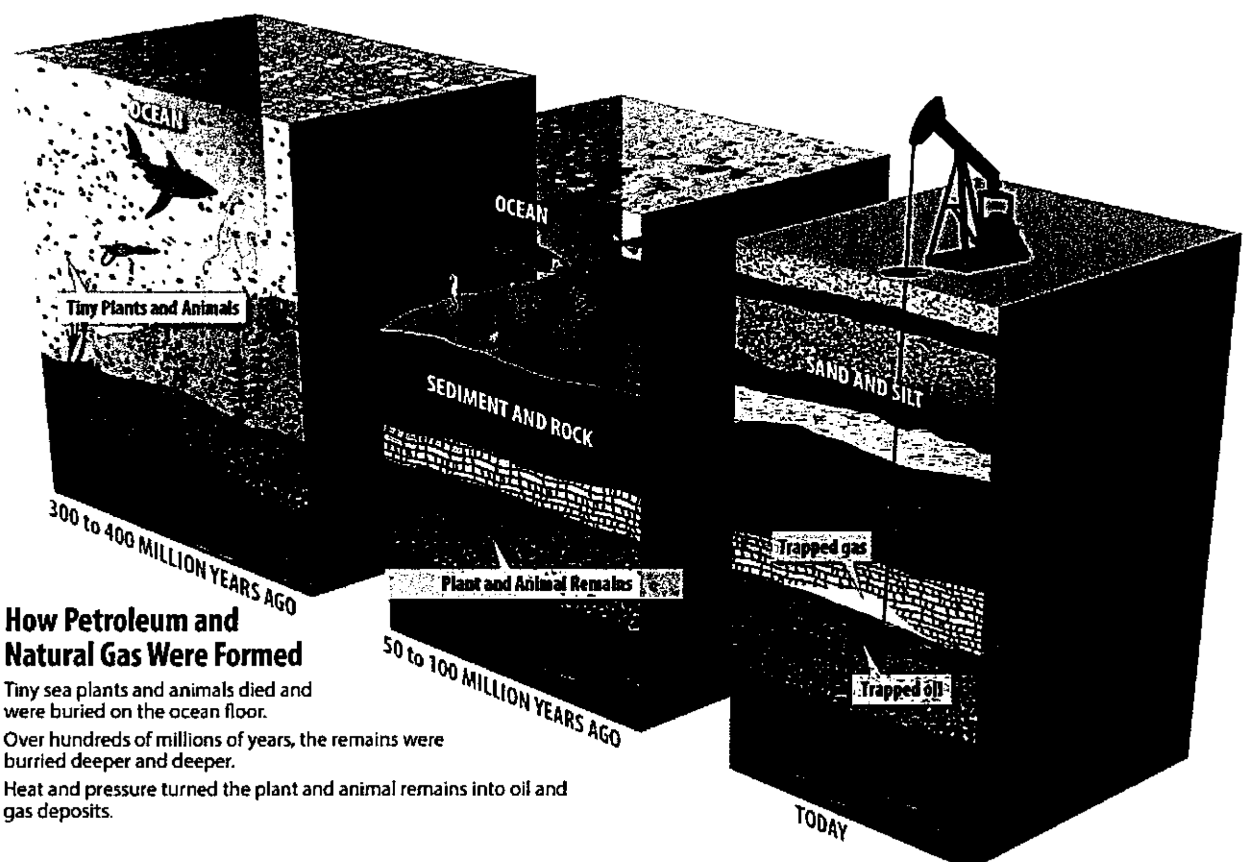
The ancient peoples of Greece, Persia, and India discovered natural gas many centuries ago. The people were mystified by the burning springs created when natural gas seeping from cracks in the ground was ignited by lightning. They sometimes built temples around these eternal flames so they could worship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

Note: not to scale

Natural Gas

Natural Gas at a Glance, 2016

Classification:
- nonrenewable

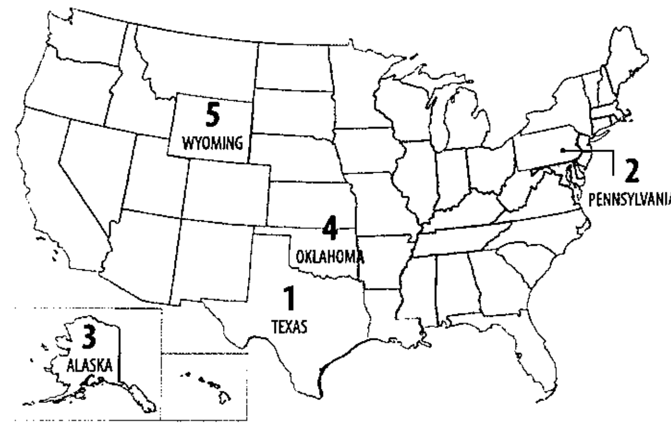
Major Uses:
- heating, industry, electricity

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

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

Data: Energy Information Administration

Top Natural Gas Producing States, 2016



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.

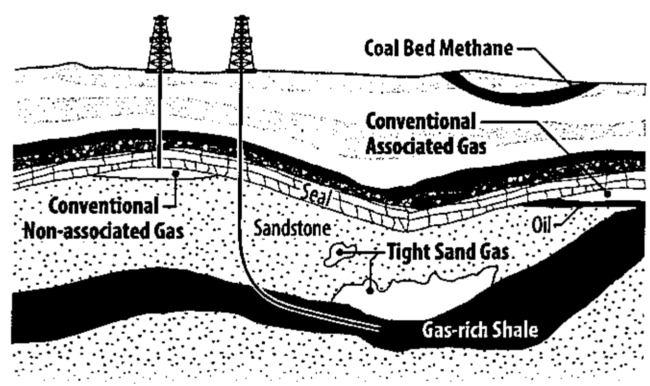
After natural gas comes out of the ground, it goes to a processing plant where it is cleaned of impurities and separated into its various components. Approximately 90 percent of natural gas is composed of methane, but it also contains other gases such as propane and butane.

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.

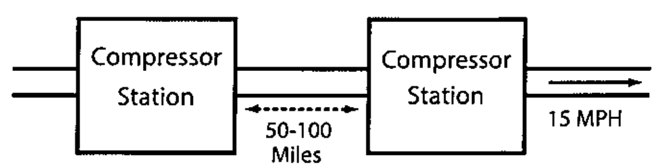
Another source of natural gas is the methane produced in landfills. Landfill gas is considered a renewable source of methane since it comes from decaying garbage. This **biogas** recovered from landfills is usually burned on the landfill site to generate electricity for the facility itself.

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.

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.

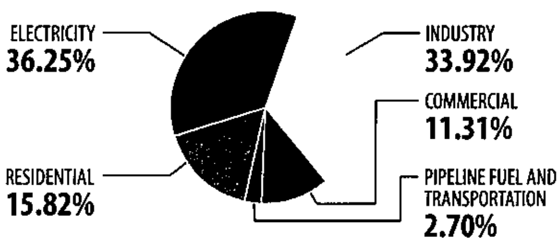
Natural Gas Use

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.

Natural Gas

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.

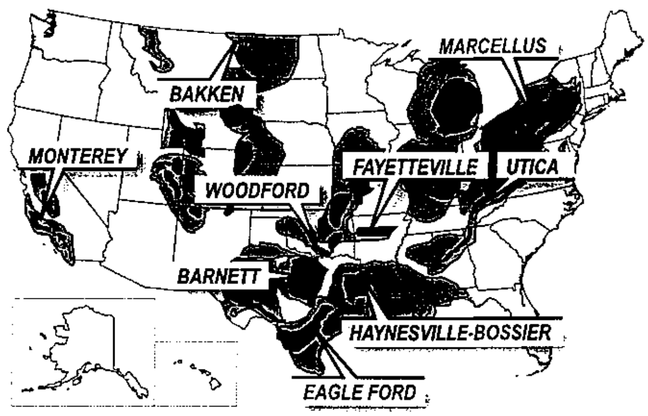
▪ Methane Hydrates

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

Shale Gas Plays ■ Major 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.

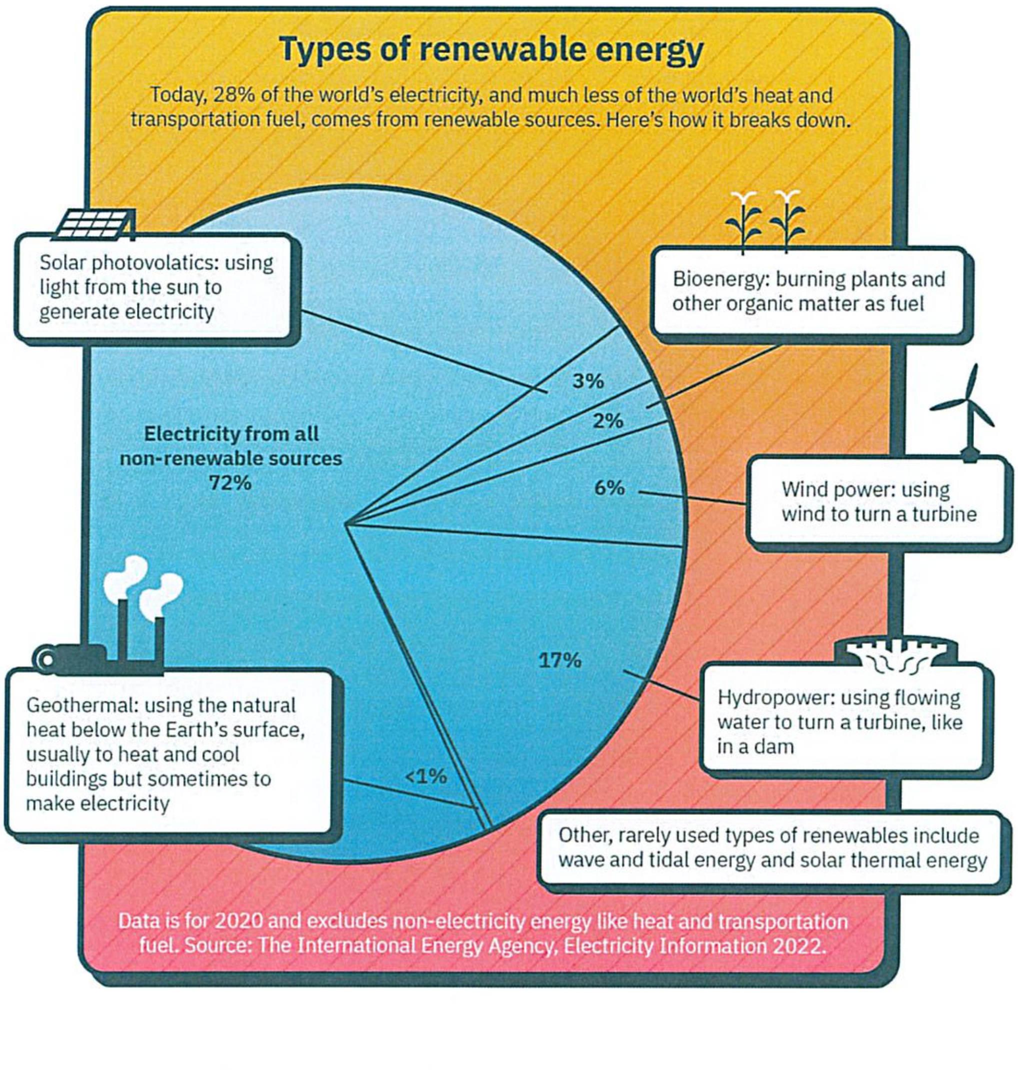
▪ Liquefied Natural Gas

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.

best places to generate renewable energy are often far away from the areas that use that electricity. For these reasons, adding much more renewable energy to our electric grid will require other changes, including more energy storage, backup generation, strategies to match electricity use with times of high power generation, and infrastructure for long-distance power transmission.

A Growing Source of Energy

Renewable energy also needs to compete with well-established and cheap fossil fuels. Renewable energy has grown quickly over the last decade, driven by policy support (tax incentives, R&D funding and mandates requiring the use of renewables) and falling costs (especially in solar photovoltaics and wind turbines). Globally, wind and solar electricity grew from just 32 terawatt-hours in 2000 to over 2,400 terawatt-hours in 2020: more than enough to power the entire country of India.[1] Nonetheless, together they still only provide 9% of electricity worldwide.[1] As societies work to lower their greenhouse gas emissions, renewable energy is expected to play a large role, especially if we switch more heating and transportation to run on electric power and solve the problem of affordable, large-scale energy storage. How much of our energy we ultimately get from renewables will also depend on their ability to compete with other low-carbon technologies, such as nuclear, carbon capture and storage and hydrogen.



