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NEW YORK 2024

RENEWABLE ENERGY FOR A SUSTAINABLE FUTURE

2024 Current Environmental Issue

STUDY RESOURCES

Part A

Renewable Energy for a Sustainable Future

Current Environmental Issue Study Resources- Part A

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Current Issue Part A Study Resources

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Study Resources

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Introduction to Energy

Paleontological Research Institution – April 7, 2022

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

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

What is energy?

Energy is an interdisciplinary topic, and the concepts used to understand energy in the Earth system are fundamental to all disciplines of science. One cannot study physics or understand biomes, photosynthesis, fire, evolution, seismology, chemical reactions, or genetics without considering energy. Everything we do depends upon energy—without it there would be no civilization, no sunlight, no food, and no life. Energy moves people and goods, produces electricity, and heats our homes and businesses. It is used in manufacturing and other industrial processes.

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

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

The transition from brute force and burning wood to the production and use of various industrial sources of energy has occurred remarkably quickly, happening in the course of just a few generations. Much of the rural US was without access to electricity until the 1930s, and cars have been around for only slightly longer. Yet, many of us take these conveniences for granted today. The transition to industrial sources of energy has caused changes in virtually every aspect of human life, from transportation to economics to war to architecture. In the US, every successive generation has enjoyed the luxury of more advanced technology (e.g., the ability to travel more frequently, more quickly, and over greater distances). Especially as the global population grows and standards of living increase in some parts of the world, so too does global energy demand continue to grow.

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

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

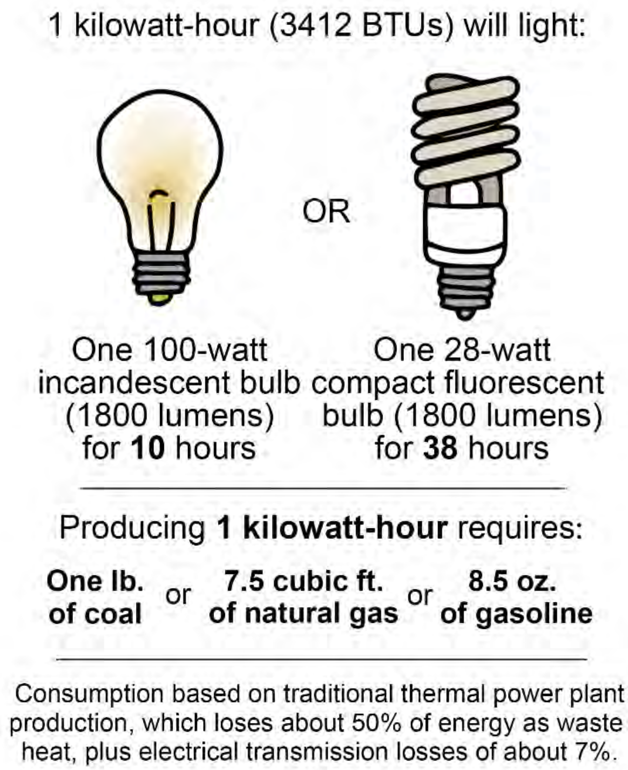
What do different units of energy mean?

Heat is energy. Measurements of heat can be thought of as the most basic way to measure energy. The British thermal unit (abbreviated BTU or BTU) is the most commonly used unit for heat energy. By definition, one BTU is approximately the amount of heat required to raise one pound of water by one degree Fahrenheit. One BTU is also about the amount of energy released by burning a single wooden match.

A joule is the energy expended (or work done) to apply a force of one newton over a distance of one meter. Since a typical apple weighs about one newton (about 100 grams or 3.6 ounces), lifting an apple one meter requires about a joule of energy. A BTU is roughly 1055 joules. That means that one BTU—the energy contained in a wooden match—is equivalent to the total amount of energy required to lift an apple 1055 meters (about 3461 feet) or a bit over one kilometer (about 0.66 or 2/3 miles).

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

Another measure of energy, the kilowatt-hour (kWh), represents the amount of energy required to light ten 100-watt light bulbs for one hour. One kWh is about 3412 BTUs or about 3.6 million joules.

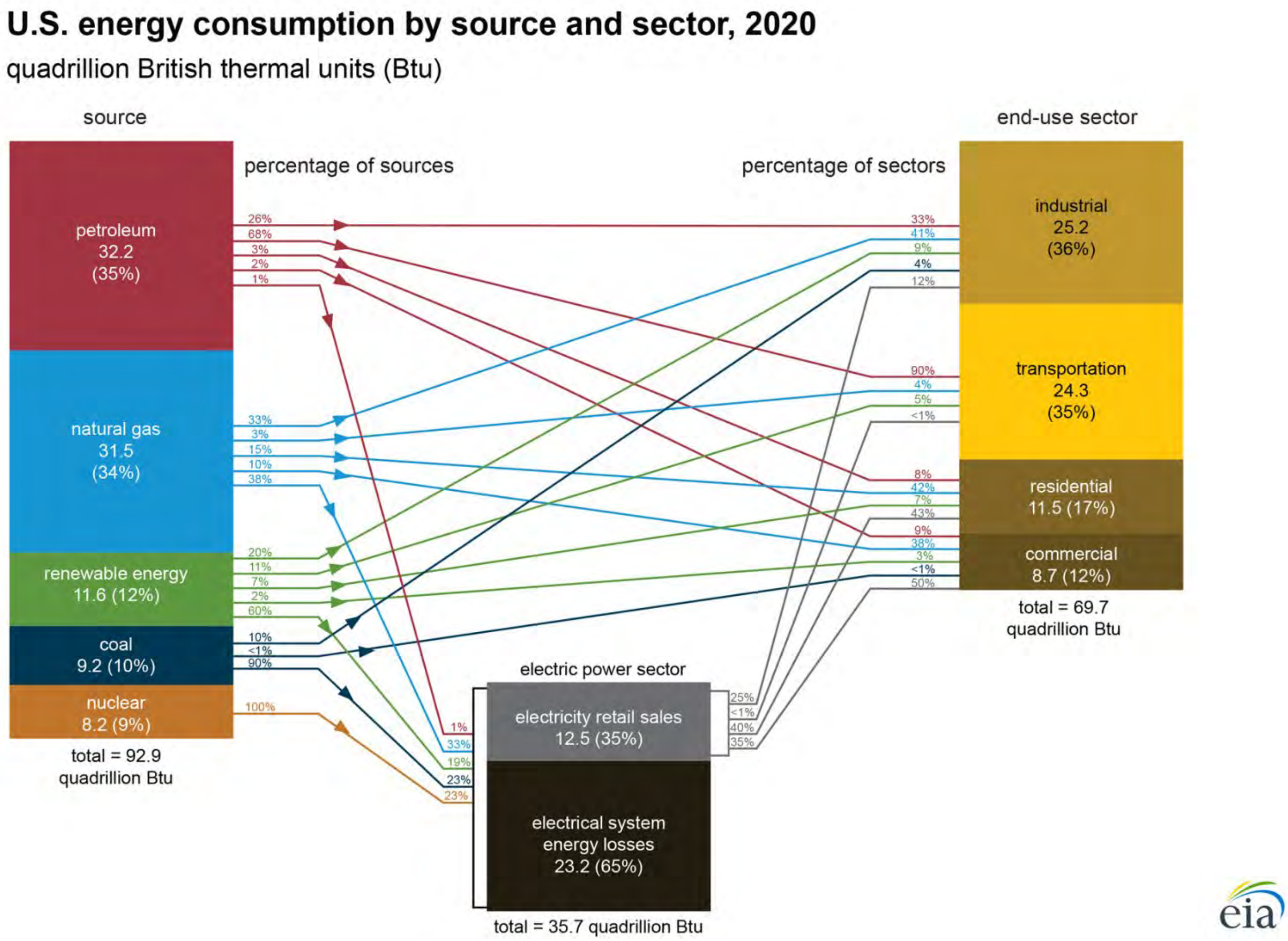


Examples of uses and sources of 1 kWh. 1kWh will light a 100-watt incandescent lighbulb for 10 hours and one 28-watt compact fluorescent bulb for 38 hours. Producing 1kWh requires one pound of coal or 7.5 cubic feet of natural gas or 8.5 ounces of gasoline. About 50% of energy used is lost as waste and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

How do we look at energy in the Earth system?

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

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



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

Becoming "energy literate"

Energy is neither lost nor gained within the universe, but rather is constantly flowing through the Earth system. In order to fully understand energy in our daily lives and make informed decisions, we need to understand energy in the context of that system. Becoming energy literate gives us the tools to apply this understanding to solving problems and answering questions.

Energy Literacy Principles*

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

1. Energy is a physical quantity that follows precise natural laws.
2. Physical processes on Earth are the result of energy flow through the Earth system.
3. Biological processes depend on energy flow through the Earth system.
4. Various sources of energy can be used to power human activities, and often this energy must be transferred from source to destination.

5. Energy decisions are influenced by economic, political, environmental, and social factors.
6. The amount of energy used by human society depends on many factors.
7. The quality of life of individuals and societies is affected by energy choices.

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

Fossil fuels

Fossil fuels—oil, natural gas, and coal—are made of the preserved organic remains of ancient organisms. Organic matter is only preserved when its rate of accumulation is higher than the rate of its decay. This most often happens when the oxygen supply is so low that aerobic bacteria (oxygen-loving bacteria) cannot thrive, which greatly slows the breakdown of organic matter. When organic matter does not break down, over time it will be incorporated into buried sediment. After burial, the organic material is compacted and heated with the rest of the rock, eventually transforming it into fossil fuels.

The history of surface environments, evolution of life, and geologic processes beneath the surface have all influenced where fossil fuel deposits formed and accumulated. Coal is formed when preserved plant matter is buried, compacted, and heated. The largest coal beds were swampy environments where fallen forest trees and leaves were buried in stagnant muds. Petroleum and natural gas originate deep underground through a slow process that involves the heating of sedimentary rocks that contain an abundance of organic matter. The largest oil and gas reserves were at one time nutrient-rich seas with abundant surface phytoplankton and organic-rich bottom sediments.

Oil and natural gas

Oil and natural gas form from organic matter in the pores of sediments subjected to heat and pressure. The organic matter is primarily composed of photosynthetic plankton that die and sink to the bottom of large water bodies in vast numbers. Shale in particular is often organic rich, because organic matter settles and accumulates in the same places that mud (clay and silt particles) settles out of the water.

In most environments, organic matter is recycled by bacteria before it can be buried, but the quiet waters where mud accumulates are often relatively stagnant and low in oxygen. In these places, the bacterial decay rate is low relative to the rate at which organic matter sinks and becomes buried in muddy sediments. Under such conditions, organic matter may accumulate enough to make up several percent or more of the deposited sediment.

Oil and gas reservoirs

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

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

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

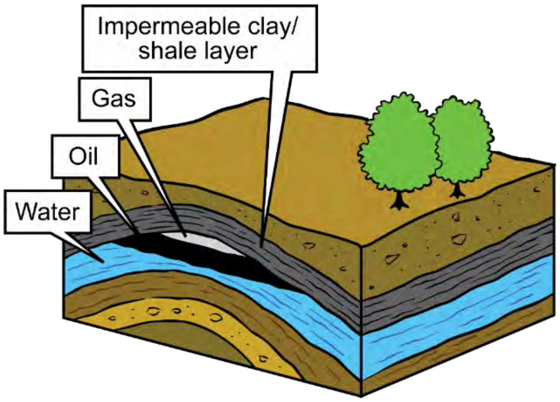


Diagram of an oil and gas reservoir. In this image, natural gas and fluids (water and oil) have accumulated in a layer of permeable reservoir rock, where they are separated by density (gas is lightest, water densest). An impermeable clay or shale layer that has been folded serves as a barrier to further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

Oil shale or shale oil?