SOLAR AT A GLANCE

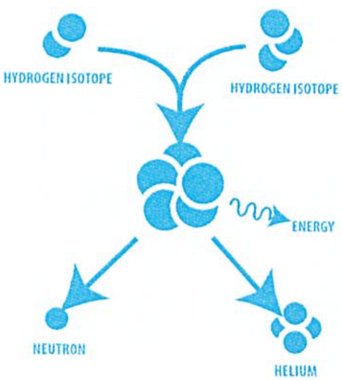
NEED National Energy Education Development www.need.org

WHAT IS SOLAR?

Solar energy is radiant energy that is produced by the sun. Every day the sun radiates, or sends out, an enormous amount of energy. The sun radiates more energy in one second than people have used since the beginning of time!

NUCLEAR FUSION

The process of fusion most commonly involves hydrogen isotopes combining to form a helium atom with a transformation of matter. This matter is emitted as radiant energy.



PHOTOVOLTAIC CELLS

Photovoltaic comes from the words photo meaning "light" and volt, a measurement of electricity. Sometimes photovoltaic cells are called PV cells orsolar cells for short. These are the four steps that show how a PV cell is made and how it produces electricity.

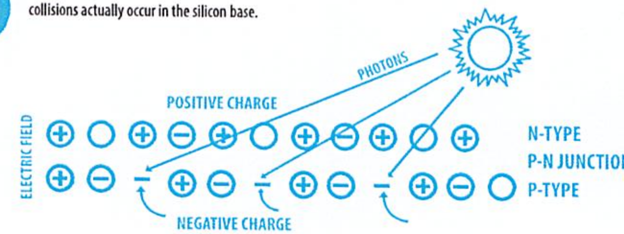
⊕ PROTON — FREE ELECTRON ⊖ TIGHTLY-HELD ELECTRON ◯ A LOCATION THAT CAN ACCEPT AN ELECTRON

1 A slab (or wafer) of pure silicon is used to make a PV cell. The top of the slab is very thinly diffused with an "n" dopant such as phosphorous. On the base of the slab a small amount of a "p" dopant, typically boron, is diffused. The boron side of the slab is 1,000 times thicker than the phosphorous side.

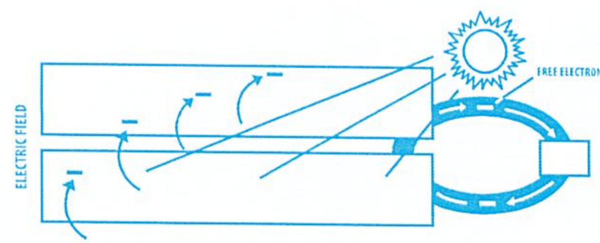
The phosphorous has one more electron in its outer shell than silicon, and the boron has one less. These dopants help create the electric field that motivates the energetic electrons out of the cell created when light strikes the PV cell. The phosphorous gives the wafer of silicon an excess of free electrons; it has a negative character. This is called then-type silicon (n = negative). The n-type silicon is not charged—it has an equal number of protons and electrons—but some of the electrons are not held tightly to the atoms. They are free to move to different locations within the layer. The boron gives the base of the silicon a positive character, because it has a tendency to attract electrons. The base of the silicon is called p-type silicon (p = positive). The p-type silicon has an equal number of protons and electrons; it has a positive character but not a positive charge.

2 Where the n-type silicon and p-type silicon meet, free electrons from the n-layer flow into the p-layer for a split second, then form a barrier to prevent more electrons from moving between the two sides. This point of contact and barrier is called the p-n junction. When both sides of the silicon slab are doped, there is a negative charge in the p-type section of the junction and a positive charge in the n-type section of the junction due to movement of the electrons and "holes" at the junction of the two types of materials. This imbalance in electrical charge at the p-n junction produces an electric field between the p-type and n-type silicon

3 If the PV cell is placed in the sun, photons of light strike the electrons in the p-n junction and energize them, knocking them free of their atoms. These electrons are attracted to the positive charge in the n-type silicon and repelled by the negative charge in the p-type silicon. Most photon-electron collisions actually occur in the silicon base.



4 A conducting wire connects the p-type silicon to an electrical load, such as a light or battery, and then back to the n-type silicon, forming a complete circuit. As the free electrons are pushed into the n-type silicon they repel each other because they are of like charge. The wire provides a path for the electrons to move away from each other. This flow of electrons is an electric current that travels through the circuit from the n-type to the p-type silicon. In addition to the semi-conducting materials, solar cells consist of a top metallic grid or other electrical contact to collect electrons from the semi-conductor and transfer them to the external load, and a back contact layer to complete the electrical circuit



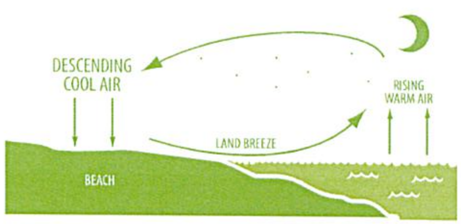
TOP SOLAR STATES

WIND AT A GLANCE

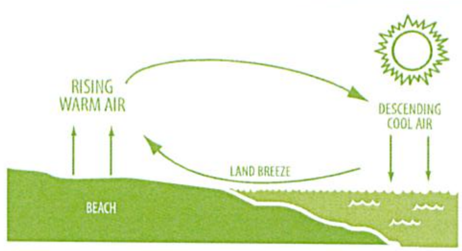
WHAT IS WIND?

Wind is simply air in motion. It is produced by the uneven heating of the Earth's surface by energy from the sun. Since the Earth's surface is made of very different types of land and water, it absorbs the sun's radiant energy at different rates. Much of this energy is converted into heat as it is absorbed by land areas, bodies of water, and the air overthese formations.

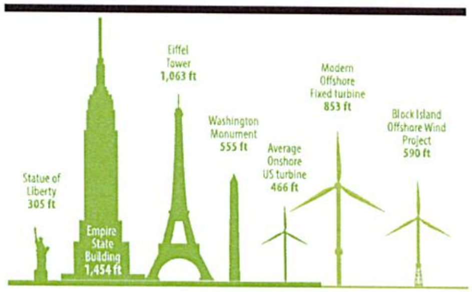
LAND BREEZE



SEA BREEZE



TURBINE SIZE



WIND TURBINES

Wind is harnessed and converted into electricty using wind turbines. They convert the wind's kinetic energy into motion energy that generates electricty. The following steps illustrate how.

1 The moving air spins the turbine blades.

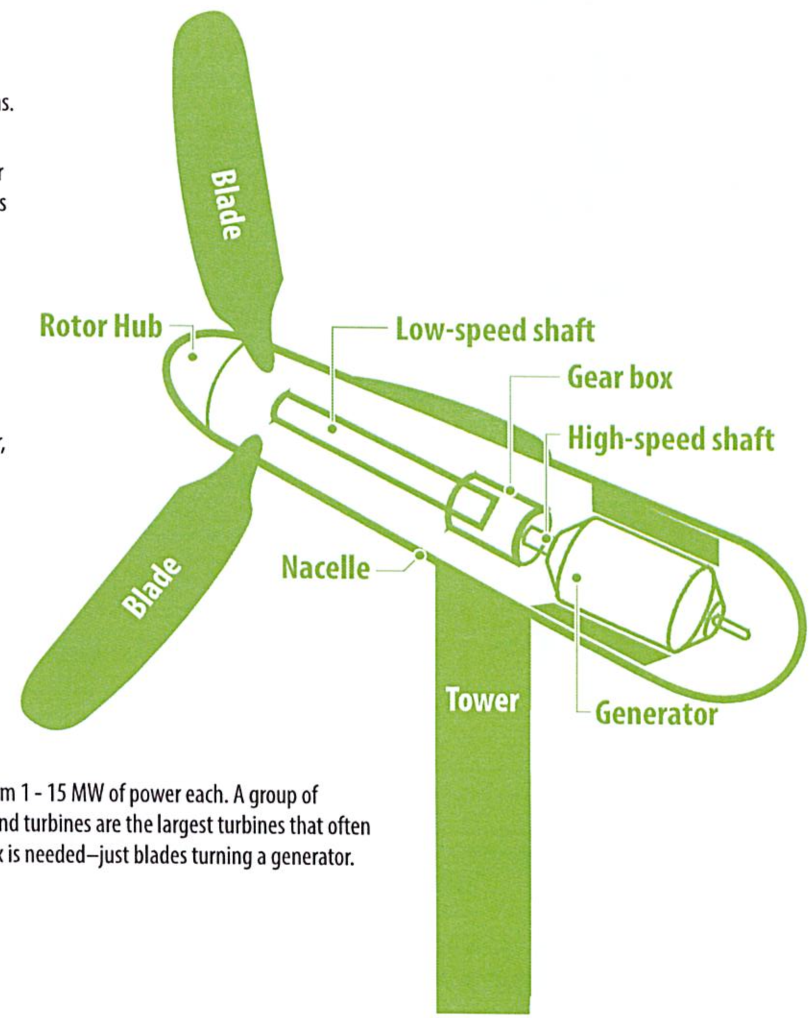
2 The blades are connected to a low-speed shaft. When the blades spin, the shaft turns.

3 The low-speed shaft is connected to a gear box. Inside, a large slow-moving gear turns a small gear quickly.

4 The small gear turns another shaft at high speed.

5 The high-speed shaft is connected to a generator. As the shaft turns the generator, it produces electricity.

6 The electric current is sent through cables down the turbine tower to a transformer that changes the voltage of the current before it is sent out on transmission lines



Large turbines can generate anywhere from 1 - 15 MW of power each. A group of turbines is called a wind farm. Offshore wind turbines are the largest turbines that often use a direct drive design where no gearbox is needed—just blades turning a generator.

TOP WIND STATES

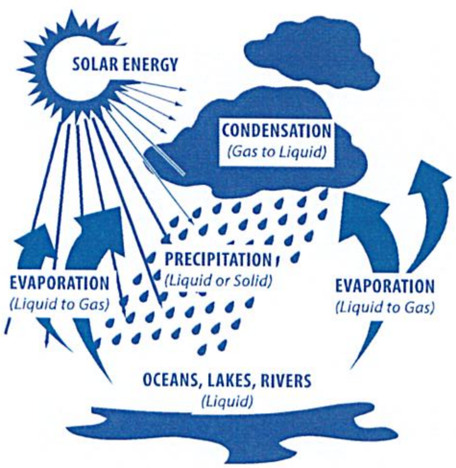
Data: Energy Information Administration

HYDROPOWER AT A GLANCE

WHAT IS HYDROPOWER?

Hydropower (from the Greek word hydor, meaning water) is energy that comes from the force of moving water. The fall and movement of water is part of a continuous natural cycle called the water cycle. Energy from the sun evaporates water in the Earth's oceans and rivers and draws it upward as water vapor. When the water vapor reaches the cooler air in the atmosphere, it condenses and forms clouds. The moisture eventually falls to the Earth as rain or snow, replenishing the water in the oceans and rivers. Gravity drives the moving water, transporting it from high ground to low ground. The force of moving water can be extremely powerful.

THE WATER CYCLE



HYDROKINETICS

In the U.S., most hydropower is generated using conventional designs. Hydropower has the potential for growth by using hydrokinetic technologies: energy from moving waves, tides, and currents.

HYDROPOWER PLANT

A conventional hydropower plant is a system with three parts: a power plant where the electricity is produced; a dam that can be opened or closed to control water flow; and a reservoir (artificial lake) where water can be stored.