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

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

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

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

Natural asphalt

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

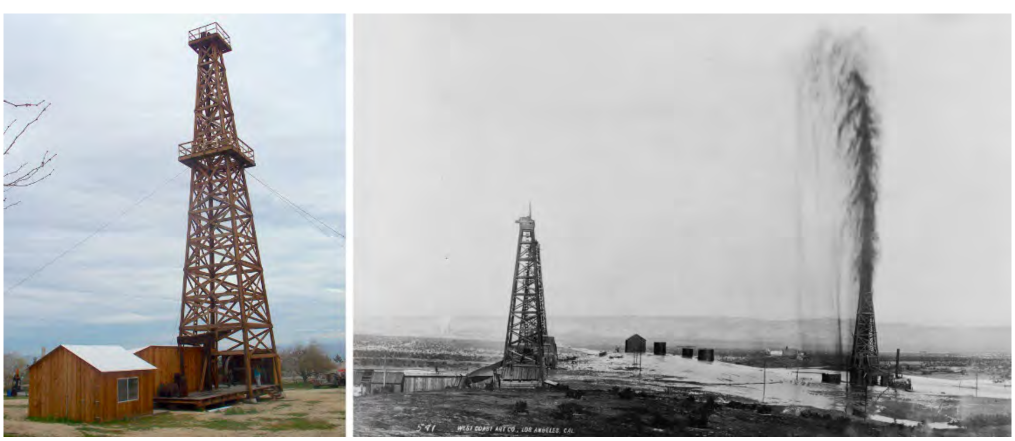
Natural asphalt seeps (tar pits) in California. ***Left:*** *Bubbles in a tar pit in La Brea, Los Angeles, California. Photo by Daniel Schwen (Wikimedia Commons, Creative Commons Attribution license 2.5 Generic license, image cropped).* ***Right:*** *Asphalt seep in Carpinteria, Califronia. Photo by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

Oil drilling

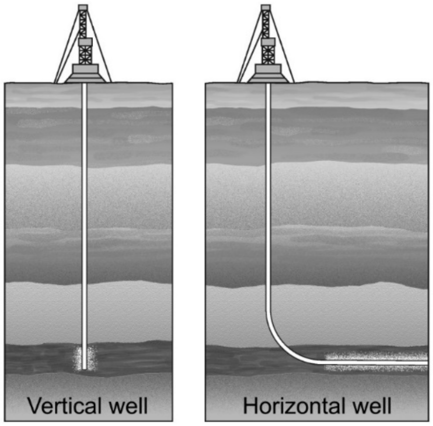
Conventional wells

Once an oil trap or reservoir rock has been detected on land, oil crews excavate a broad, flat pit for equipment and supplies around the area where the well will be drilled. Once the initial hole is prepared, an apparatus called a drilling rig is set up. The rig is a complex piece of machinery designed to drill through rock to a predetermined depth. A typical drilling rig usually contains generators to power the system, motors and hoists to lift the rotary drill, and circulation systems to remove rock from the borehole and lubricate the drill bit with mud.

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



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



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

The support structure used to hold the drilling apparatus is called a derrick. In the early days of oil exploration, drilling rigs were semi-permanent structures and derricks were left onsite after the wells were completed. Today, however, most rigs are mobile and can be moved from well to well. Once the well has been drilled to a depth just above the oil reservoir, a cement casing is poured into the well to structurally reinforce it. Once the casing is set and sealed, oil is then allowed to flow into the well, the rig is removed, and production equipment can be put in place to extract the oil.

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

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

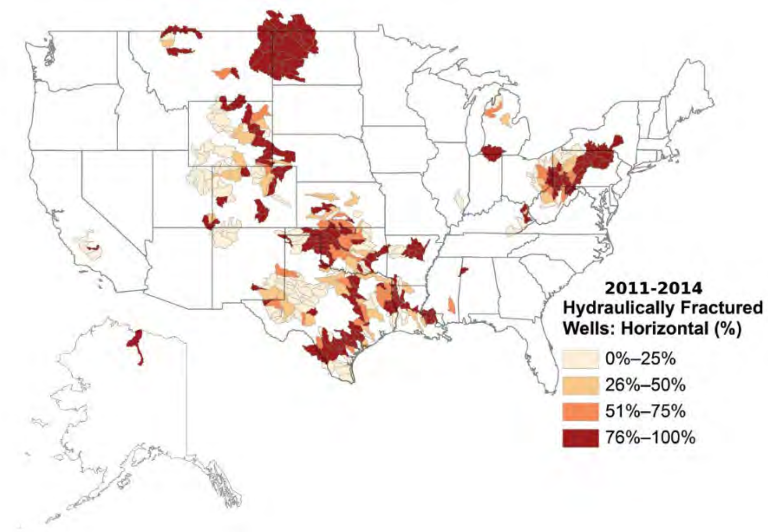
Hydraulic fracturing ("fracking")

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

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

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

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



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

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

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

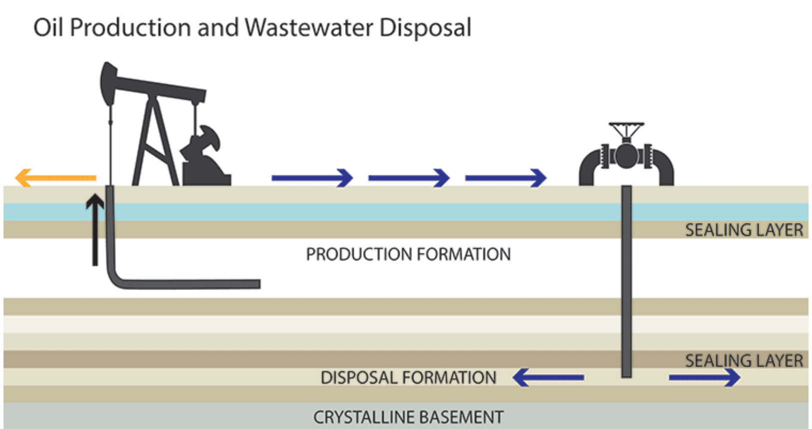
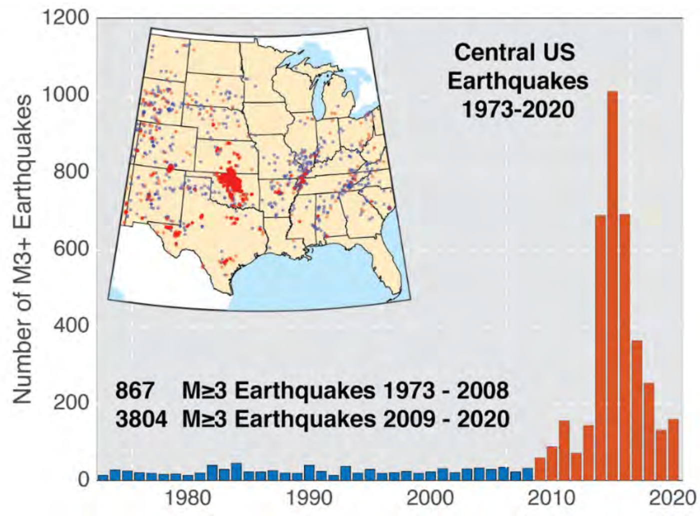


Diagram showing pumping of oil (left) and injection of wastewater into a well (right). Note that wastewater is injected deep underground beneath a sealing layer of impermeable rock. [Source: USGS (public domain)](#).

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

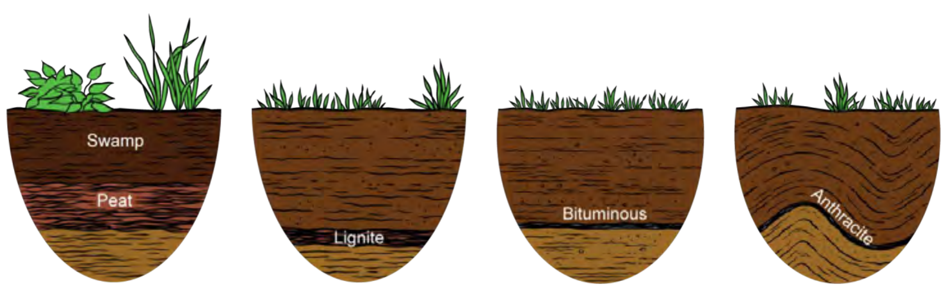


Coal

How does coal form?

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

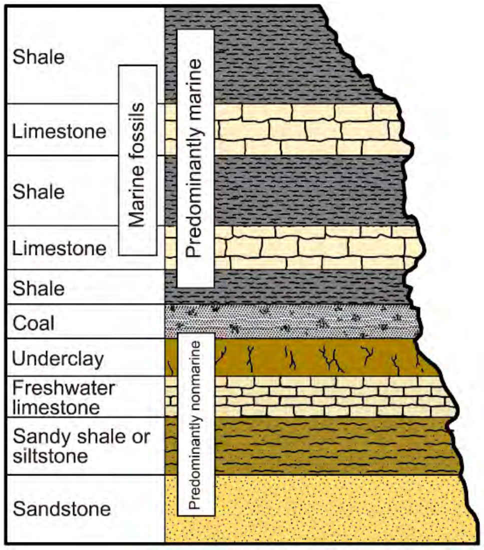
Over time, the coal may become more carbon rich as water and other components are squeezed out. Peat may become lignite, bituminous, and eventually anthracite coal. By the time a peat bed has been turned into a layer of anthracite, they layer is one-tenth of its original thickness and is up to 95% carbon.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



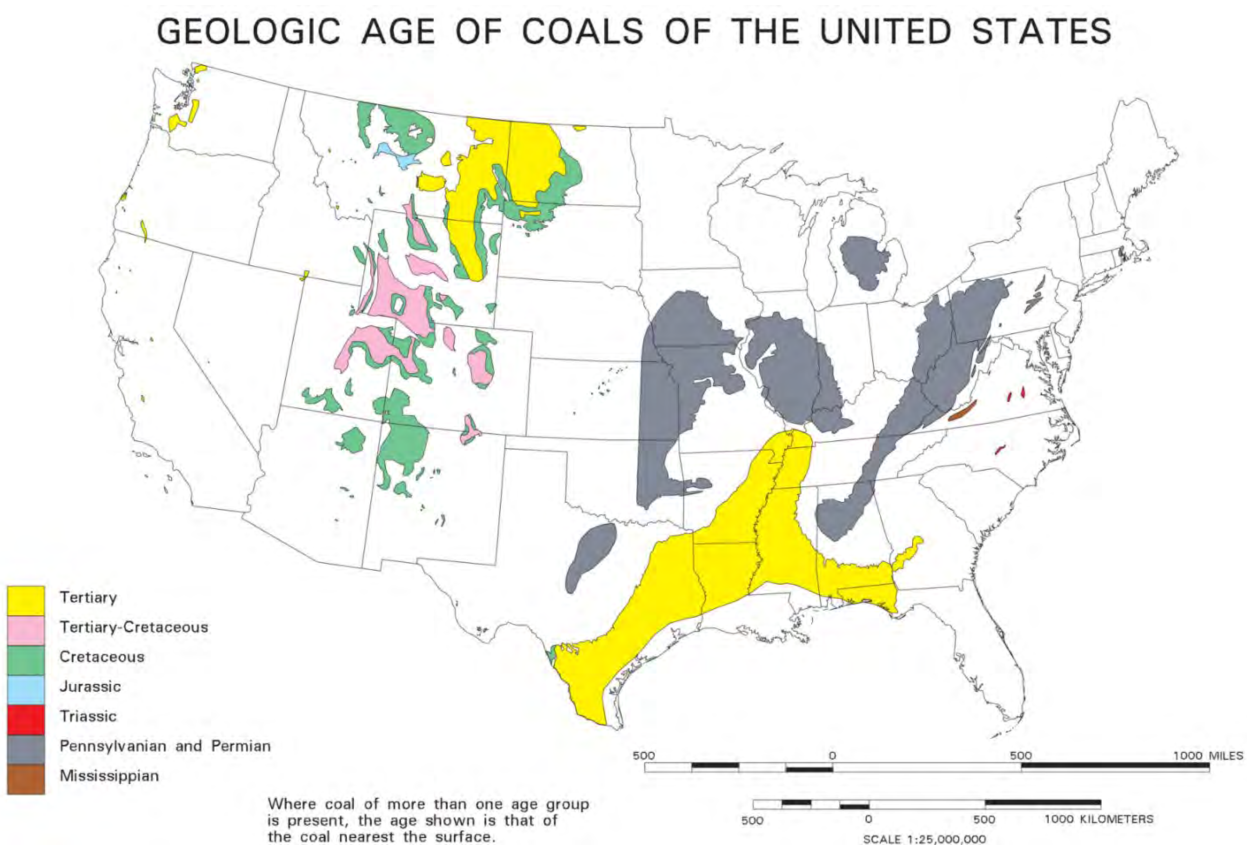
Stages in the formation of coal, from left to right: Peat is buried beneath a swamp. Through compaction and loss of water, it forms lignite. Through further compression, the coal transforms into bituminous coal and finally anthracite coal. Image modified from original by Jim Houghton, published in The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

When did coal form?

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



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



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

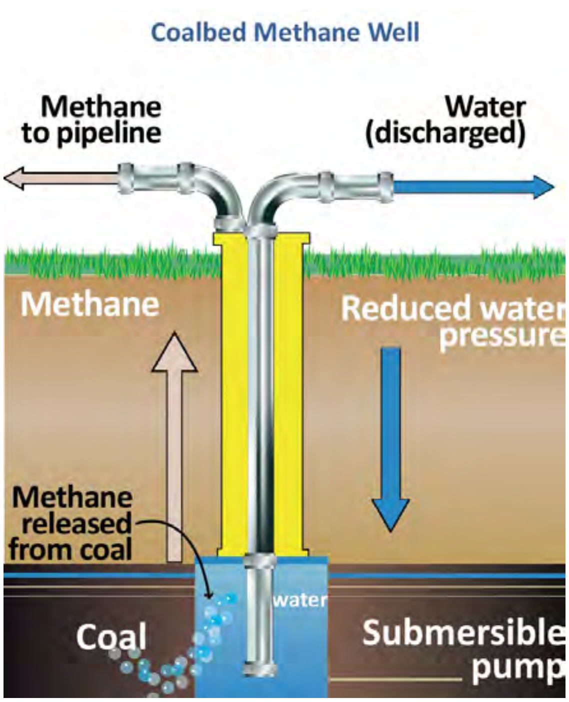
Thick coal deposits are not found in coastal deposits and deltas that formed during earlier times even though geologic and climatic conditions were similar. This is because the plants that made up the coastal swamp forests that produced enough biomass to form large peat deposits had not yet evolved.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

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

Coalbed methane

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

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



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

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

Renewable energy

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

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

Bioethanol and biomass plants

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

Geothermal energy

Geothermal energy comes from heat within the Earth, which is created on an ongoing basis by radioactivity. This energy powers mantle convection and plate tectonics. The highest-temperature conditions exist in tectonically active areas, like the Basin and Range of the western US, Iceland (part of the mid-Atlantic ridge), Japan (an area of subduction), and Hawaii and Yellowstone (areas with hot spots).

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

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

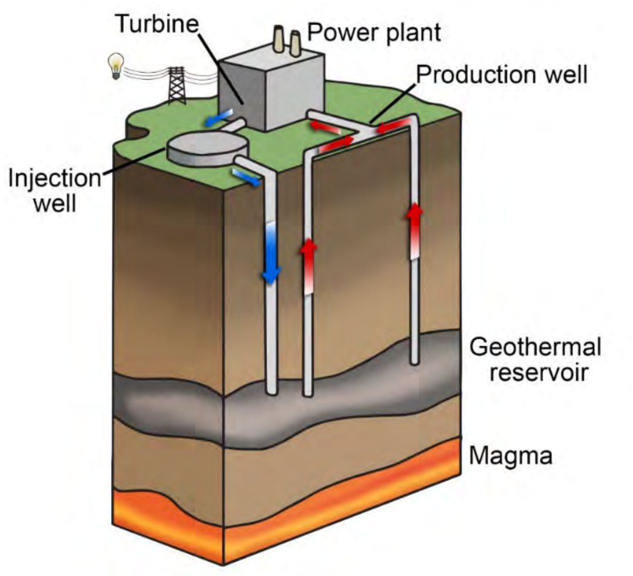


Diagram of a geothermal plant. Image modified from original by Wade Greenberg-Brand, published in The Teacher-Friendly Guide to the Geology of the Northwest Central US, edited by Mark D. Lucas, Robert M. Ross, and Andrielle N. Swaby (published by the Paleontological Research Institution, 2015) (CC BY-NC-SA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

Hydroelectricity

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

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

Wind energy

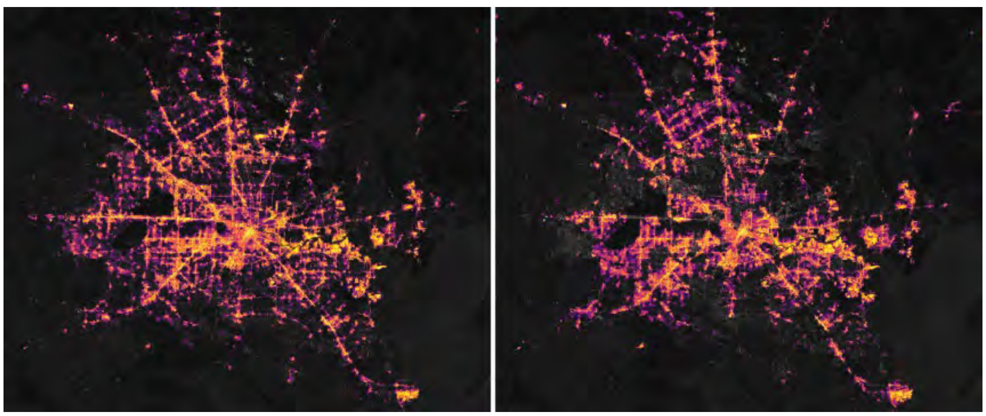
Economically useful wind energy depends on steady high winds. Variation in wind speed is in large part influenced by the shape and elevation of the land surface. For example, higher elevations tend to have higher wind speeds, and flat areas can allow winds to pick up speed without interruption; thus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

Some regions may have locally high wind speeds that can support strategically placed wind farms. Constricted valleys parallel to wind flow may funnel air into high velocities. Elevated ridges perpendicular to wind flow can also force fast winds across them. Thus, the wind velocities of these areas can vary geographically in quite complicated ways.

The future of energy in the US

Americans have come to rely on a diverse and abundant energy system, one that provides a continuous supply of energy with few interruptions. However, climate change is projected to play a big part in altering our supply, production, and demand for energy. Increases in temperatures will be accompanied by an increase in the need for energy for cooling. At the same time, projected increases in the number of severe weather events—hurricanes, floods, tornados, winter storms, and other extreme weather—will continue to have a significant effect on energy infrastructure like power grids.

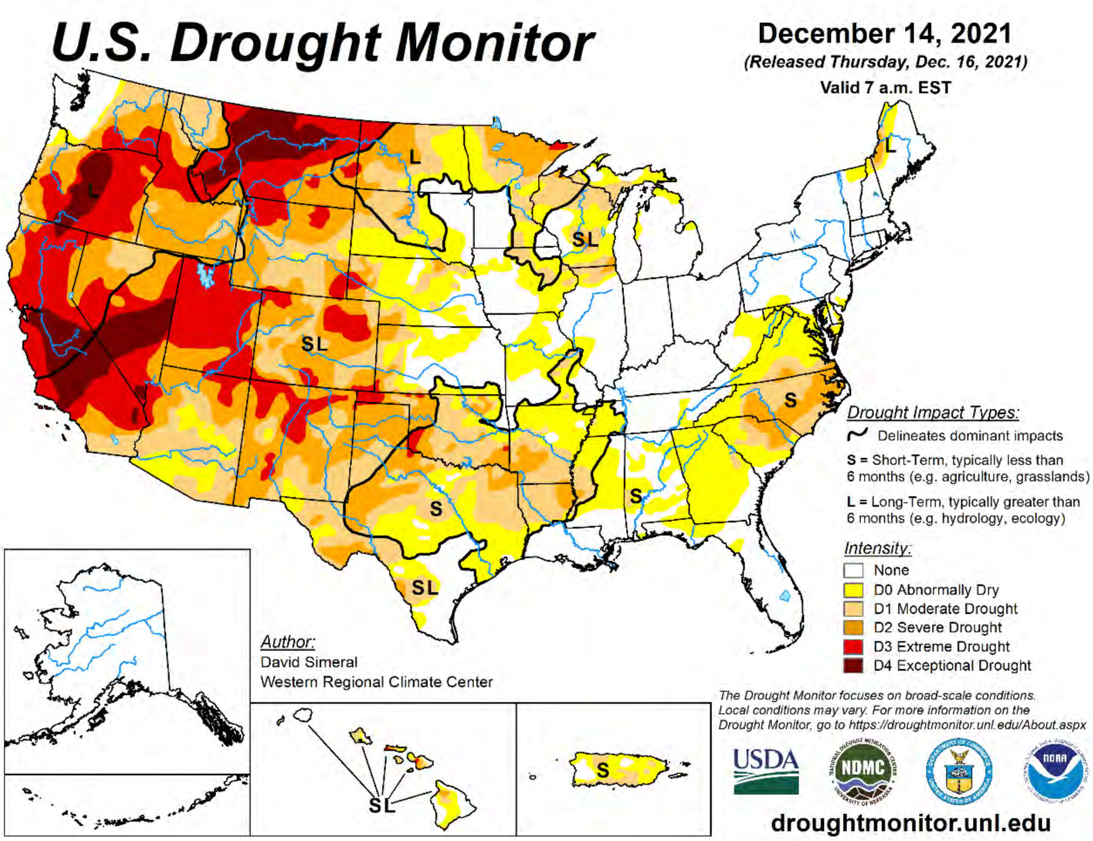
When severe winter storms hit Texas in early 2021, the state's power grid was overwhelmed by high energy demand combined with a lack of engineering for winter conditions and isolation from the power grid in the rest of the US. Power to many buildings was purposely shut off to keep the grid from failing.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



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

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

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



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

Energy is a commodity, and supply and demand around the world will also affect the US energy system. As the global population grows and industrialization of the world continues, demand for energy will increase even further as resources are depleted. These factors can significantly affect US energy costs through competition for imported and exported energy products.

Mediation of our energy production could have a huge positive impact on climate change. Unfortunately, there is no energy production system or source currently available that is truly sustainable. All forms of energy have negative impacts on the environment, as do many of the ways in which we use them.

Until we have a sustainable means of producing and delivering energy, we are faced with a sort of "energy triage"; we need to consider which means of energy production and transport make the least impact. The answer to this problem will be multifaceted, depending in large part on which energy resources and delivery methods are available in each part of the US.

Adaptation

Adaptation—changing our habits of energy use and delivery—will make it easier for our existing energy infrastructure to adjust to the needs brought on by climate change. Investing in adaptation can pay off in the short term by reducing risks and vulnerabilities, thus minimizing future risks. Increasing sustainable energy practices—including extraction, production, and usage—and improving infrastructure and delivery methods will go a long way toward decreasing the effects of climate change and increasing our energy security.

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

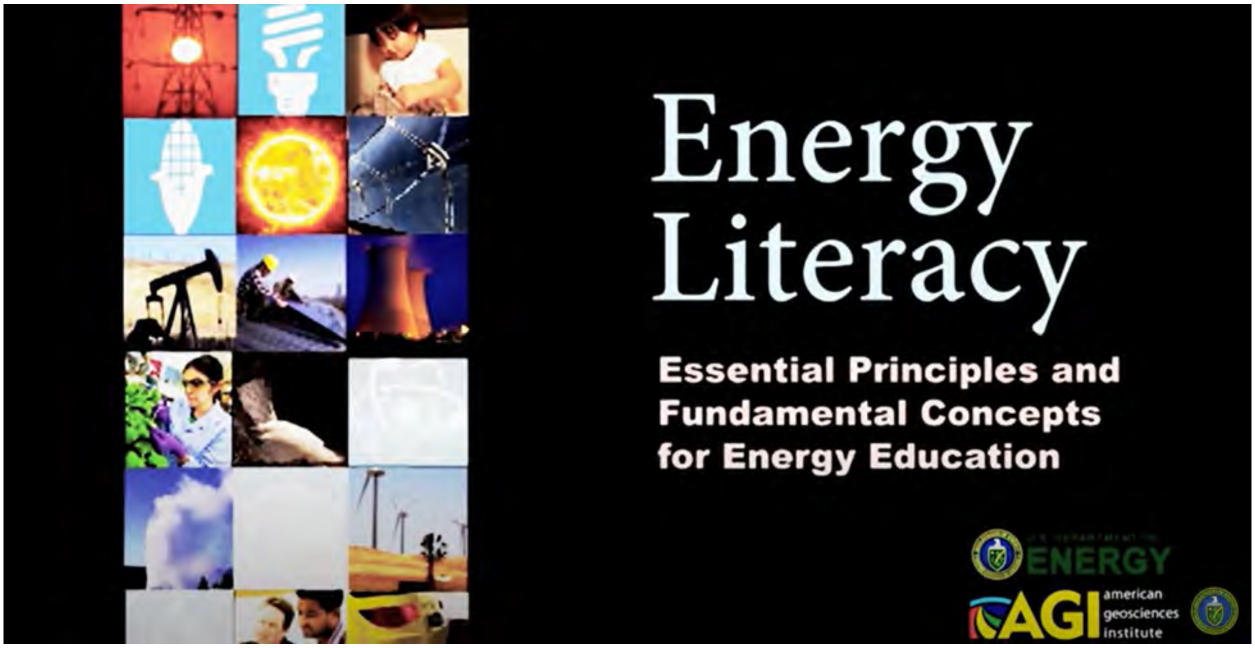
Key points to keep in mind regarding the future of energy

1. Extreme weather events are affecting energy production and delivery facilities, causing supply disruptions of varying lengths and magnitudes and affecting other infrastructure that depends on energy supply. The frequency and intensity of extreme weather events are expected to increase.
2. Higher summer temperatures are likely to increase electricity use, causing higher summer peak loads, while warmer winters are likely to decrease energy demands for heating. Net energy use is projected to increase as rising demands for cooling outpace declining heating energy demands.
3. Both episodic and long-lasting changes in water availability will constrain different forms of energy production.
4. In the longer term, sea level rise will affect the coastal facilities and infrastructure on which many energy systems, markets, and consumers depend.
5. As we invest in new energy technologies, future energy systems will differ from those of the present in uncertain ways. Depending on the ways in which our energy system changes, climate change will introduce both new risks and new opportunities.