HEAD AND FLOW

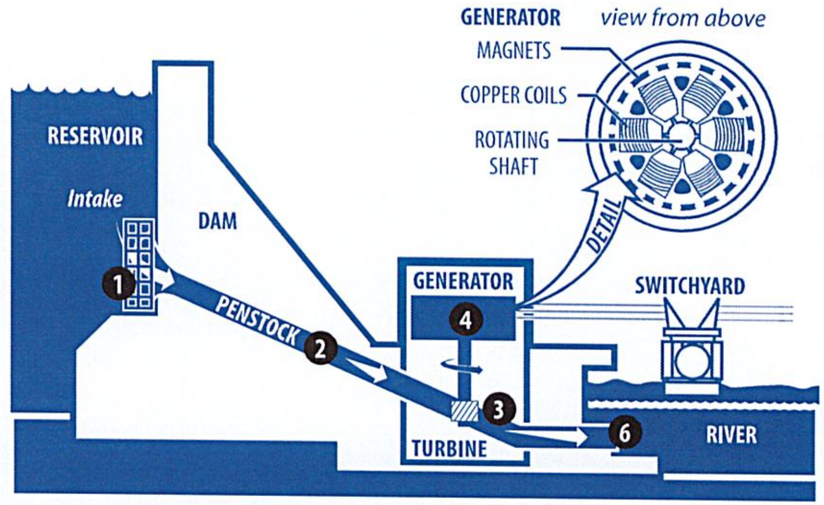
The amount of electricity that can be generated at a hydro plant is determined by two factors: head and flow. Head is how far the water drops. It is the distance from the highest level of the dammed water to the point where it goes through the power-producing turbine. Flow is how much water moves through the system—the more water that moves through a system, the higher the flow. Generally, a high-head plant needs less water flow than a low-head plant to produce the same amount of electricity. If a river has high flow rates, a reservoir may not be needed.

STORING ENERGY

One of the biggest advantages of a hydropower plant is its ability to store energy. The water in a reservoir is, after all, stored energy. Water can be stored in a reservoir and released when needed for electricity production. During the day when people use more electricity, water can flow through a plant to generate electricity. Then, during the night when people use less electricity, water can be held back in the reservoir. Storage also makes it possible to save water from winter rains for generating power during the summer, or to save water from wet years for generating electricity during dry years.

PUMPED STORAGE SYSTEMS

Some hydropower plants use pumped storage systems. A pumped storage system operates much like a public fountain does; the same water is used again and again. At a pumped storage hydropower plant, flowing water is used to make electricity and then stored in a lower pool. Depending on how much electricity is needed, the water may be pumped back to an upper pool. Pumping water to the upper pool requires electricity so hydro plants usually use pumped storage systems only when there is peak demand for electricity



1. Water in a reservoir behind a hydropower dam flows through an intake screen, which filters out large debris, but allows fish to pass through.
2. The water travels through a large pipe, called a penstock.
3. The force of the water spins a turbine at a low speed, allowing fish to pass through unharmed.
4. Inside the generator, the shaft spins coils of copper wire inside a ring of magnets. This creates an electric field, producing electricity.
5. Electricity is sent to a switchyard, where a transformer increases the voltage, allowing it to travel through the electric grid.
6. Water flows out of the penstock into the downstream river.

TOP HYDRO STATES

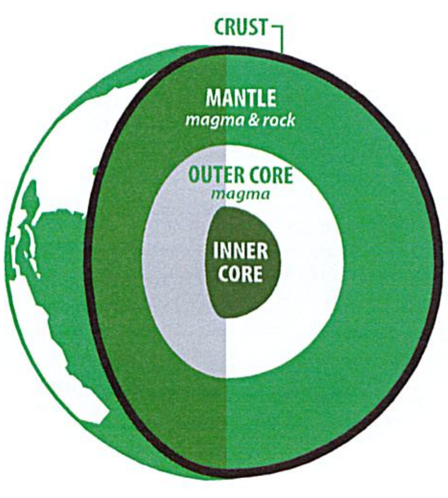
GEOTHERMAL AT A GLANCE

WHAT IS GEOTHERMAL?

Geothermal energy comes from the heat within the Earth. The word geothermal comes from the Greek words geo, meaning earth, and therme, meaning heat. People around the world use geothermal energy to produce electricity, to heat homes and buildings, and to provide hot water for a variety of uses.

THE EARTH'S INTERIOR

The Earth's core lies almost 4,000 miles beneath the Earth's surface. The double-layered core is made up of very hot molten iron surrounding a solid iron center. Estimates of the temperature of the core range from 5,000 to 11,000 degrees Fahrenheit. Surrounding the Earth's core is the mantle, thought to be partly rock and partly magma. The mantle is about 1,800 miles thick. The outermost layer of the Earth, the insulating crust, is not one continuous sheet of rock, like the shell of an egg, but is broken into pieces called plates. These slabs of continents and ocean floor drift apart and push against each other at the rate of about two centimeters per year in a process called plate tectonics. This process can cause the crust to become faulted (cracked), fractured, or thinned, allowing plumes of magma to rise up into the crust.



USES OF GEOTHERMAL

Today, we drill wells into geothermal reservoirs deep underground and use the steam and heat to drive turbines in electric power plants. The hot water is also used directly to heat buildings, to increase the growth rate of fish in hatcheries and crops in greenhouses, to pasteurize milk, to dry foods products and lumber, and for mineral baths.

When geothermal reservoirs are located near the surface, we can reach them by drilling wells. Exploratory wells are drilled to search for reservoirs. Once a reservoir has been found, production wells are drilled. Hot water and steam—at temperatures of 250ºF to 700ºF—are brought to the surface and used to generate electricity at power plants near the production wells. **THERE ARE SEVERAL DIFFERENT TYPES OF GEOTHERMAL POWER PLANTS:**

FLASH STEAM PLANTS

Most geothermal power plants are flash steam plants. Hot water from production wells flashes (explosively boils) into steam when it is released from the underground pressure of the reservoir. The force of the steam is used to spin the turbine generator. To conserve water and maintain the pressure in the reservoir, the steam is condensed into water and injected back into the reservoir to be reheated

DRY STEAM PLANTS

A few geothermal reservoirs produce mostly steam and very little water. In dry steam plants, the steam from the reservoir shoots directly through a rock-catcher into the turbine generator. The rock-catcher protects the turbine from small rocks that may be carried along with the steam from the reservoir.

BINARY CYCLE POWER PLANTS

Binary cycle power plants transfer the thermal energy from geothermal hot water to other liquids to produce electricity. The geothermal water is passed through a heat exchanger in a closed pipe system, and then reinjected into the reservoir. The heat exchanger transfers the heat to a working fluid—usually isobutane or isopentane—which boils at a lower temperature than water. The vapor from the working fluid is used to turn the turbines. Binary systems can, therefore, generate electricity from reservoirs with lower temperatures. Since the system is closed, there is little heat loss and almost no water loss, and virtually no emissions.

HYBRID POWER PLANTS

In some power plants, flash and binary systems are combined to make use of both the steam and the hot water.

USES OF GEOTHERMAL ENERGY

HEATING

The most widespread use of geothermal resources—after bathing—is to heat buildings. In the Paris basin in France, geothermal was used to heat homes 600 years ago. More than 150,000 homes in France use geothermal heat today.

INDUSTRY

The heat from geothermal water is used worldwide for dying cloth, drying fruits and vegetables, washing wool, manufacturing paper, pasteurizing milk, and drying timber products. It is also used to help extract gold and silver from ore. In Klamath Falls, OR, hot water is piped under sidewalks and bridges to keep them from freezing in winter.

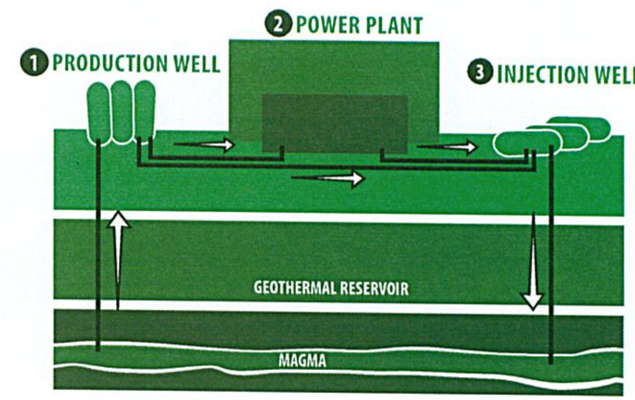
HOT SPRING BATHING AND SPAS

For centuries, people have used hot springs for cooking and bathing. The early Romans used geothermal water to treat eye and skin diseases and, at Pompeii, to heat buildings. Medieval wars were even fought over lands for their hot springs.

AGRICULTURE AND AQUACULTURE

Water from geothermal reservoirs is used in many places to warm greenhouses that grow flowers, vegetables, and other crops. Natural warm water can also speed the growth of fish, shellfish, reptiles, and amphibians.

GEOTHERMAL POWER PLANT



1. **Production Well:** Geothermal fluids, such as hot water and steam, are brought to the surface and piped into the power plant.
2. **Power Plant:** Inside the power plant, the geothermal fluid turns the turbine blades, which spins a shaft, which spins magnets inside a large coil of wire to generate electricity.
3. **Injection Well:** Used geothermal fluids are returned to the reservoir.

BIOMASS AT A GLANCE

NEED National Energy Education Development

WHAT IS BIOMASS?

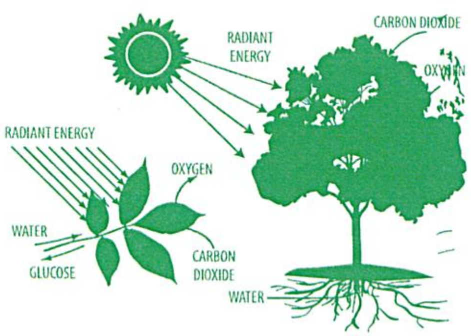
Biomass is any organic matter—wood, crops, seaweed, animal wastes—that can be used as an energy source. Biomass is probably our oldest source of energy after the sun. For thousands of years, people have burned wood to heat their homes and cook their food.

Biomass gets its energy from the sun. All organic matter contains stored energy from the sun. During a process called photosynthesis, sunlight gives plants the energy they need to convert water and carbon dioxide into oxygen and sugars. These sugars, called carbohydrates, supply plants and the animals that eat plants with energy. Foods rich in carbohydrates are a good source of energy for the human body.

Biomass is a renewable energy source because its supplies are not limited. We can always grow trees and crops, and waste will always exist.

PHOTOSYNTHESIS

In the process of photosynthesis, plants convert radiant energy from the sun into chemical energy in the form of glucose (or sugar)



water + carbon dioxide + sunlight → glucose + oxygen

$$6\,H_2O + 6\,CO_2 + \text{radiant energy} \rightarrow C_6H_{12}O_6 + 6\,O_2$$

TYPES OF BIOMASS

We use four types of biomass today—wood and agricultural products, solid waste, landfill gas and biogas, and alcohol fuels (like Ethanol or Biodiesel).

1 WOOD AND AGRICULTURAL PRODUCTS

Most biomass used today is home grown energy. Wood—logs, chips, bark, and sawdust—accounts for just under half of biomass energy. But any organic matter can produce biomass energy. Other biomass sources can include agricultural waste products like fruit pits and corncobs.

Wood and wood waste are used to generate electricity. Much of the electricity is used by the industries making the waste; it is not distributed by utilities, it is a process called cogeneration. Paper mills and saw mills use much of their waste products to generate steam and electricity for their use. However, since they use so much energy, they need to buy additional electricity from utilities.

2 SOLID WASTE

Burning trash turns waste into a usable form of energy. One ton (2,000 pounds) of garbage contains about as much heat energy as 500 pounds of coal. Garbage is not all biomass; perhaps half of its energy content comes from plastics, which are made from petroleum and natural gas. Power plants that burn garbage for energy are called waste-to-energy plants. These plants generate electricity much as coal-fired plants do, except that combustible garbage—not coal—is the fuel used to fire their boilers.

3 LANDFILL GAS AND BIOGAS

Bacteria and fungi are not picky eaters. They eat dead plants and animals, causing them to rot or decay. A fungus on a rotting log is converting cellulose to sugars to feed itself. Although this process is slowed in a landfill, a substance called methane gas is still produced as the waste decays. New regulations require landfills to collect methane gas for safety and environmental reasons. Methane gas is colorless and odorless, but it is not harmless. The gas can cause fires or explosions if it seeps into nearby homes and is ignited. Landfills can collect the methane gas, purify it, and use it as fuel. Methane can also be produced using energy from agricultural and human wastes. Biogas digesters are airtight containers or pits lined with steel or bricks. Waste put into the containers is fermented without oxygen to produce a methane-rich gas. This

4 ETHANOL

Ethanol is an alcohol fuel (ethyl alcohol) made by fermenting the sugars and starches found in plants and then distilling them. Any organic material containing cellulose, starch, or sugar can be made into ethanol. The majority of the ethanol produced in the United States comes from corn. New technologies are producing ethanol from cellulose in woody fibers from trees, grasses, and crop residues.