Energy Decisions Video

US Department of Energy, 2015 – 5 minutes

https://youtu.be/9Wub1_Dk_Ok



Appendix

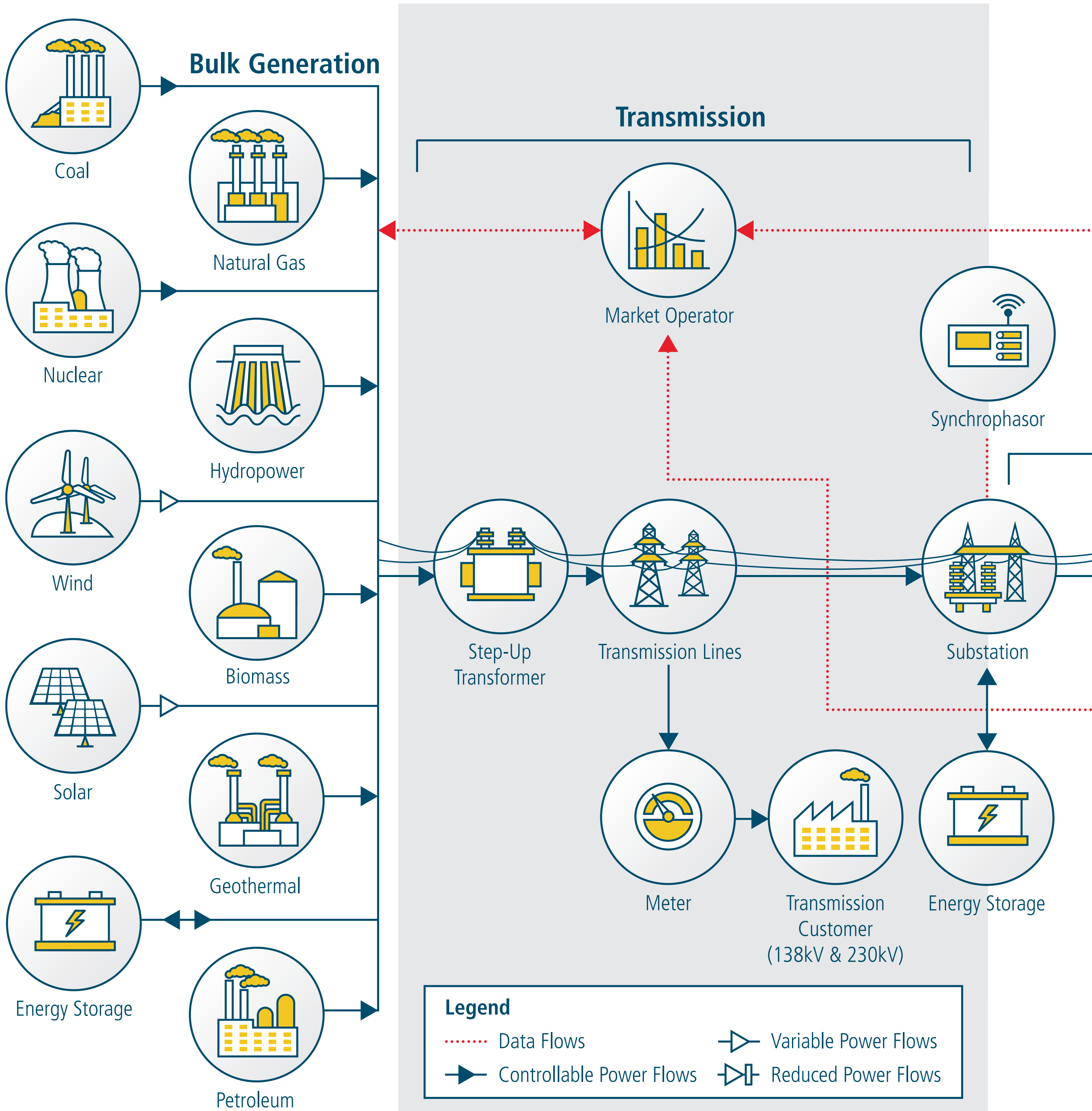
ELECTRICITY SYSTEM OVERVIEW

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

Elements of the Electricity System

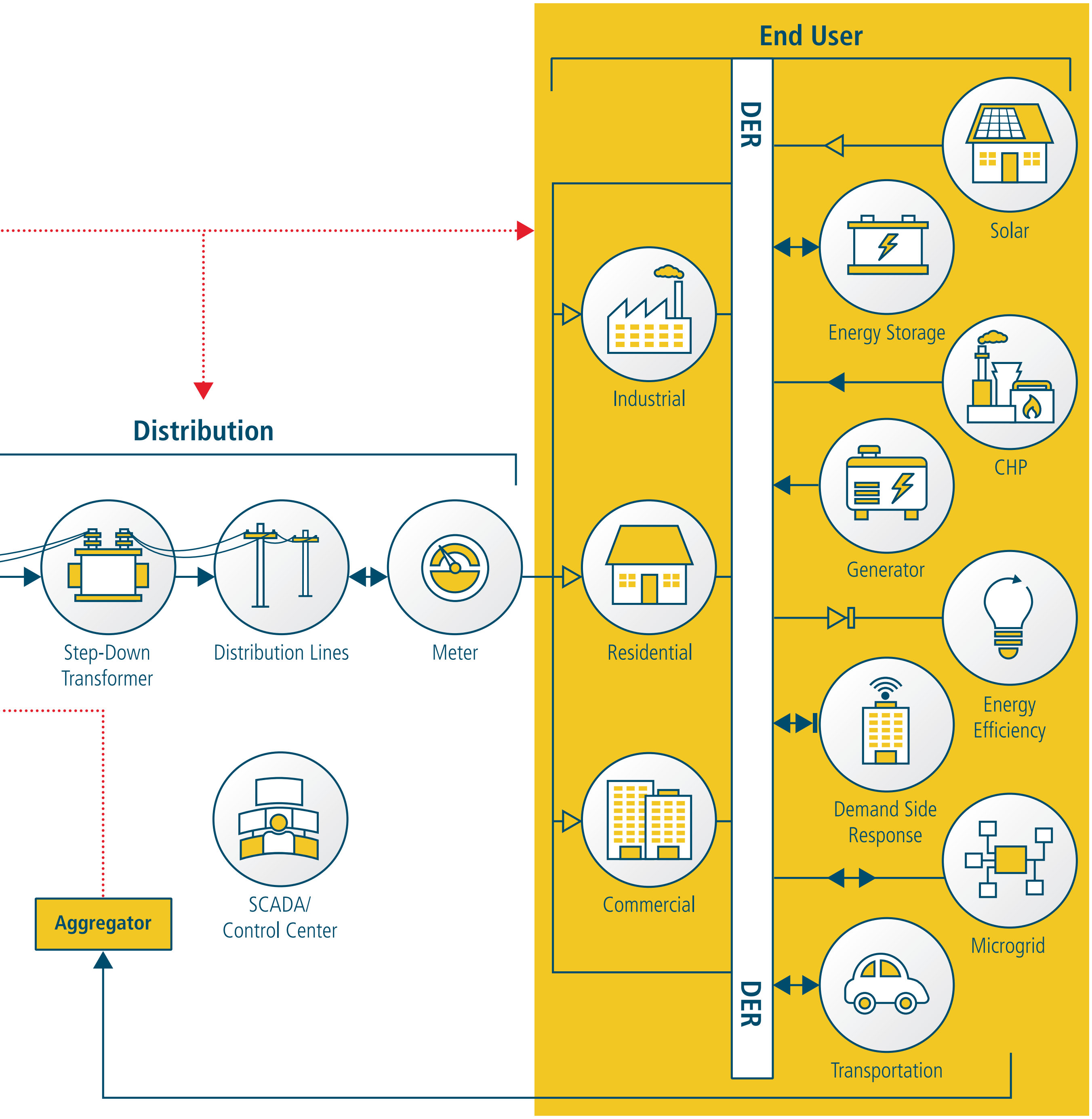
The U.S. electric power system is an immensely complex system-of-systems, comprising generation, transmission, and distribution subsystems and myriad institutions involved in its planning, operation, and oversight (Figure A-1). End use and distributed energy resources (DER) are also important parts of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

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



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

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


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

Generation

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

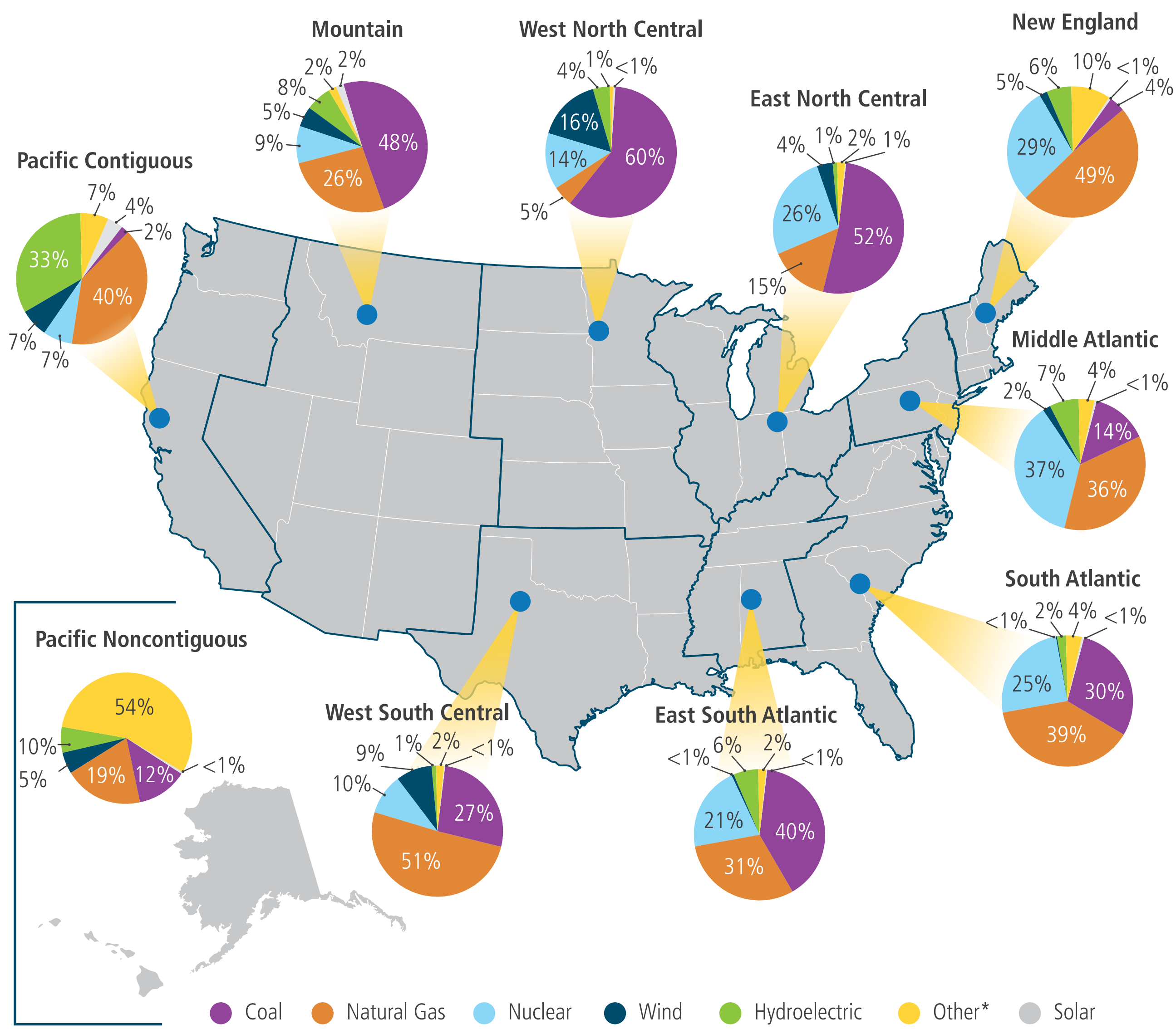
In 2014, there were over 6,500 operational power plants of at least 1 megawatt in the U.S. electric power system.[a, 3, 4] These power plants delivered nearly 3,764 billion kilowatt-hours (kWh) of power in 2014, supplying electricity to over 147 million residential, commercial, and industrial customers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

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

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

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

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

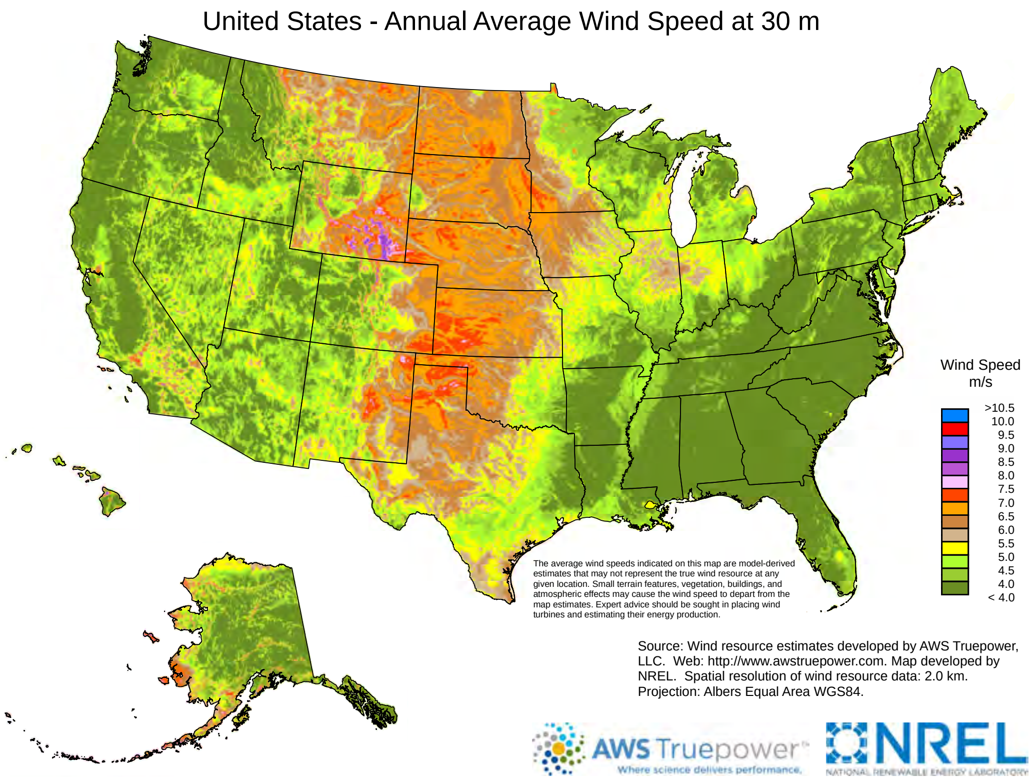


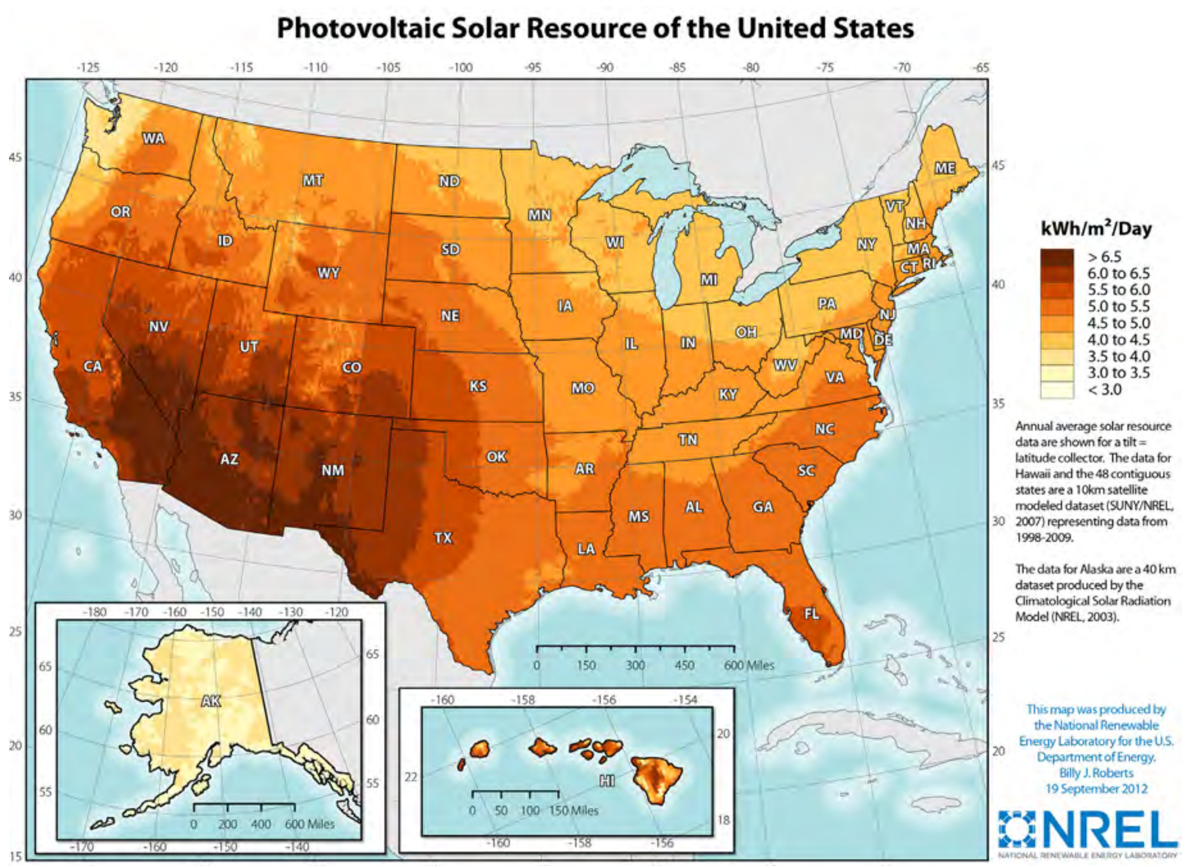
*Includes the following Energy Information Administration fuel type designations: Distillate Petroleum, Geothermal, Biogenic Municipal Solid Waste and Landfill Gas, Other Gases, Other Renewables, Other (including nonbiogenic municipal solid waste), Petroleum Coke, Residual Petroleum, Waste Coal, Waste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

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

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

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





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

Transmission

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

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

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

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

Distribution System

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

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

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

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

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

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

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

Electric Substations
Color by Minimum Volatage kV
- 450 to 1,000
- 300 to 450
- 230 to 300

Electric Transmission Lines (by voltage class)
Color by Volatage Class kV
- 230–300
- 345
- 500
- 735 and Above
- DC Line

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

Distributed Energy Resources (DER)

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

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

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

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

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

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

End Use

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

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

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

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

Brief History of the U.S. Electricity Industry

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

The Beginning of the Electricity Industry

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

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

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

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

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

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

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

The State Regulatory Compact

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

[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

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

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.

History of Oil

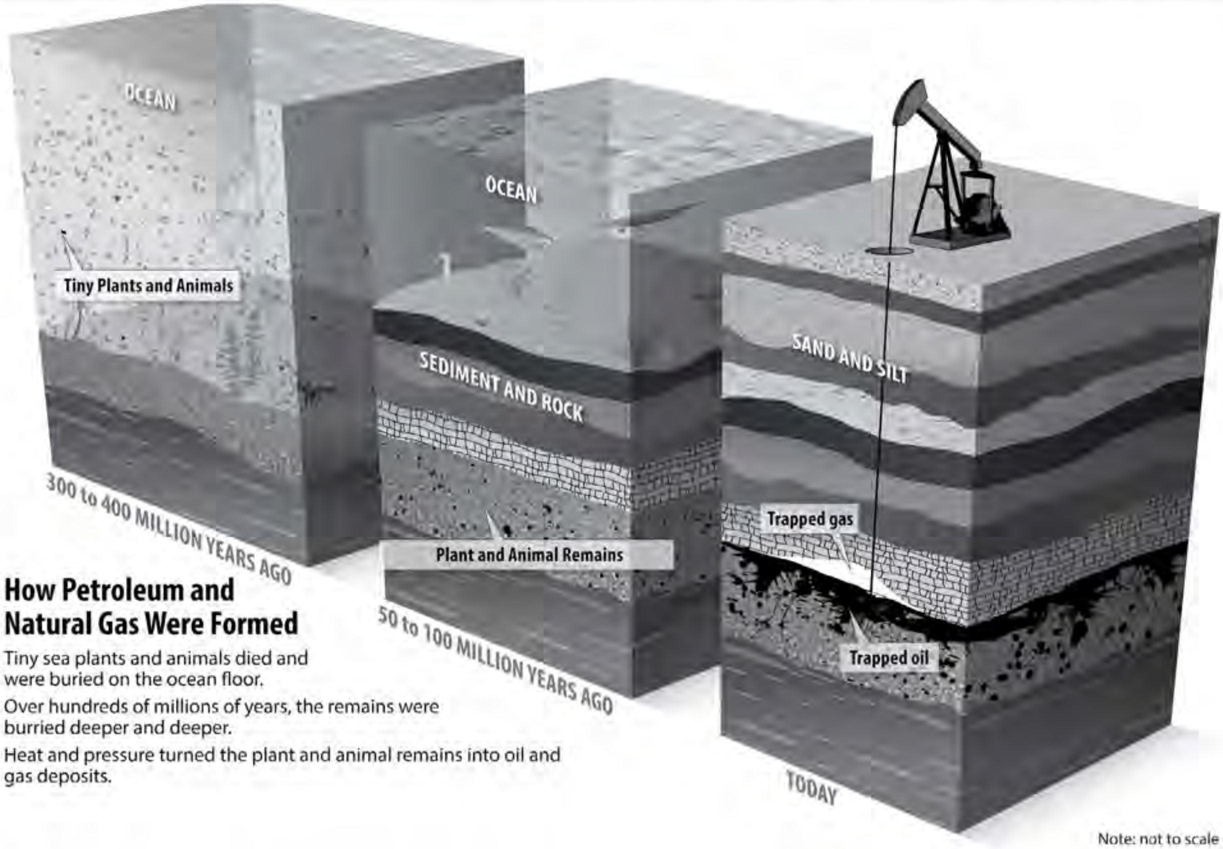
People have used naturally available **crude oil** for thousands of years. The ancient Chinese and Egyptians, for example, burned oil to produce light.

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.