Today nearly all of the gasoline sold in the U.S. contains around 10 percent ethanol and is known as E10. In 2011, the U.S. Environmental Protection Agency (EPA) approved the introduction of E15 (15 percent ethanol, 85 percent gasoline) for use in passenger vehicles from model year 2001 and newer. Fuel containing 85 percent ethanol and 15 percent gasoline (E85) qualifies as an alternative fuel. There are about 20 million flexible fuel vehicles (FFV) on the road that can run efficiently on E85 or E10. However, a small percentage of these vehicles use E85 regularly.

BIODIESEL

Biodiesel is a fuel made by chemically reacting alcohol with vegetable oils, animal fats, or greases, such as recycled restaurant grease. Most biodiesel today is made from soybean oil. Biodiesel is most often blended with petroleum diesel in ratios of two percent (B2), five percent (B5), or 20 percent (B20). It can also be used as neat (pure) biodiesel (B100). Biodiesel fuels are compatible with and can be used in unmodified diesel engines with the existing fueling infrastructure. It is one of the fastest growing transportation fuels in the U.S.

Biodiesel contains virtually no sulfur, so it can reduce sulfur levels in the nation's diesel fuel supply, even compared with today's low sulfur fuels. While removing sulfur from petroleum-based diesel results in poor lubrication, biodiesel is a superior lubricant and can reduce the friction of diesel fuel in blends of only one or two percent. This is an important characteristic because the Environmental Protection Agency now requires that sulfur levels in diesel fuel be 97 percent lower than they were prior to 2006.

Biofuel

By Kristala Jones Prather – MIT Climate – September 3, 2020

Biofuel is any liquid fuel made from "biomass"—that is, plants and other biological matter like animal waste and leftover cooking fat. Biofuels can be used as replacements for petroleum-based fuels like gasoline and diesel. As we search for fuels that won't contribute to the greenhouse effect and climate change, biofuels are a promising option because the carbon dioxide (CO_2) they emit is recycled through the atmosphere. When the plants used to make biofuels grow, they absorb CO_2 from the air, and it's that same CO_2 that goes back into the atmosphere when the fuels are burned. In theory, biofuels can be a "carbon neutral" or even "carbon negative" way to power cars, trucks and planes, meaning they take at least as much CO_2 out of the atmosphere as they put back in.

A major promise of biofuels is that they can lower overall CO_2 emissions without changing a lot of our infrastructure. They can work with existing vehicles, and they can be mass-produced from biomass in the same way as other biotechnology products, like chemicals and pharmaceuticals, which are already made on a large scale. In the future, we may also be able to move large amounts of biofuels through existing pipelines.

Toward advanced biofuels

Today, many different biofuels are in production, made in many different ways. The most common process is to use bacteria and yeast to ferment starchy foods like corn into ethanol, a partial replacement for gasoline. Most gasoline sold in the U.S. is mixed with 10% ethanol.

Newer research in biofuels aims to produce higher-grade fuels like jet fuel; to create cleaner-burning fuels that are better for the environment and human health; or to use less valuable biomass like algae, grasses, woody shrubs, or waste from cooking, logging and farming. While some of these "advanced biofuels" are already in production, none are being used in nearly the amounts of "first-generation" ethanol and biodiesel.

Climate challenges

There are many challenges to making biofuels that are truly carbon neutral. That's because many steps used to create biofuels—fermentation, the energy for processing, transportation, even the fertilizers used to grow plants—may emit CO_2 and other greenhouse gases even before the fuels are burned. The farmland used to grow biomass can also have its own climate impacts, especially if it takes the place of CO_2-storing forests. This means that the details of how biofuels are made and used are very important for their potential as a climate solution.

Producing biofuels

There are many different biofuels in production or under development, and even the same biofuel might be made in more than one way. If we want biofuels to help protect our planet from climate change, every step in the process matters.

Agriculture

Most biofuels come from farms. Good farming practices can help trap extra carbon in the soil. On the other hand, many fertilizers release greenhouse gases into the atmosphere.

Feedstock

The “feedstock” is just the plant or other organic material used to make a biofuel. Do we use something valuable and hard to grow, like corn or palm oil? Or cheap plants that don’t need good farmland? Or waste from other industries, like logging and cooking?

Energy

Every method of processing biofuels takes energy, which we can get from carbon-free sources like solar or wind, or by burning fossil fuels.

Processing

Turning feedstocks into biofuels is not easy. Facilities may have to extract energy-rich oils or starches from the raw material, or ferment, heat, or chemically treat the feedstocks.

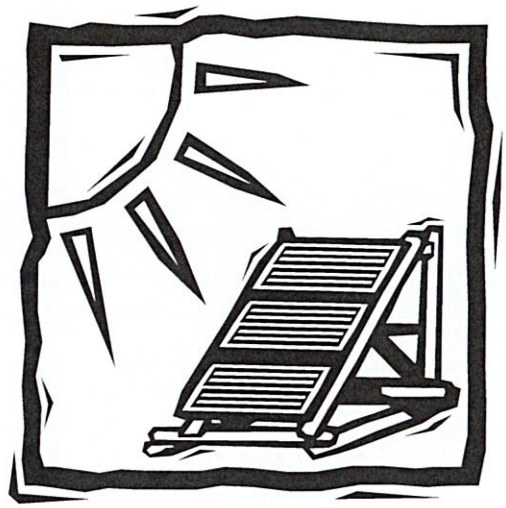
Transportation

Most biofuels today can’t be moved through the pipelines we use for oil and gas. That leaves trucks, trains and ships, all of which emit greenhouse gases.

Use

Eventually, the fuel is burned and the carbon inside it is emitted back into the atmosphere. It can replace gasoline or jet fuel, or it can be used more like natural gas, to provide electricity or heat.

Facts about Solar Energy: Solar Electricity



Introduction
Harnessing energy from the sun holds great promise for meeting future energy needs because solar energy is a renewable and clean energy resource. Fossil fuels will eventually run out and the future of nuclear power is uncertain. For these reasons, other energy sources need to be harnessed. Solar energy is one of these sources.

Solar energy is produced by the sun, which is essentially a gigantic nuclear fusion reactor running on hydrogen fuel. The sun converts five million tons of matter into energy every second. Solar energy reaches the Earth's surface as ultraviolet (UV) light, visible light, and infrared light. Many other electromagnetic waves are stopped in the upper parts of the atmosphere. Scientists expect that the sun will continue to provide light and heat energy for the next five billion years.

Solar Energy Potential
The amount of solar energy that strikes Earth's surface per year is about 29,000 times greater than all of the energy used in the United States. Put another way, in one hour more energy from the sun falls on the earth than is used by everyone in the world in an entire year. The solar energy falling on Wisconsin each year is roughly equal to 844 quadrillion Btu of energy, which is almost 550 times the amount of energy used in Wisconsin.

Although the amount of solar energy reaching Earth's surface is immense, it is spread out over a large area. There are also limits to how efficiently it can be collected and converted into electricity and stored. These factors, in addition to geographic location, time of day, season, local landscape, and local weather, affect the amount of solar energy that can actually be used.

Producing Solar Electricity
Solar electricity is measured like most electricity, in kilowatt-hours, a unit of energy. Solar cells convert sunlight directly into electricity, and many solar-powered devices have been in use for decades, including wrist watches and calculators. Traditional cells are made of silicon, a material that comprises 28 percent of the Earth's crust. One solar cell measuring four inches across can produce one watt of electricity on a clear, sunny day. However, its efficiency can be affected by many factors including the wavelength of light, the temperature, and reflection. To produce more electricity, cells are wired together into panels (about 40 cells), and panels are wired together to form arrays.

Solar cells are reliable and quiet, and they can be installed quickly and easily. They are also mobile and easily maintained. They provide an ideal electrical power source for satellites, outdoor lighting, navigational beacons, and water pumps in remote areas. In the United States, more than 784,000 homes and businesses have 'gone solar.'

Facts about Solar Energy: Solar Electricity

Concentrated Solar Power (CSP)

Solar energy can be used to heat a fluid to produce steam that spins a turbine connected to an electrical generator. These systems are called solar thermal electric systems. Concentrated solar power systems use mirrors to reflect and concentrate sunlight onto a small area. The concentrated sunlight heats a fluid and creates steam, which then powers a turbine generating electricity.

One type of solar thermal electric system, the solar power tower, uses mirrors to track and focus sunlight onto the top of a heat collection tower (see Fig. 1.1). An experimental 10-megawatt solar power tower called Solar Two was tested in the desert near Barstow, California. It was used to demonstrate the advantages of using molten salt for heat transfer and thermal storage. The experiment showed that this type of solar energy production was efficient in collecting and dispatching energy. The world's largest operating power tower system is the Ivanpah Solar Electric Generating System in the Mojave Desert of California. Ivanpah currently runs 69 percent below operating capacity, lacking thermal storage. It cannot compete with PV panels which have undergone a huge price reduction and can be installed on homes.

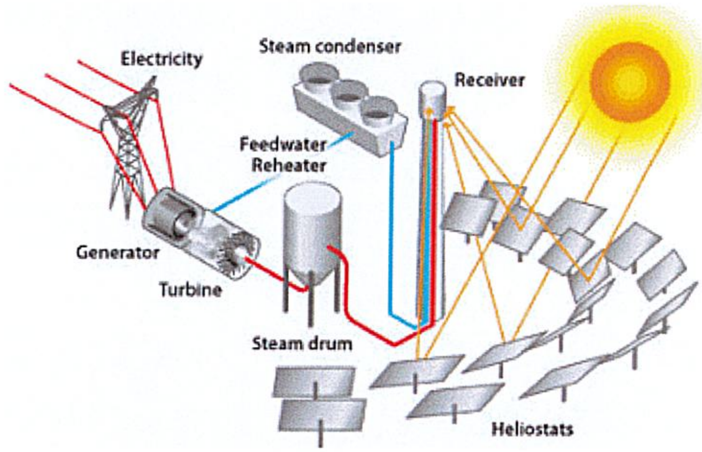


Fig. 1.1 Power Tower Power Plant

Source: energy.gov/eere/energybasics/articles/power-tower-system-concentrating-solar-power-basics

A second type of solar thermal electric system is called a parabolic trough. It is a linear concentrator system and uses curved, mirrored collectors shaped like troughs. The concentrated sunlight heats a working fluid running through the pipes that is then used as a heat source to generate electricity (see Fig 1.2). The largest system of this type is located in northern San Bernadino County in California with a capacity of 354 MW combined from three locations.

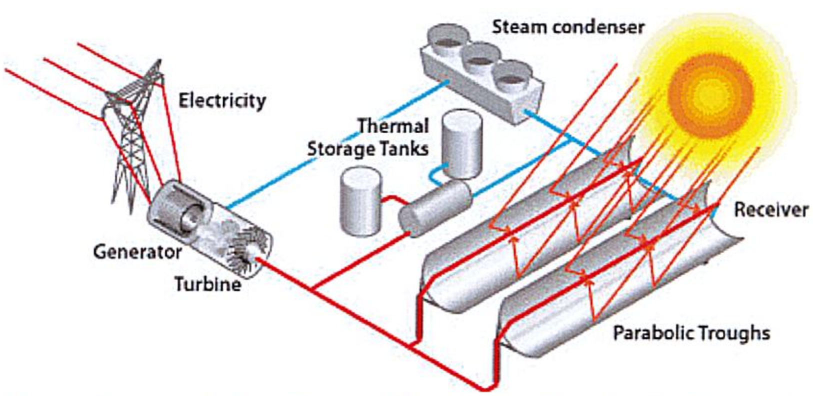


Fig. 1.2 Linear Concentrator Power Plant using Parabolic Tough Collectors

Source: energy.gov/eere/energybasics/articles/linear-concentrator-system-basics-concentrating-solar-power

Facts about Solar Energy: Solar Electricity

A third type of solar thermal electric system is an enclosed trough which use mirrors encapsulated in glass like a greenhouse to focus sunlight on a tube containing water, yielding high-pressure steam (see Fig. 1.3). This system was designed to produce heat for enhanced oil recovery.

Fig. 1.3 View from inside the enclosed-trough parabolic solar mirrors, used to concentrate sun and generate steam for enhanced oil recovery (EOR).