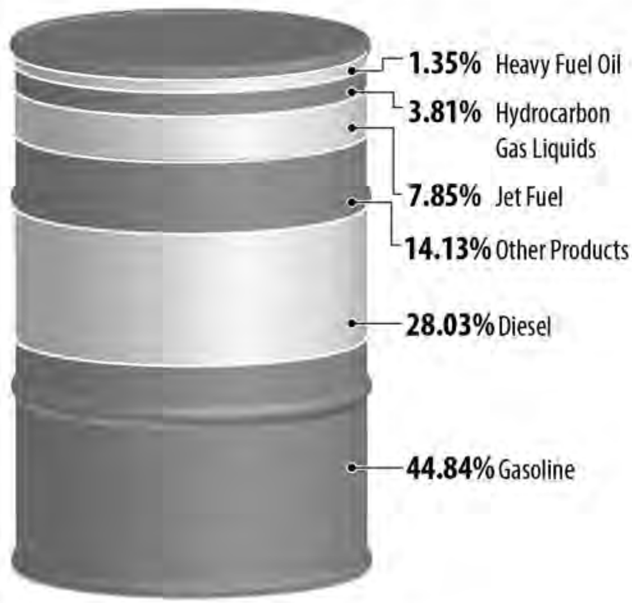
Refineries use many different methods to make these products. One method is a heating process called **distillation**. Since oil products have different boiling points, molecule sizes, and densities, the end products can be distilled, or separated. For example, asphalts have a higher boiling point than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

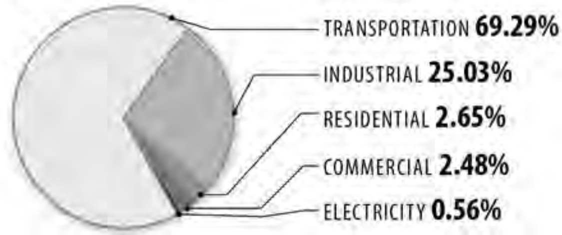
In 2010, the Macondo (Deepwater Horizon) well accident released oil into the Gulf of Mexico for several months. The companies involved in developing Macondo, the Coast Guard, and the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) quickly began work to determine the cause of the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

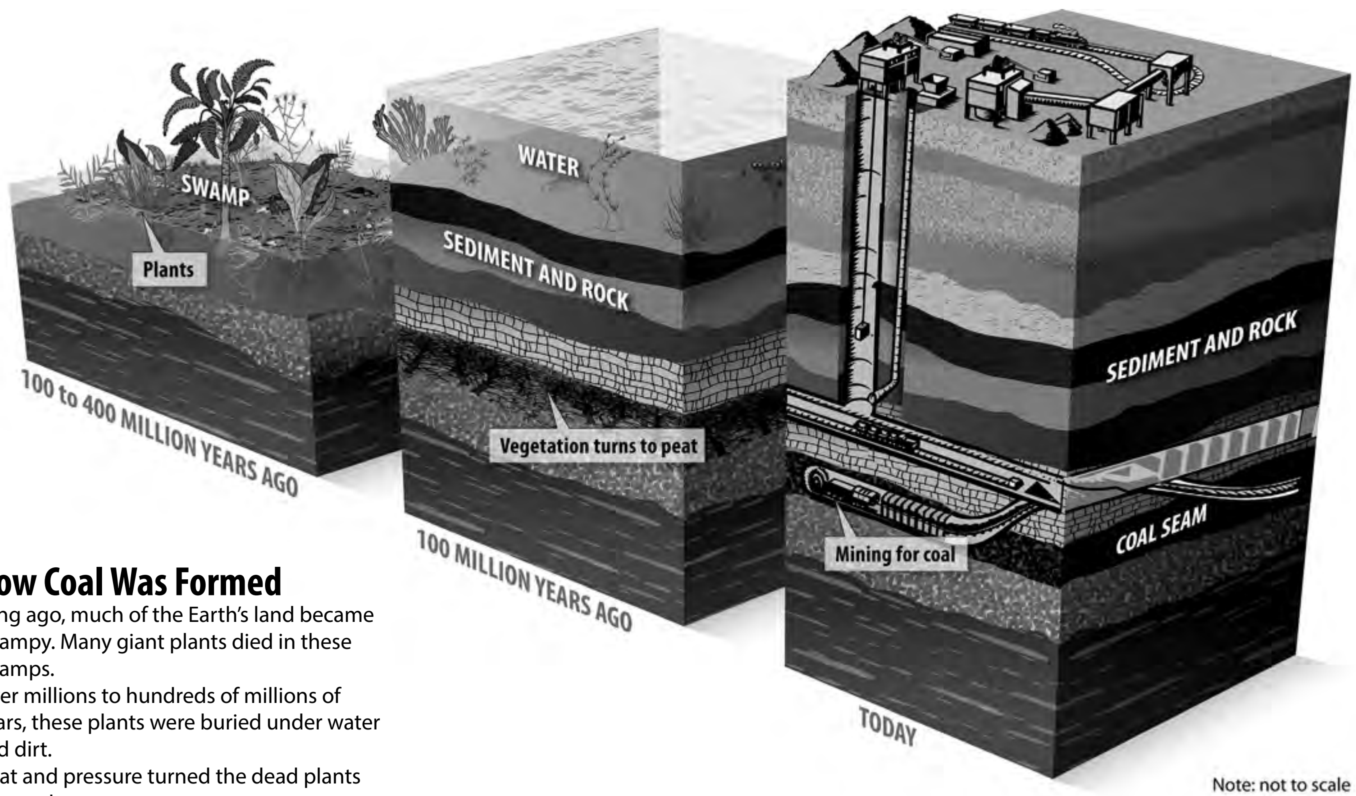
Seams of coal—ranging in thickness from a fraction of an inch to hundreds of feet—may represent hundreds or thousands of years of plant growth. One seam, the seven-foot thick Pittsburgh seam, may represent 2,000 years of rapid plant growth. One acre of this seam contains about 14,000 tons of coal.

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.

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

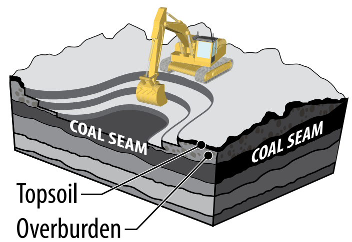
After coal comes out of the ground, it typically goes on a conveyor belt to a preparation plant that is located at the mining site. The plant cleans and processes coal to remove dirt, rock, ash, sulfur, and other impurities, increasing the heating value of the coal.

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.

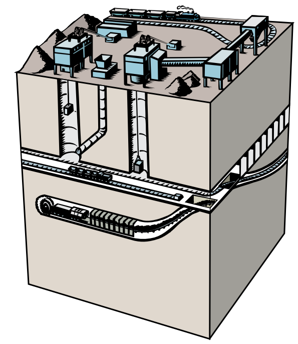
Underground pipelines can easily move petroleum and natural gas to market. But that's not so for coal. Huge trains transport more than two-thirds of U.S. coal for some or all of its journey to market.

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

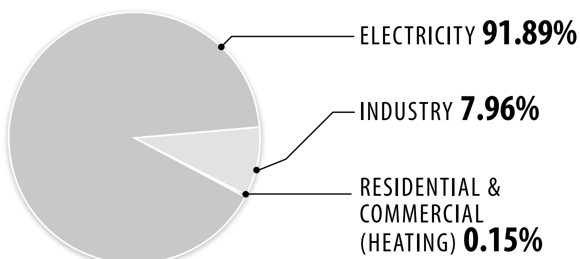
When scientists estimate how much coal, petroleum, natural gas, or other energy sources there are in the United States, they use the term **reserves**. Reserves are deposits that can be harvested using today's methods and technology.

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.

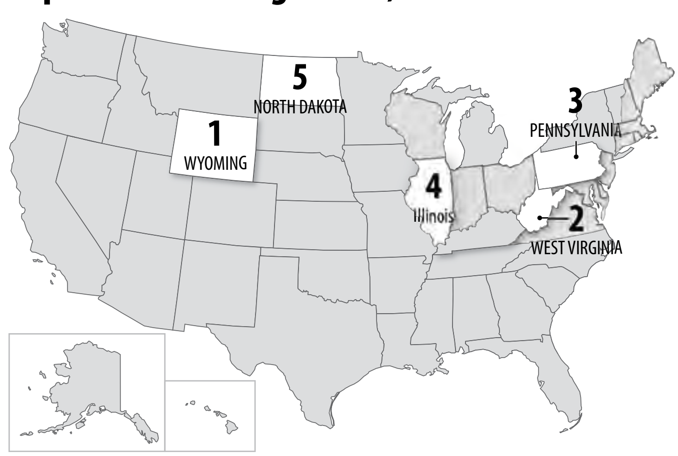
The Federal Government is by far the largest owner of the nation's coalbeds. The Bureau of Land Management leases over 570 million acres of coal bed mineral estates to landowners. Most of these leases are found in Western states.

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

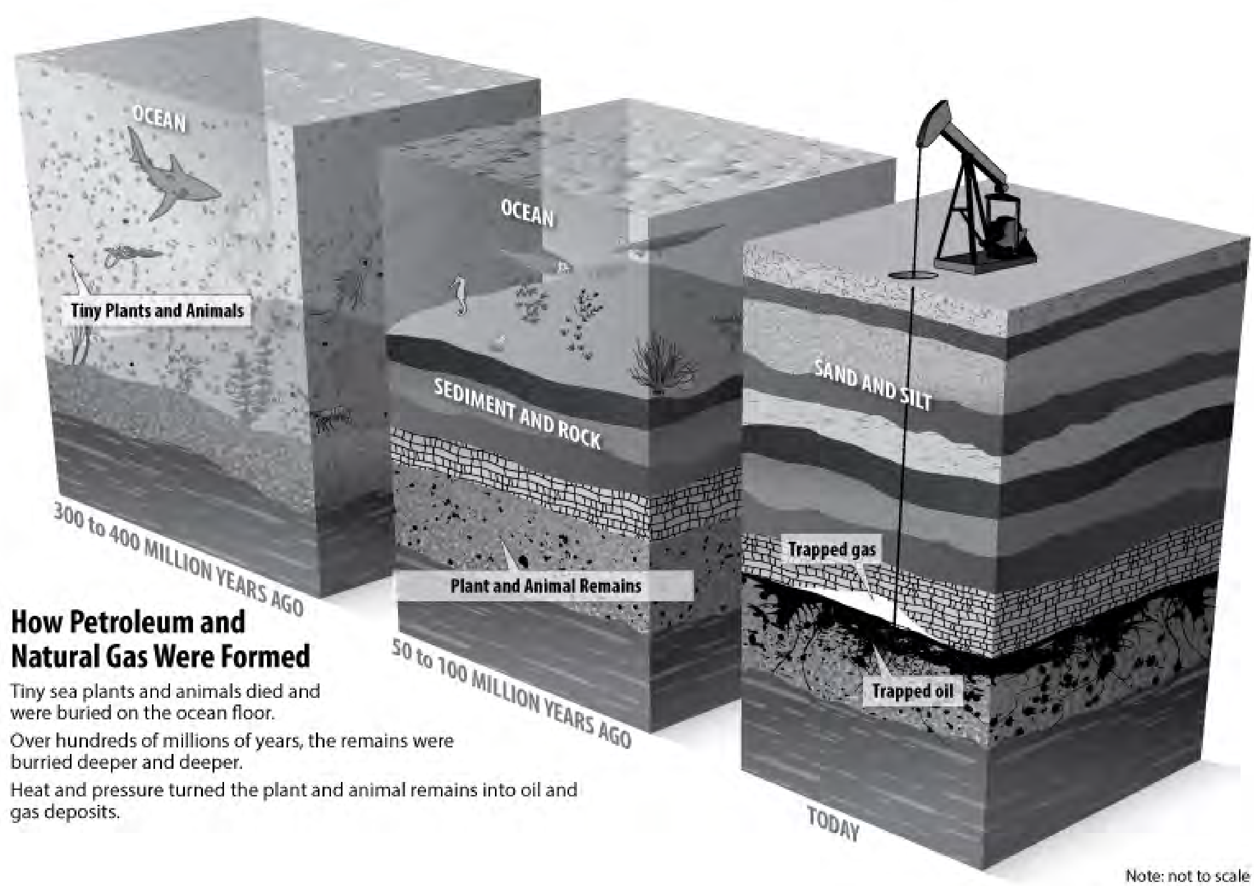
The ancient peoples of Greece, Persia, and India discovered natural gas many centuries ago. The people were mystified by the burning springs created when natural gas seeping from cracks in the ground was ignited by lightning. They sometimes built temples around these eternal flames so they could worship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



Natural Gas

Natural Gas at a Glance, 2016

Classification:
- nonrenewable

Major Uses:
- heating, industry, electricity

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

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

Data: Energy Information Administration

Producing Natural Gas

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

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

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

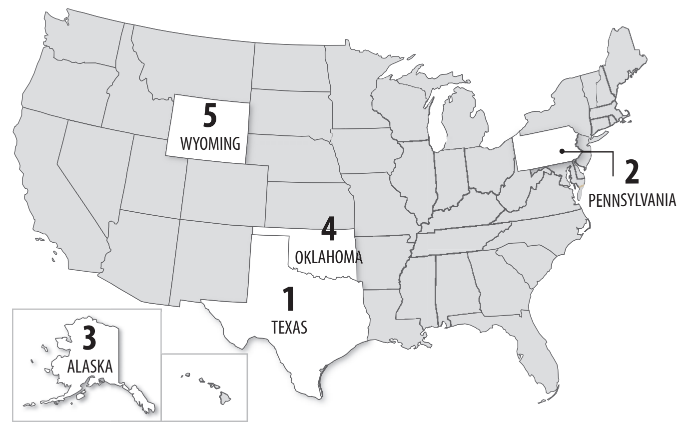
After natural gas comes out of the ground, it goes to a processing plant where it is cleaned of impurities and separated into its various components. Approximately 90 percent of natural gas is composed of methane, but it also contains other gases such as propane and butane.