Source: commons.wikimedia.org/wiki/File%3AInside_an_enclosed_CSP_Trough.jpg

A fourth type of solar thermal electric system is a Dish Stirling system which uses a mirrored dish similar in appearance to a satellite dish (see Fig. 1.4). This system, like the others, uses mirrors to concentrate and reflect solar energy and the heat generated is used to produce electricity by concentrating sunlight onto a receiver– located at the dish's focal point – containing a working fluid that powers a Stirling Engine.

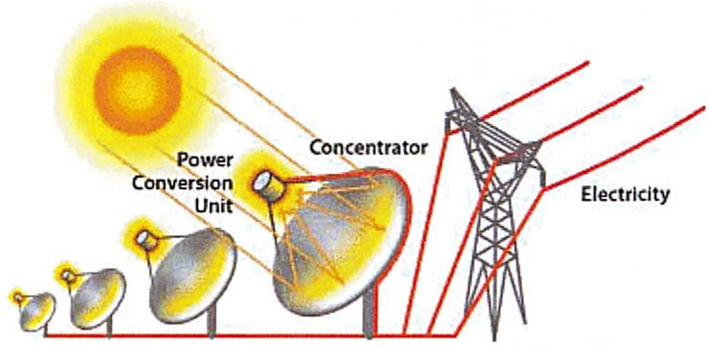


Fig. 1.4 Dish/Engine Power Plant

Source: energy.gov/eere/energybasics/articles/dishengine-system-concentrating-solar-power-basics

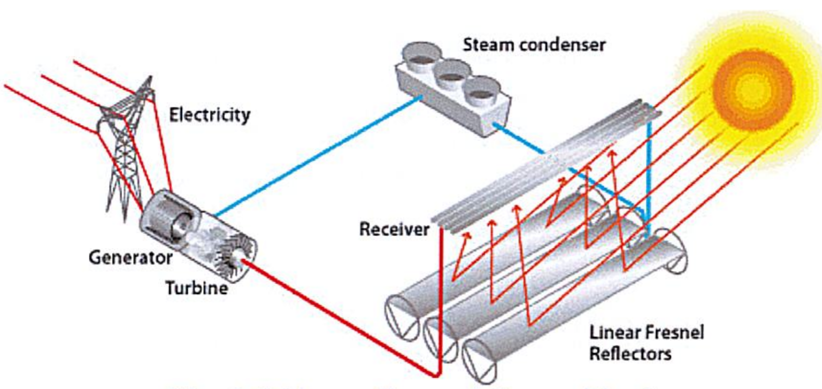


Fig. 1.5 Linear Fresnel Power Plant

Source: energy.gov/eere/sunshot/downloads/linear-fresnel-power-plant-illustration

A fifth type of solar thermal electric system called Fresnel reflectors are long, thin segments of mirrors that focus sunlight onto a fixed absorber located at a common focal point of the reflectors (see Fig. 1.5). Flat mirrors allow more reflective surface than parabolic reflectors and are much cheaper.

Facts about Solar Energy: Solar Electricity

Solar Electricity Production

Of the total electricity production in the United States, solar energy provides less than 2 percent. In Wisconsin only about 0.4 percent of total electricity production is from solar energy. A negligible amount of electricity from solar energy is currently being generated by individual homeowners and businesses.

Effects

Solar electricity has many benefits. Solar electric systems have no fuel costs, low operating and maintenance costs, produce virtually no emissions or waste while functioning, and even raise the value of homes.

Solar electric systems can be built quickly and in many sizes. They are well-suited to rural areas, developing countries, and other communities that do not have access to centrally generated electricity.

Solar electricity also has limitations. It is not available at night and is less available during cloudy days, making it necessary to store the produced electricity. Backup generators can also be used to support these systems. During the manufacturing process of photovoltaic cells, some toxic materials and chemicals are used. Some systems may use hazardous fluids to transfer heat. Adverse impacts can be experienced in areas that are cleared or used for large solar energy generating sites. Large-scale solar electric systems need large amounts of land to collect solar energy. This may cause conflicts if the land is in an environmentally sensitive area or is needed for other purposes. Deaths of birds and insects may occur if they happen to fly directly into a beam of light concentrated by a CSP.

Sometimes large-scale solar electric systems are placed in deserts or marginal lands. CSP developments are common in the southwestern United States (Colorado and Mojave Deserts); however, these locations are not without conflict either. For example, the Mojave desert tortoise is a threatened species that is in decline due to a complex array of threats including habitat loss and degradation.

Another idea is to place solar cells on rooftops, over parking lots, in yards, and along highways, and then connect the systems to an electric utility's power-line system. As the use of solar electric systems increases, laws may be needed to protect peoples' right to access the sun.

Solar Array Near Cantil, California

Source: Hanwha Q CELLS USA.

Facts about Solar Energy: Solar Electricity

Outlook

The sun is expected to remain much as it is today for another five billion years. Because we can anticipate harvesting the sun's energy for the foreseeable future, the outlook for solar energy is optimistic. Continued growth in utility-scale solar power generation is expected. The flexibility and environmental benefits of solar electricity make it an attractive alternative to fossil and nuclear fuels. Although the cost of solar panels has dropped significantly, other solar installations (such as CSP) are relatively expensive when compared to the amount of electricity they generate. Land issues and the need for electricity storage or backup systems are also obstacles, of which many experts are confident can be overcome. Incentives are increasingly offered at the utility, county, state, and federal levels. The U.S. Department of Energy's SunShot Initiative has launched an effort to make solar energy more cost-competitive with other types of energy. Incentives such as these will ultimately assist in the continued growth of solar energy.

In the near future, the use of solar electric systems will likely continue to increase in the Southern and Western parts of the United States where sunshine is plentiful. Solar energy growth in Wisconsin has been slower than that of Southern and Western states but currently has 22 MW of solar energy installed, equivalent to what is needed to power 3,000 homes. A number of homeowners and businesses in Wisconsin have already demonstrated that solar electric systems can meet their needs, and it is reasonable to expect growth of solar electric power in Wisconsin as well.

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The Wisconsin K-12 Energy Education Program is supported through funding from

Wisconsin K-12 Energy Education Program (KEEP)
College of Natural Resources
University of Wisconsin-Stevens Point

The Dark Side of Solar Power

by Atalay Atasu, Serasu Duran, and Luk N. Van Wassenhove – Harvard Business Review

June 18, 2021

Summary: Solar energy is a rapidly growing market, which should be good news for the environment. Unfortunately there's a catch. The replacement rate of solar panels is faster than expected and given the current very high recycling costs, there's a real danger that all used panels will go straight to landfill (along with equally hard-to-recycle wind turbines). Regulators and industry players need to start improving the economics and scale of recycling capabilities before the avalanche of solar panels hits.

It's sunny times for solar power. In the U.S., home installations of solar panels have fully rebounded from the Covid slump, with analysts predicting more than 19 gigawatts of total capacity installed, compared to 13 gigawatts at the close of 2019. Over the next 10 years, that number may quadruple, according to industry research data. And that's not even taking into consideration the further impact of possible new regulations and incentives launched by the green-friendly Biden administration.

Solar's pandemic-proof performance is due in large part to the Solar Investment Tax Credit, which defrays 26% of solar-related expenses for all residential and commercial customers (just down from 30% during 2006–2019). After 2023, the tax credit will step down to a permanent 10% for commercial installers and will disappear entirely for home buyers. Therefore, sales of solar will probably burn even hotter in the coming months, as buyers race to cash in while they still can.

Tax subsidies are not the only reason for the solar explosion. The conversion efficiency of panels has improved by as much as 0.5% each year for the last 10 years, even as production costs (and thus prices) have sharply declined, thanks to several waves of manufacturing innovation mostly driven by industry-dominant Chinese panel producers. For the end consumer, this amounts to far lower up-front costs per kilowatt of energy generated.

This is all great news, not just for the industry but also for anyone who acknowledges the need to transition from fossil fuels to renewable energy for the sake of our planet's future. But there's a massive caveat that very few are talking about.

Panels, Panels Everywhere

Economic incentives are rapidly aligning to encourage customers to trade their existing panels for newer, cheaper, more efficient models. In an industry where circularity solutions such as recycling remain woefully inadequate, the sheer volume of discarded panels will soon pose a risk of existentially damaging proportions.

To be sure, this is not the story one gets from official industry and government sources. The International Renewable Energy Agency (IRENA)'s official projections assert that "large amounts of annual waste are anticipated by the early 2030s" and could total 78 million tonnes by the year 2050. That's a staggering amount, undoubtedly. But with so many years to prepare, it describes a billion-dollar opportunity for recapture of valuable materials rather than a dire threat. The threat is hidden by the fact that IRENA's predictions are premised upon customers keeping their panels in place for the entirety of their 30-year life cycle. They do not account for the possibility of widespread early replacement.

Our research does. Using real U.S. data, we modeled the incentives affecting consumers' decisions whether to replace under various scenarios. We surmised that three variables were particularly salient in determining replacement decisions: installation price, compensation rate (i.e., the going rate for solar energy sold to the grid), and module efficiency. If the cost of trading up is low enough, and the efficiency and compensation rate are high enough, we posit that rational consumers will make the switch, regardless of whether their existing panels have lived out a full 30 years.

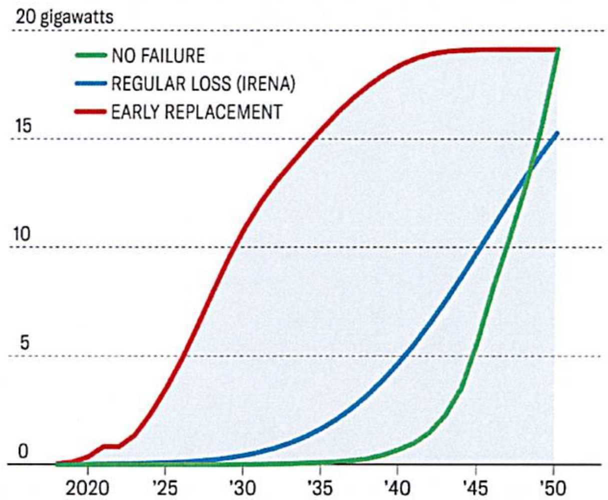
As an example, consider a hypothetical consumer (call her "Ms. Brown") living in California who installed solar panels on her home in 2011. Theoretically, she could keep the panels in place for 30 years, i.e., until 2041. At the time of installation, the total cost was $40,800, 30% of which was tax deductible thanks to the Solar Investment Tax Credit. In 2011, Ms. Brown could expect to generate 12,000 kilowatts of energy through her solar panels, or roughly $2,100 worth of electricity. In each following year, the efficiency of her panel decreases by approximately one percent due to module degradation.

Now imagine that in the year 2026, halfway through the life cycle of her equipment, Ms. Brown starts to look at her solar options again. She's heard the latest generation of panels are cheaper and more efficient — and when she does her homework, she finds that that is very much the case. Going by actual current projections, the Ms. Brown of 2026 will find that costs associated with buying and installing solar panels have fallen by 70% from where they were in 2011. Moreover, the new-generation panels will yield $2,800 in annual revenue, $700 more than her existing setup when it was new. All told, upgrading her panels now rather than waiting another 15 years will increase the net present value (NPV) of her solar rig by more than $3,000 in 2011 dollars. If Ms. Brown is a rational actor, she will opt for early replacement. And if she were especially shrewd in money matters, she would have come to that decision even sooner — our calculations for the Ms. Brown scenario show the replacement NPV overtaking that of panel retention starting in 2021.

The Solar Trash Wave

According to our research, cumulative waste projections will rise far sooner and more sharply than most analysts expect, as the below graph shows. The green "no failure" line tracks the disposal of panels assuming that no faults occur over the 30-year life cycle; the blue line shows the official International Renewable Energy Agency (IRENA) forecast, which allows for some replacements earlier in the life cycle; and the red line represents waste projections predicted by our model.

Cumulative capacity



Source: International Renewable Energy Agency, Electricity Data Browser, Global Solar Atlas

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If early replacements occur as predicted by our statistical model, they can produce 50 times more waste in just four years than IRENA anticipates. That figure translates to around 315,000 metric tonnes of waste, based on an estimate of 90 tonnes per MW weight-to-power ratio.

Alarming as they are, these stats may not do full justice to the crisis, as our analysis is restricted to residential installations. With commercial and industrial panels added to the picture, the scale of replacements could be much, much larger.

The High Cost of Solar Trash

The industry's current circular capacity is woefully unprepared for the deluge of waste that is likely to come. The financial incentive to invest in recycling has never been very strong in solar. While panels contain small amounts of valuable materials such as silver, they are mostly made of glass, an extremely low-value material. The long life span of solar panels also serves to disincentivize innovation in this area.

As a result, solar's production boom has left its recycling infrastructure in the dust. To give you some indication, First Solar is the sole U.S. panel manufacturer we know of with an up-and-running recycling initiative, which only applies to the company's own products at a global capacity of two million panels per year. With the current capacity, it costs an estimated $20–$30 to recycle one panel. Sending that same panel to a landfill would cost a mere $1–$2.

The direct cost of recycling is only part of the end-of-life burden, however. Panels are delicate, bulky pieces of equipment usually installed on rooftops in the residential context. Specialized labor is required to detach and remove them, lest they shatter to smithereens before they make it onto the truck. In addition, some governments may classify solar panels as hazardous waste, due to the small amounts of heavy metals (cadmium, lead, etc.) they contain. This classification carries with it a string of expensive restrictions — hazardous waste can only be transported at designated times and via select routes, etc.

The totality of these unforeseen costs could crush industry competitiveness. If we plot future installations according to a logistic growth curve capped at 700 GW by 2050 (NREL's estimated ceiling for the U.S. residential market) alongside the early-replacement curve, we see the volume of waste surpassing that of new installations by the year 2031. By 2035, discarded panels would outweigh new units sold by 2.56 times. In turn, this would catapult the LCOE (levelized cost of energy, a measure of the overall cost of an energy-producing asset over its lifetime) to four times the current projection. The economics of solar — so bright-seeming from the vantage point of 2021 — would darken quickly as the industry sinks under the weight of its own trash.

Who Pays the Bill?

It will almost certainly fall to regulators to decide who will bear the cleanup costs. As waste from the first wave of early replacements piles up in the next few years, the U.S. government — starting with the states, but surely escalating to the federal level — will introduce solar panel recycling legislation. Conceivably, future regulations in the U.S. will follow the model of the European Union's WEEE Directive, a legal framework for the recycling and disposal of electronic waste throughout EU member states. The U.S. states that have enacted electronics-recycling legislation have mostly cleaved to the WEEE model. (The Directive was amended in 2014 to include solar panels.) In the EU, recycling responsibilities for past (historic) waste have been apportioned to manufacturers based on current market share.

A first step to forestalling disaster may be for solar panel producers to start lobbying for similar legislation in the United States immediately, instead of waiting for solar panels to start clogging landfills. In our experience drafting and implementing the revision of the original WEEE Directive in the late 2000s, we found one of the biggest challenges in those early years was assigning responsibility for the vast amount of accumulated waste generated by companies no longer in the electronics business (so-called orphan waste).

In the case of solar, the problem is made even thornier by new rules out of Beijing that shave subsidies for solar panel producers while increasing mandatory competitive bidding for new solar projects. In an industry dominated by Chinese players, this ramps up the uncertainty factor. With reduced support from the central government, it's possible that some Chinese producers may fall out of the market. One of the reasons to push legislation now rather than later is to ensure that the responsibility for recycling the imminent first wave of waste is shared fairly by makers of the equipment concerned. If legislation comes too late, the remaining players may be forced to deal with the expensive mess that erstwhile Chinese producers left behind.

But first and foremost, the required solar panel recycling capacity has to be built, as part of a comprehensive end-of-life infrastructure also encompassing uninstallation, transportation, and (in the meantime) adequate storage facilities for solar waste. If even the most optimistic of our early-replacement forecasts are accurate, there may not be enough time for companies to accomplish this alone. Government subsidies are probably the only way to quickly develop capacity commensurate to the magnitude of the looming waste problem. Corporate lobbyists can make a convincing case for government intervention, centered on the idea that waste is a negative externality of the rapid innovation necessary for widespread adoption of new energy technologies such as solar. The cost of creating end-of-life infrastructure for solar, therefore, is an inescapable part of the R&D package that goes along with supporting green energy.

It's Not Just Solar

The same problem is looming for other renewable-energy technologies. For example, barring a major increase in processing capability, experts expect that more than 720,000 tons worth of gargantuan wind-turbine blades will end up in U.S. landfills over the next 20 years. According to prevailing estimates, only five percent of electric-vehicle batteries are currently recycled — a lag that automakers are racing to rectify as sales figures for electric cars continue to rise as much as 40% year-on-year. The only essential difference between these green technologies and solar panels is that the latter doubles as a revenue-generating engine for the consumer. Two separate profit-seeking actors — panel producers and the end consumer — thus must be satisfied in order for adoption to occur at scale.

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None of this should raise serious doubts about the future or necessity of renewables. The science is indisputable: Continuing to rely on fossil fuels to the extent we currently do will bequeath a damaged if not dying planet to future generations. Compared with all we stand to gain or lose, the four decades or so it will likely take for the economics of solar to stabilize to the point that consumers won't feel compelled to cut short the life cycle of their panels seems decidedly small. But that lofty purpose doesn't make the shift to renewable energy any easier in reality. Of all sectors, sustainable technology can least afford to be shortsighted about the waste it creates. A strategy for entering the circular economy is absolutely essential — and the sooner, the better.

Atalay Atasu is a professor of technology and operations management and the Bianca and James Pitt Chair in Environmental Sustainability at INSEAD.

Serasu Duran is a professor at the University of Calgary's Haskayne School of Business in Calgary, Alberta.

Luk N. Van Wassenhove is the Henry Ford Chaired Professor of Manufacturing, Emeritus, at INSEAD and leads its Humanitarian Research Group and its Sustainable Operations Initiative.

Advantages and Challenges of Wind Energy

Wind Energy Technologies Office, 2023

Wind energy offers many advantages, which explains why it's one of the fastest-growing energy sources in the world. To further expand wind energy's capabilities and community benefits, researchers are working to address technical and socio-economic challenges in support of a decarbonized electricity future.

Advantages of Wind Power

- Wind power creates good-paying jobs. There are over 120,000 people working in the U.S. wind industry across all 50 states, and that number continues to grow. According to the U.S. Bureau of Labor Statistics, wind turbine service technicians are the second fastest growing U.S. job of the decade. Offering career opportunities ranging from blade fabricator to asset manager, the wind industry has the potential to support hundreds of thousands of more jobs by 2050.
- Wind power is a domestic resource that enables U.S. economic growth. In 2022, wind turbines operating in all 50 states generated more than 10% of the net total of the country's energy. That same year, investments in new wind projects added $20 billion to the U.S. economy.
- Wind power is a clean and renewable energy source. Wind turbines harness energy from the wind using mechanical power to spin a generator and create electricity. Not only is wind an abundant and inexhaustible resource, but it also provides electricity without burning any fuel or polluting the air. Wind continues to be the largest source of renewable power in the United States, which helps reduce our reliance on fossil fuels. Wind energy helps avoid 329 million metric tons of carbon dioxide emissions annually – equivalent to 71 million cars worth of emissions that along with other atmospheric emissions cause acid rain, smog, and greenhouse gases.
- Wind power benefits local communities. Wind projects deliver an estimated $1.9 billion in state and local tax payments and land-lease payments each year. Communities that develop wind energy can use the extra revenue to put towards school budgets, reduce the tax burden on homeowners, and address local infrastructure projects.
- Wind power is cost-effective. Land-based, utility-scale wind turbines provide one of the lowest-priced energy sources available today. Furthermore, wind energy's cost competitiveness continues to improve with advances in the science and technology of wind energy.
- Wind turbines work in different settings. Wind energy generation fits well in agricultural and multi-use working landscapes. Wind energy is easily integrated in rural or remote areas, such as farms and ranches or coastal and island communities, where high-quality wind resources are often found.

Challenges of Wind Power

- Wind power must compete with other low-cost energy sources. When comparing the cost of energy associated with new power plants, wind and solar projects are now more economically competitive than gas, geothermal, coal, or nuclear facilities. However, wind projects may not be cost-competitive in some locations that are not windy enough. Next-generation technology, manufacturing improvements, and a better understanding of wind plant physics can help bring costs down even more.
- Ideal wind sites are often in remote locations. Installation challenges must be overcome to bring electricity from wind farms to urban areas, where it is needed to meet demand. Upgrading the nation's transmission network to connect areas with abundant wind resources to population centers could significantly reduce the costs of expanding land-based wind energy. In addition, offshore wind energy transmission and grid interconnection capabilities are improving.
- Turbines produce noise and alter visual aesthetics. Wind farms have different impacts on the environment compared to conventional power plants, but similar concerns exist over both the noise produced by the turbine blades and the visual impacts on the landscape.
- Wind plants can impact local wildlife. Although wind projects rank lower than other energy developments in terms of wildlife impacts, research is still needed to minimize wind-wildlife interactions. Advancements in technologies, properly siting wind plants, and ongoing environmental research are working to reduce the impact of wind turbines on wildlife.

	Recent years	2030	2050
Heat pumps in industry (in millions)	<1 (8)	35	80
Heat pumps in buildings (in millions)	58 (9)	447	793
Investment needed in heat pumps (USD billion/year)	64 (10)	237	230
Clean hydrogen production[b] (million tonnes per year)	0.7 (11)	125	523
Investment needs in clean hydrogen and derivitives infrastructure (including electrolysers, feedstock and infrastructure) (USD billion/year)	1.1 (12)	100	170
Industrial consumption of clean hydrogen (EJ)	0	14.4	40

Source: (IRENA, 2023b).

Notes: 1. 2020; 2. 2020; 3. 2020; 4. 2020; 5. 2020; 6. 2022; 7. 2020; 8. 2020; 9. 2020; 10. 2022; 11. 2021 - clean hydrogen here refers to the combination of hydrogen produced by electrolysis powered by renewables (green hydrogen) and hydrogen produced from natural gas in combination with carbon capture and storage (blue hydrogen); 12. 2022.

BOX I.1 | Electrification and energy security in Europe

The onset of the crisis in Ukraine in February 2022 triggered a severe energy crisis in Europe. Not only did the price of natural gas from Russia soar, but electricity prices also climbed steeply because of the still high use of gas to generate power. As a result, European industries, which are highly reliant on natural gas, are losing competitiveness, and energy bills for European citizens have soared dramatically.

This energy crisis is revealing the need for Europe to accelerate its energy transition. In addition to lessening the impacts of climate change, resilient and more secure energy systems will ensure stability, competitiveness, affordability and sustainability. Integrating high shares of renewables in the power system and using the resulting clean electricity to fuel end uses will decrease the dependence on gas that helped cause the current crisis. The current energy crisis in Europe may ultimately be an accelerator for the much-needed energy transition.

Snapshot freddy © Shutterstock.com

The idea is called: Agrivoltaics

Agrivoltaics is the use of land for both agriculture and solar photovoltaic energy generation. It's also sometimes referred to as agrisolar, dual use solar, low impact solar. Solar grazing is a variation where livestock graze in and around solar panels. This system looks at agriculture and solar energy production as compliments to the other instead of as competitors. By allowing working lands to stay working, agrivoltaic systems could help farms diversify income. Other benefits include energy resilience, and a reduced carbon footprint.

A symbiotic 'cooling' relationship occurs when growing crops (or native grasses and forbs) under solar panels. Together, each helps keep the other cool. While all crops need sunlight to grow, too much can cause some to get stressed, especially cool season plants such as brassicas. Plants growing under the diffused shade of photovoltaic panels are buffered from the day's most intense rays. Shade reduces air temperature and the amount of water evaporating from soils; a win-win for both plants and farm workers on hot summer days. The plants in turn give off water vapor that helps to naturally cool the photovoltaic panels from below, which can increase panel efficiency.

Agrivoltaics in the Northeast

The largest agrivoltaics site in the U.S. is on a blueberry farm in Rockport, Maine. This new 10-acre, 4.2-megawatt project is the first of its kind in the state, and will offer critical insights and experience. Researchers from University of Maine Cooperative Extension are evaluating the impact of panel installation on the blueberry plants. They will also see how the crop fares over time under the solar array.

Another form of agrivoltaics seen across the Northeast integrates livestock and pastures. This concept is commonly referred to as 'solar grazing.' It has taken off in recent years as a win-win-win for farmers, solar companies, and the environment. Traditionally, the grasses that would grow up between solar panels need to be mowed to prevent the plants from shading the panels and reducing their efficiency. However, when sheep can be used, the high maintenance costs associated with mowing are eliminated for the solar company. At the same time, local shepherds can benefit from an added revenue stream to graze their sheep at these sites. Removing mowing operations not only keeps grassy areas safer for wildlife (i.e., nesting ground birds), but means less fuels and emissions too.