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

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

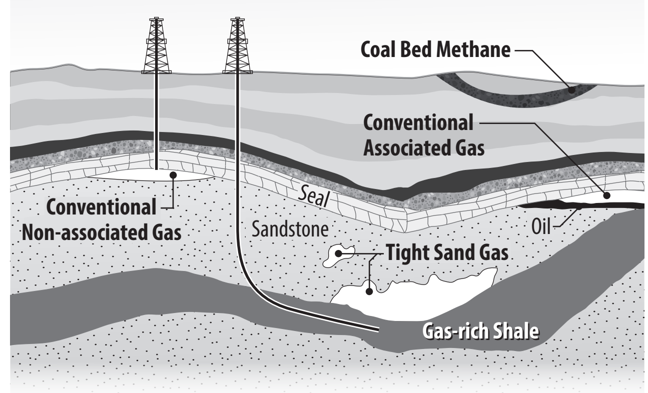
Today, natural gas is produced in 34 states, but the top five states—Texas, Pennsylvania, Alaska, Oklahoma, and Wyoming—produce 64 percent of the total. Natural gas is also produced offshore. A little more than five percent of U.S. natural gas comes from offshore wells. Altogether, the U.S. produces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

Top Natural Gas Producing States, 2016

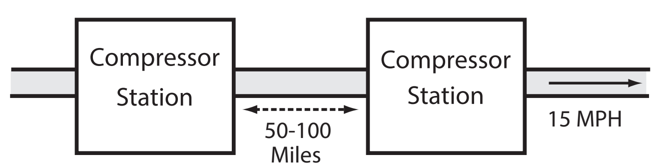


Data: Energy Information Administration

Locations of Natural Gas



Natural Gas Distribution System



Transporting and Storing Natural Gas

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

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

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

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

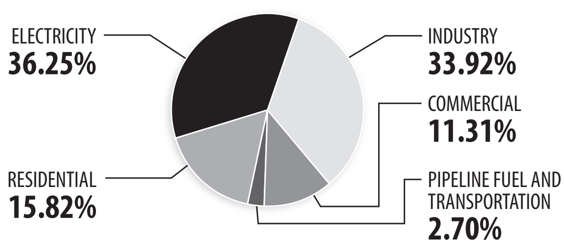
Natural Gas Use

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

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

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

U.S. Natural Gas Consumption by Sector, 2016



Data: Energy Information Administration

Measuring Natural Gas

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

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

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

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

Natural Gas Reserves

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

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

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

Natural Gas Prices

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

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

Natural Gas and the Environment

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

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

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

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.

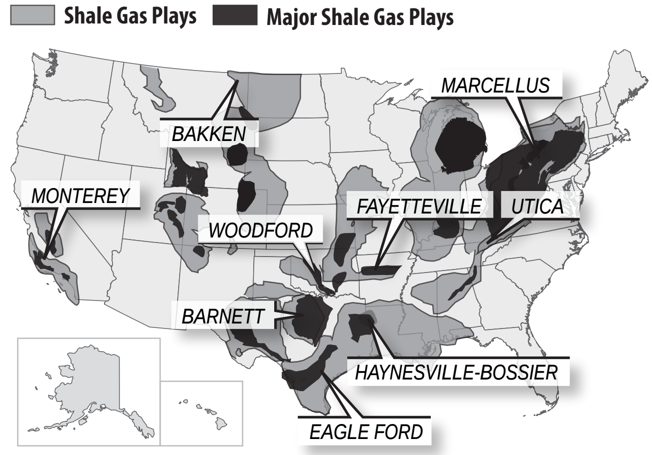
Continued technological innovations promise to make shale gas an important part of the United States' energy future.

Methane Hydrates

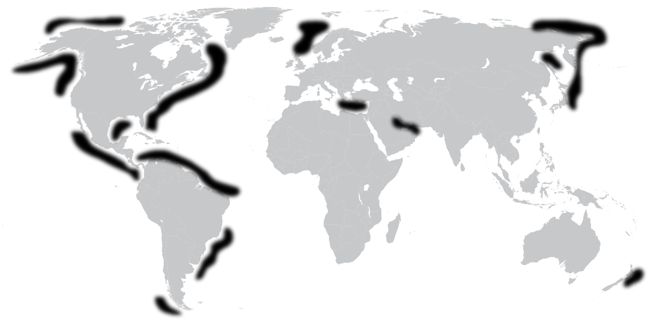
Buried in the sediments of the ocean floor is a reserve of methane so vast it could possibly fuel the entire world. In sediments on the ocean floor, tiny bacteria continuously break down the remains of sea animals and plants, producing methane gas. Under the enormous pressure and cold temperatures at 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



Likely Methane Hydrate Deposits



Biogases

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

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

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

Liquefied Natural Gas

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

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

Understanding Power System Threats and Impacts

Background

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

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

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

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

Identifying Threats

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

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

What is a Power System Threat?

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

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

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

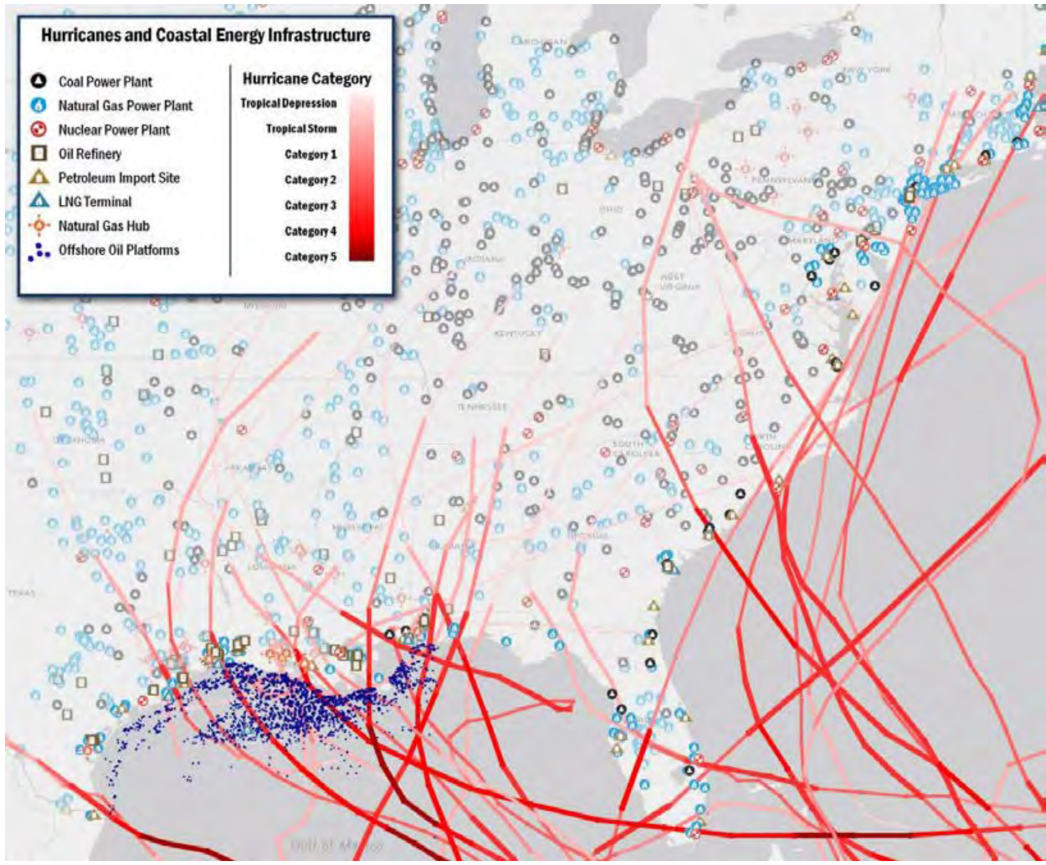


Figure 1. Historical data used to show storm tracks and coastal energy infrastructure in the United States. *https://www.energy.gov/sites/prod/files/2017/01/f34/2016%20DOE%20Climate%20Adaptation%20Plan_0.pdf*

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

Likelihood of Threat Occurrence

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

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

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

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

Connecting Threats to Possible Power System Impacts

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

Table 1. Scoring Framework for Threat Likelihood

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

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

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

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

Table 2. Threats and Potential Impacts on the Power Sector

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

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

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

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

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

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

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

Resilient Energy Platform

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

Resources

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

NCF-Envirothon 2024 New York

Current Issue Part A Study Resources

Key Topic #2: Renewable Energy and Infrastructure

7. Describe the criteria for an energy source to be renewable, and identify examples.
8. Explain how Solar, Wind, and Hydroelectric systems generate electricity, and identify the technological advancements that have made this possible.
9. Identify the environmental, social, and economic advantages and disadvantages of Solar, Wind, and Hydroelectric power, and evaluate their suitability for meeting the world's energy needs in the future. *(See also Key Topic #3)*
10. Explain the setup and design of renewable energy infrastructure and distribution systems.
11. Describe how renewable energy can contribute to energy security.

Study Resources

Resource Title	Source	Located on
Renewable Energy	*Jennifer Morris – MIT Climate Portal – February 2, 2023*	Pages 55 -56
Solar at a Glance	*National Energy Education Development, 2023*	Page 57
Wind at a Glance	*National Energy Education Development, 2023*	Page 58
Hydropower at a Glance	*National Energy Education Development, 2023*	Page 59
Geothermal at a Glance	*National Energy Education Development, 2023*	Page 60
Biomass at a Glance	*National Energy Education Development, 2023*	Page 61
Biofuel	*Kristala Jones Prather – MIT Climate, 2020*	Pages 62 - 63
Facts About Solar Energy: Solar Electricity	*Wisconsin Center for Environmental Education, 2020*	Pages 64 - 68
The Dark Side of Solar Power	*Atalay Atasu, Serasu Duran, and Luk N. Van Wassenhove – Harvard Business Review, 2021*	Pages 69 -73
Advantages and Challenges of Wind Energy	*Wind Energy Technologies Office, 2023*	Pages 74 - 75

Study Resources begin on the next page! ➡

Renewable Energy

By Jennifer Morris – MIT Climate Portal – February 2, 2023

Renewable energy is energy from sources we cannot run out of. Some types of renewable energy, like wind and solar power, come from sources that are not depleted when used. Others, like biomass, come from sources that can be replenished. Common types of renewable energy are wind, solar, hydropower, biomass and geothermal. Renewable energy has two advantages over the fossil fuels that provide most of our energy today. First, there is a limited amount of fossil fuel resources (like coal, oil and natural gas) in the world, and if we use them all we cannot get any more in our lifetimes. Second, renewable energy produces far less carbon dioxide (CO2) and other harmful greenhouse gases and pollutants. Most types of renewable energy produce no CO2 at all once they are running. For this reason, renewable energy is widely viewed as playing a central role in climate change mitigation and a clean energy transition.

Renewable vs. carbon-free

Most kinds of renewable energy are also "carbon-free": they do not emit CO2 or other greenhouse gases into the atmosphere. Because of this, and because renewables like wind and solar power are so popular in climate activism, the terms "renewable energy" and "carbon-free energy" are sometimes confused. But not all renewable energy is carbon-free, and not all carbon-free energy is renewable.

Biofuels and bioenergy are renewable: we can regrow plants that we burn for fuel. But they are not necessarily carbon-free. Growing plants absorbs CO2; burning plants releases CO2. The total impact on CO2 in the atmosphere depends on how sustainably the bioenergy is produced.

Nuclear energy is carbon-free: a nuclear power plant does not emit any CO2, or any other greenhouse gases. But it is not renewable. Nuclear reactors use uranium, and if we run out of uranium, we can never get it back.