Researchers and farmers around the country are currently experimenting and collecting data on what crops, pollinator plants, and/or livestock situations work best with photovoltaic setups. Agrivoltaic systems can offer farmers many exciting opportunities. How agricultural systems perform, and how project economics shake out is still to be determined. Also to be seen is how states and communities will decide to address policy regulations and/or zoning laws based on this dual land use option.

Agrivoltaics Research

The U.S. Department of Energy is supporting solar development and agriculture with their InSPIRE program. This program is managed by the National Renewable Energy Laboratory

(NREL). It seeks to improve the mutual benefits of solar, agriculture, and native landscapes. Currently, there are 22 projects sites across the U.S. These bring together a wide array of researchers, farmers, and industry partners.

NREL research projects located in the Northeast:

- University of Massachusetts Amherst: Researchers are studying the effects of co-locating solar energy panels and agriculture operations at up to eight different farms across the state. This research will help farmers and communities make informed decisions about solar.
- Cornell University: Researchers are looking at the benefits of pollinator-friendly plantings on solar farms. One goal is to see if wildflower plantings on solar sites can increase pollinator populations. Another is to see if wildflower plantings on solar farms encourage pollinators to visit crop flowers. Other Cornell research is looking at how sheep grazing may influence pollinator habitat and sequestration of soil carbon.

Other regional agrivoltaic research projects of note:

- Rutgers University: In June 2021 the Dual-use Solar Act was passed in New Jersey. This act set up a pilot program "to enable a limited number of farmers to have agrivoltaic systems on their property while the technology is being tested, observed and refined." Funds also went to the New Jersey Agricultural Experiment Station to build and study agrivoltaic systems on their research farms.
- University of Vermont: This past fall, UVM Extension's Center for Sustainable Agriculture put on a workshop called, Solar Energy in Vermont's Working Landscape. The event brought together experts and stakeholders to address existing practices and barriers to solar grazing adoption as well as requirements for long-term success in the state. Before this, the Center's pasture program worked with Vermont Agency of Agriculture, Food & Markets and Two Rivers-Ottauquechee Regional Commission. They developed guides for how to "balance the needs of community and farm-scale energy needs with a shared commitment to protecting agricultural lands."

While a lot of research is underway, many questions about agrivoltaic systems persist. Various research and demonstration sites around the country are working to find answers to questions like: What are the long-term impacts of solar energy infrastructure on soil quality? What crops, in what regions, are best suited for photovoltaic systems? How can both crop and energy systems be optimized? How will livestock (and wildlife) interact with solar energy equipment? What types of business agreements will work best between a solar developer or company and agricultural producer or landowner?

Five Ways to Jump-Start the Renewable Energy Transition Now

United Nations, 2023

Four key climate change indicators – greenhouse gas concentrations, sea level rise, ocean heat and ocean acidification – set new records in 2021. This is yet another clear sign that human activities are causing planetary-scale changes on land, in the ocean, and in the atmosphere, with dramatic and long-lasting ramifications.

The key to tackling this crisis is to end our reliance on energy generated from fossil fuels - the main cause of climate change.

"The good news is that the lifeline is right in front of us," says UN Secretary-General António Guterres, stressing that renewable energy technologies like wind and solar already exist today, and in most cases, are cheaper than coal and other fossil fuels. We now need to put them to work, urgently, at scale and speed.

The Secretary-General outlines five critical actions the world needs to prioritize now to transform our energy systems and speed up the shift to renewable energy - "because without renewables, there can be no future."

Make renewable energy technology a global public good

For renewable energy technology to be a global public good - meaning available to all, and not just to the wealthy - it will be essential to remove roadblocks to knowledge sharing and technological transfer, including intellectual property rights barriers.

Essential technologies such as battery storage systems allow energy from renewables, like solar and wind, to be stored and released when people, communities and businesses need power. They help to increase energy system flexibility due to their unique capability to quickly absorb, hold and re-inject electricity, says the International Renewable Energy Agency.

Moreover, when paired with renewable generators, battery storage technologies can provide reliable and cheaper electricity in isolated grids and to off-grid communities in remote locations.

Improve global access to components and raw materials

A robust supply of renewable energy components and raw materials is essential. More widespread access to all the key components and materials - from the minerals needed to produce wind turbines and electricity networks, to electric vehicles - will be key.

It will take significant international coordination to expand and diversify manufacturing capacity globally. Moreover, greater investments are needed to ensure a just transition - including in people's skills training, research and innovation, and incentives to build supply chains through sustainable practices that protect ecosystems and cultures.

Level the playing field for renewable energy technologies

While global cooperation and coordination is critical, domestic policy frameworks must urgently be reformed to streamline and fast-track renewable energy projects and catalyze private sector investments.

Technology, capacity and funds for renewable energy transition exist, but there needs to be policies and processes in place to reduce market risk and enable and incentivize investments - including through streamlining the planning, permitting and regulatory processes, and preventing bottlenecks and red tape. This could include allocating space to enable large-scale build-outs in special Renewable Energy Zones.

Nationally Determined Contributions, countries' individual climate action plans to cut emissions and adapt to climate impacts, must set 1.5C aligned renewable energy targets - and the share of renewables in global electricity generation must increase from today's 29 percent to 60 percent by 2030.

Clear and robust policies, transparent processes, public support and the availability of modern energy transmission systems are key to accelerating the uptake of wind and solar energy technologies.

Shift energy subsidies from fossil fuels to renewable energy

Fossil-fuel subsidies are one of the biggest financial barriers hampering the world's shift to renewable energy. The International Monetary Fund (IMF) says that about $5.9 trillion was spent on subsidizing the fossil fuel industry in 2020 alone, including through explicit subsidies, tax breaks, and health and environmental damages that were not priced into the cost of fossil fuels. That's roughly $11 billion a day.

Fossil fuel subsidies are both inefficient and inequitable. Across developing countries, about half of the public resources spent to support fossil fuel consumption benefits the richest 20 percent of the population, according to the IMF.

Shifting subsidies from fossil fuels to renewable energy not only cuts emissions, it also contributes to the sustainable economic growth, job creation, better public health and more equality, particularly for the poor and most vulnerable communities around the world.

Triple investments in renewables

At least $4 trillion a year needs to be invested in renewable energy until 2030 – including investments in technology and infrastructure – to allow us to reach net-zero emissions by 2050.

Not nearly as high as yearly fossil fuel subsidies, this investment will pay off. The reduction of pollution and climate impact alone could save the world up to $4.2 trillion per year by 2030.

The funding is there - what is needed is commitment and accountability, particularly from the global financial systems, including multilateral development banks and other public and private financial institutions, that must align their lending portfolios towards accelerating the renewable energy transition.

In the Secretary-General's words, "renewables are the only path to real energy security, stable power prices and sustainable employment opportunities."

can purchase energy shares, each worth €100, related with their specific annual consumption. For example, a standard household with an average annual electricity consumption of 2,400 kilowatt hours needs to invest €900 to cover 70% of its energy demand for 25 years. Every €100 contribution corresponds to 170-200 kWh per year, which will be compensated from the energy bill with Som Energia. The cost of generation is roughly 3.5-4 cents per kilowatt hour, whereas the current market price is about 4.5-5 cents per kilowatt hour. Thus, the participants can save 1 cent per kilowatt hour while other costs such as taxes, grid access fees and so on stay the same (Roselló, 2015). After 25 years the sum originally invested will be returned to the investor and, during this period, the investor enjoys energy bill savings. Implemented in 2015, the project bore fruit in May 2016 as the first collectively-owned solar field providing energy to about 1,300 households started to work. In total, more than 2,700 people have already participated and together they have invested more than €2,548,400, which will be invested in even more community-owned power plants (Palmada, 2016). The great support for the Generation kWh project is a perfect example of what citizens want: to participate and be part of the change.

Collective Self-Consumption in Cities

This is not the only example of how citizens can take power into their own hands. Generation kWh works on bigger installations but how can solar energy be generated and consumed in cities? For instance, Barcelona has a surface area of more than 100km2. Nobody would expect 100km2 to be completely covered by solar panels but there are so many rooftops or building façades that can be used for producing energy. The potential resources of installing PV in this city are 7-14 MW of PV technology installed on public and private rooftops. Installing PV panels on buildings means that the energy is produced where it is needed: in crowded areas where somebody is always using the oven, charging an electric car or washing clothes (Camaño-Martín, 2008).

The Mieterstrom Model for Self-Consumption in Cities

To put this into effect, the German Mieterstrom neighbour solar supply model can be used. It shows how residents can get access to power generated on their building rooftops. The functioning of the Mieterstrom model is quite simple: neighbour solar supply is based on locally-generated electricity and this electricity is used directly by the tenants in multi-family houses or neighbourhoods. An energy provider offers to supply PV electricity to the residents of a building directly from the roof and to supply energy via the grid if there is no energy being generated at a given moment. One important detail of this model is that not all the tenants have to participate. About 50-75% of the total electricity production can be used, and participating households usually cover 35% of their own electricity requirements via the PV (Zuber, 2017). The advantage is that the consumer does not have to pay high investment costs for a solar installation on a building where they might only stay for a few years but they receive electricity produced as locally as possible. Furthermore, they will pay a cheaper price because the supplier does not have to pay grid access fees as the energy is supposed to be consumed instantaneously (Roesch, 2013; Dunlop, 2016). In the near future, Spanish people will have a glimmer of hope of getting access to shared self-consumption in buildings. The Constitutional Court of Spain took a step in the right direction and eliminated obstacles to shared self-consumption on 2 June 2017, which had

URANIUM AT A GLANCE

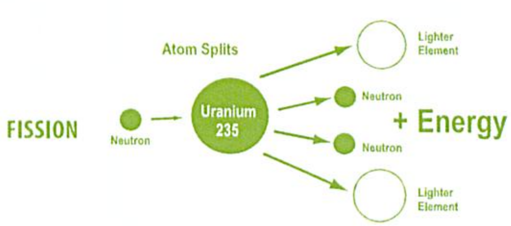
WHAT IS URANIUM?

Uranium is a naturally occurring radioactive element, that is very hard and heavy and is classified as a metal. It is also one of the few elements that is easily fissioned. It is the fuel used by nuclear power plants. Uranium was formed when the Earth was created and is found in rocks all over the world. Rocks that contain a lot of uranium are called uranium ore, or pitch-blende. Uranium, although abundant, is a nonrenewable energy source.

Three forms (isotopes) of uranium are found in nature, uranium-234, uranium-235 and uranium-238. These numbers refer to the number of neutrons and protons in each atom. Uranium-235 is the form commonly used for energy production because, unlike the other isotopes, the nucleus splits easily when bombarded by a neutron. During fission, the uranium-235 atom absorbs a bombarding neutron, causing its nucleus to split apart into two atoms of lighter mass. At the same time, the fission reaction releases energy as heat and radiation, as well as releasing more neutrons. The newly released neutrons go on to bombard other uranium atoms, and the process repeats itself over and over. This is called a chain reaction.

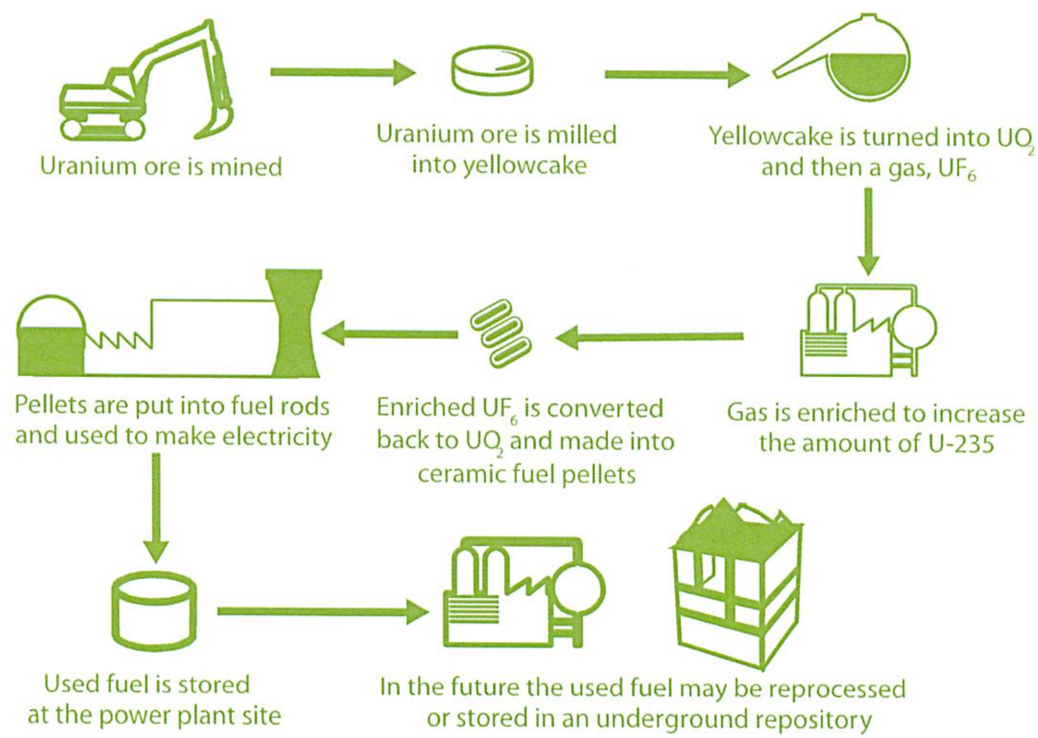
WHAT IS NUCLEAR ENERGY

Nuclear energy is energy that comes from the nucleus of an atom. Atoms are the particles that make up all objects in the universe. Atoms consist of neutrons, protons, and electrons. Nuclear energy is released from an atom through one of two processes: nuclear fusion or nuclear fission. In nuclear fusion, energy is released when the nuclei of atoms are combined or fused together. This is how the sun produces energy, In nuclear fission, energy is released when the nuclei of atoms are split apart. Nuclear fission is the only method currently used by nuclear plants to generate electricity.



URANIUM FUEL CYCLE

The steps—from mining the uranium ore, through its use in a nuclear reactor, to its disposal—are called the uranium fuel cycle.



TOP NUCLEAR STATES

Data: Energy Information Administration, 2017

Luckily, solar is cheaper than ever, thanks to the falling cost and rising efficiency of photovoltaic (PV) solar panels. But here's something to consider: figuring out the real cost of solar energy is about more than just the price tag on the panels and their rated power output. For example, there's the lifespan of the panels to take into account. And then there's the system's "solar energy yield" -- or how much electricity it will actually generate over the course of the year.

Solar panels are rated on efficiency and the power output under standard laboratory conditions. Of course, your solar energy system isn't being installed in a lab. It's going outside, where all kinds of things can change its actual solar energy yield. That's why the Energy Department's Solar Energy Technologies Office (SETO) is funding research into better, tougher modules that can last longer and generate more electricity in less-than-ideal conditions. Read on to learn about three ways the outside world can conspire to cut into your solar energy yield -- and how SETO-funded projects are working on solutions.

MAN, IT'S A HOT ONE

High temperatures reduce the voltage of a solar cell -- which, as you might guess, is a bad thing. Conventional rooftop solar modules can lose as much as 30 percent of their electricity output on hot summer days. Researchers at Arizona State University are trying to address this problem by improving the backsheet -- or bottom layer -- of a solar PV module, which serves as an electrical insulator and protects the module from moisture and other environmental damage. By studying backsheets with different heat-conducting properties, the team hopes to keep solar panels cooler and improve performance in hot weather.

DIRT DOES HURT

Another way panels lose power is simply that they get dirty. The effects of "soiling" (as it's known in the solar industry) vary widely by location, but energy yield losses of 10 percent are not uncommon. Research on environmental conditions and panel maintenance procedures could help us better understand how and why panels lose power to dirt, which in turn could lead to better prediction of soiling from one solar energy system to another and more effective dirt-resistant treatments for PV module glass.

SHADY SITUATIONS

While heat and dirt reduce solar panels' energy yield in a pretty straightforward way, shadows are a bit more complicated. In instances when a faint cloud goes over the solar module, the power levels are simply reduced. However, sometimes the light is completely or regularly blocked by a permanent structure -- like a utility pole that shades just one part of the module -- which can actually cause "hot spots" that can damage the module over time. The University of Michigan, Ann Arbor has a clever solution in the works: its "super-cell" design can actually balance power across the module at the cell level. This lets the unshaded cells keep working normally, increasing the energy yield of the module and even improving its durability.

Increasing energy yield continues to be a fruitful subject of research by SETO awardees. SETO has already made huge advances in solar cell efficiency -- including a recent announcement that a new Ohio State University design has the potential to achieve 40 percent efficiency. Increasing energy yield is what will help drive down the cost of solar power in the real world. Stay tuned for more innovation in this area.

Editor's note: This post was updated on Sept. 21, 2016, to reflect changes in the research projects receiving SETO funding.

DR. LENNY TINKER

Dr. Lenny Tinker is the program manager for the photovoltaics team. He has been at the U.S. Department of Energy Solar Energy Technologies Office (SETO) since September 2011.

MORE BY THIS AUTHOR

involves concentrating the Sun's energy through various methods to increase the intensity of energy hitting the solar cell. For more information about the different types of solar cells, click here. Figure 3 below shows the evolution of solar cell technologies and efficiencies from 1976 to 2017.

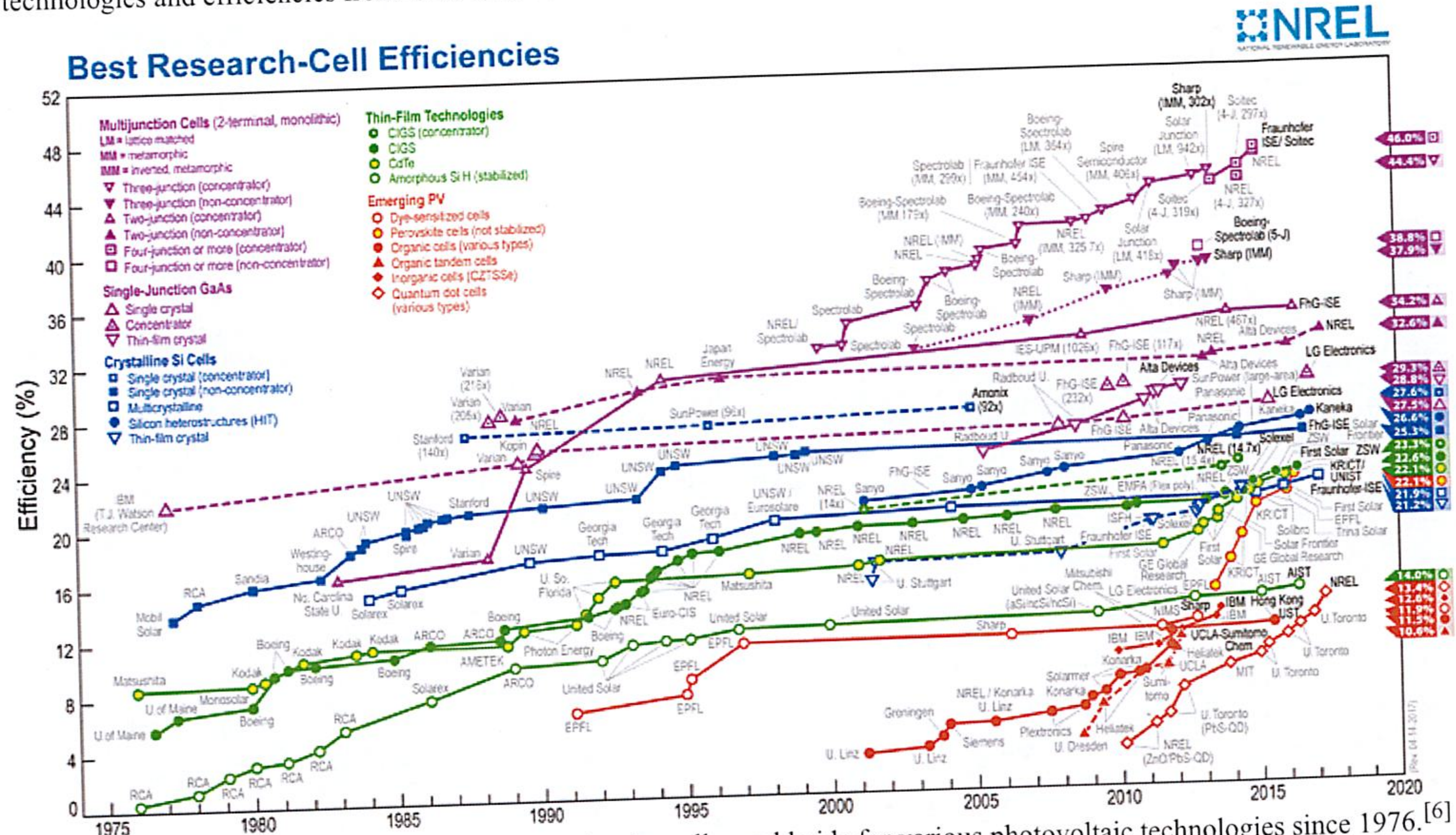


Figure 3. Conversion efficiencies of best research solar cells worldwide for various photovoltaic technologies since 1976.[6]

Power Degradation

Efficiency of solar cells and solar panels are known to decrease over time, outputting less energy every year. This is due to a variety of factors including UV exposure and weather cycles. A comprehensive report from the National Renewable Energy Laboratory (NREL) states that the median degradation rate is 0.5% per year.[7] This means that after 25 years of operation a solar panel originally rated for 300 watts of power output will only produce about 260 watts on average. Degradation in the first year of operation can also be much more profound, at around 2.5%.

For Further Reading

- Sun
- Types of PV cells
- Photovoltaic effect
- Thermal efficiency
- Or explore a random page

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3. $\lambda = \frac{hc}{E} = \frac{(6.626 kg*m^2/s)\times(3\times10^8 m/s)}{1.12eV} \times \frac{1eV}{1.6\times10^{-19}J} = 1.1\mu m$

Solar Energy

Solar energy systems use the sun's rays for electricity or thermal energy. In the United States, utility scale solar power plants are located primarily in the Southwest. However, smaller scale rooftop photovoltaic cells and hot water systems are effective in all regions. The United States has some of the best solar resources in the world, but solar made up only 0.4 percent (http://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3) of U.S. energy supply in 2014. The main barrier to widespread implementation has been the relatively high initial investment; however, costs have been decreasing in recent years. Federal tax credits are available, and many states offer incentives as well. Countries such as Germany have successfully used policy mechanisms such as feed-in tariffs to become the world leaders in solar energy production. The current U.S. industry is growing and employs 173,807 people (http://www.thesolarfoundation.org/solar-jobs-census/national/).

There are two ways to harness solar energy. **Passive systems** are structures whose design, placement, or materials optimize the use of heat or light directly from the sun. **Active systems** have devices to convert the sun's energy into a more usable form, such as hot water or electricity.

Passive Sytems

Grey

Grey hydrogen is currently the most common, and the cheapest, form of hydrogen production. It is used as a fuel and doesn't generate greenhouse gas emissions itself, but its production process does. Grey hydrogen is created from natural gas using steam reforming, which separates the hydrogen from the natural gas. However, the technologies used don't capture the carbon emissions created during the process, which are instead released into the atmosphere.

Blue

Blue hydrogen is also extracted using the steam reforming process, but it differs from grey as the carbon emissions released are captured and stored, which reduces the emissions in the atmosphere, but doesn't eliminate them. Blue hydrogen is sometimes called 'low-carbon hydrogen' as the production process doesn't avoid the creation of greenhouse gases, just stores them away.

Green

Green hydrogen doesn't generate any emissions in its entire life cycle as it uses renewable energies in the production process, making it a true source of clean energy. It is made by electrolyzing water using clean electricity created from surplus renewable energy from wind and solar power. The process causes a reaction that splits water into its components of hydrogen and oxygen (the H and O in H2O). This results in no carbon emissions being released in the process. It's a great alternative to grey and blue, but for now the main challenge is in reducing the production costs of green hydrogen to make it a truly obtainable renewable and environmentally friendly alternative.

Beyond the three biggest types of hydrogen, there's a whole array of other color options.

Source: https://www.acciona.com.au/updates/stories/what-are-the-colours-of-hydrogen-and-what-do-they-mean/?_adin=02021864894