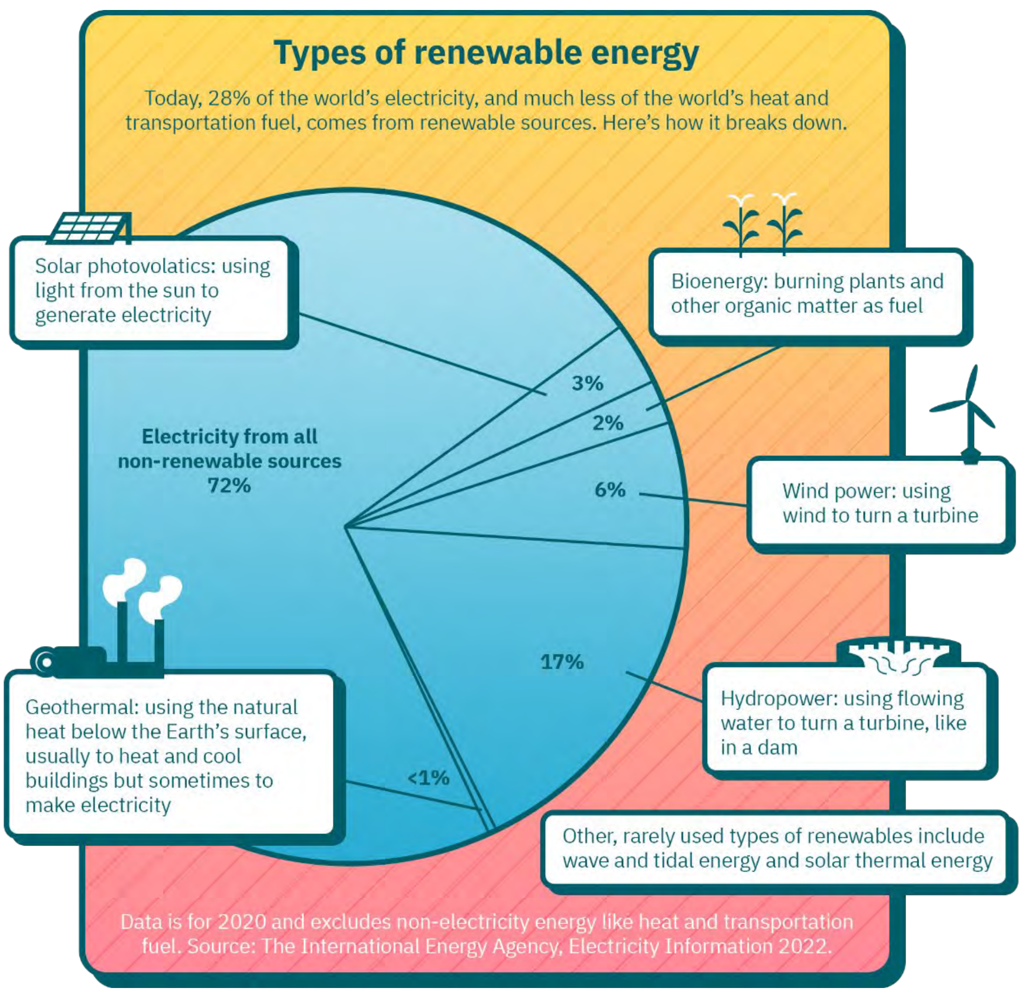
Transforming the Electric Grid

Some types of renewable energy can provide fuel for transportation (e.g. biofuels) or heating and cooling for buildings (e.g. geothermal). However, most renewable energy is used to make electricity. In 2020, renewable energy sources made up over 28% of the world's electricity, and that number is rising every year.1 Around 60% of renewable electricity worldwide comes from hydropower, which has been widely used since the invention of the electric grid, but today wind and solar power are growing fastest.

Renewable energy presents great challenges and opportunities for electricity generation. Some renewable energy sources, such as wind and solar, are "variable," meaning the amount of electricity they make changes depending on the amount of wind or sunlight available. This can cause problems for system operators, particularly when there is a mismatch between the amount of electricity demanded and the amount of wind or sun available. Another challenge is that the 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

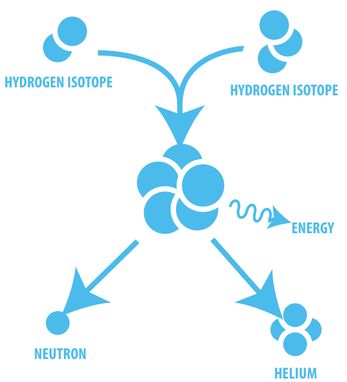
www.need.org

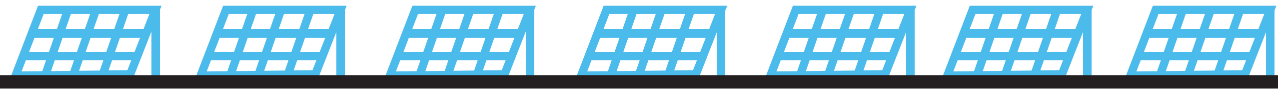
WHAT IS SOLAR?

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.





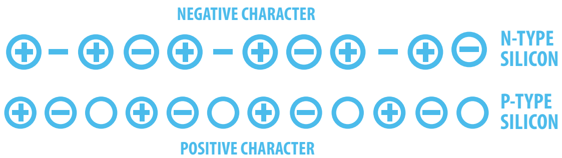
PHOTOVOLTAIC CELLS

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 electricty.

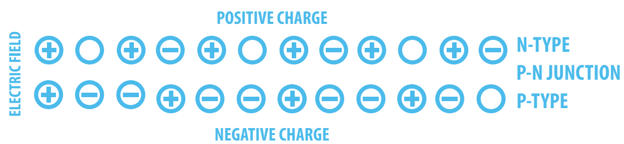
PROTON — FREE ELECTRON — TIGHTLY-HELD ELECTRON — A LOCATION THAT CAN ACCEPT AN ELECTRON

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.

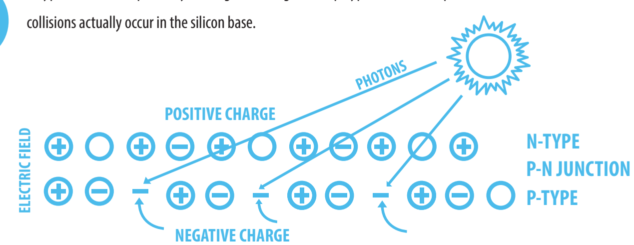
The phosphorous has one more electron in its outer shell than silicon, and the boron has one less. These dopants help create the electric field that motivates the energetic electrons out of the cell created when light strikes the PV cell. The phosphorous gives the wafer of silicon an excess of free electrons; 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.



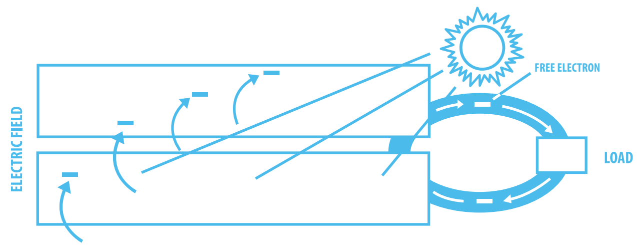
2 Where the n-type silicon and p-type silicon meet, free electrons from the n-layer flow into the p-layer for a split second, then form a barrier to prevent more electrons from moving between the two sides. This point of contact and barrier is called the p-n junction. When both sides of the silicon slab 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

Data: Energy Information Administration

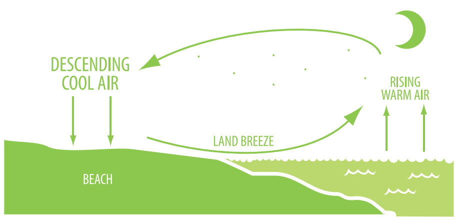
WIND AT A GLANCE

NEED
National Energy Education Development

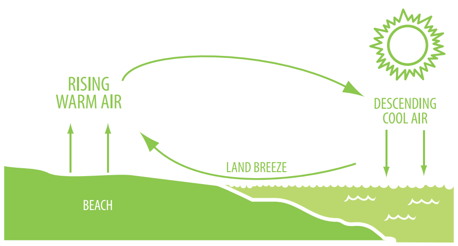
WHAT IS WIND?

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.

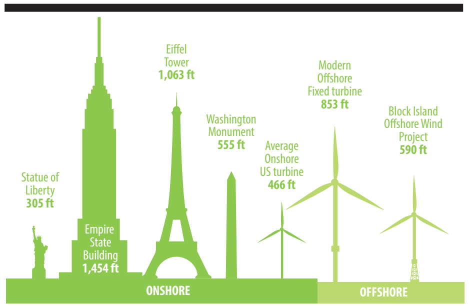
LAND BREEZE



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.

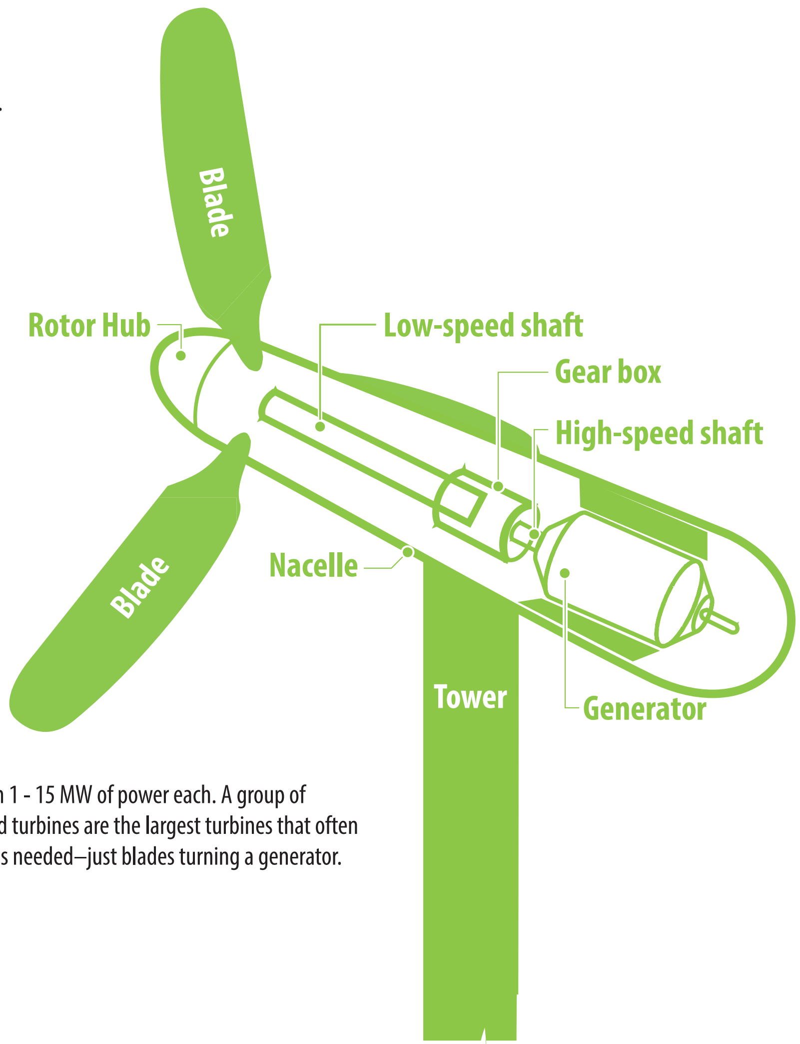
2 The blades are connected to a low-speed shaft. When the blades spin, the shaft turns.

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

TEXAS

IOWA

OKLAHOMA

KANSAS

ILLINOIS

Data: Energy Information Administration

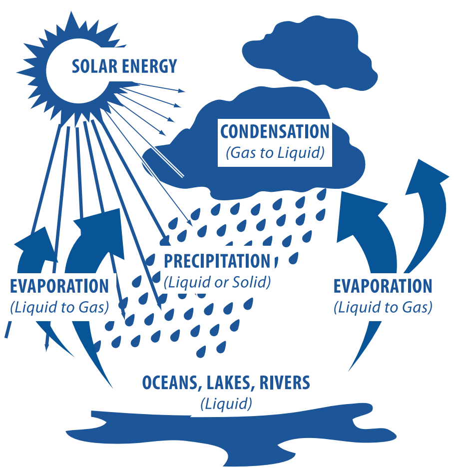
HYDROPOWER AT A GLANCE

NEED
National Energy
Education Development

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

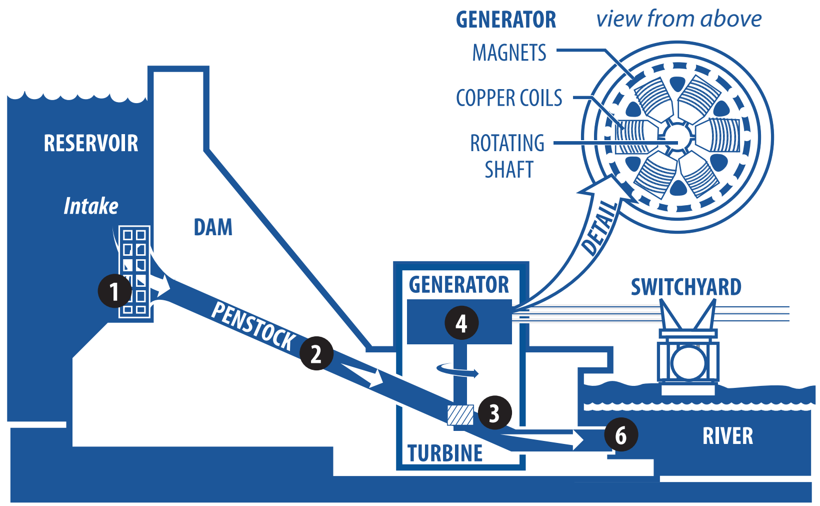
The amount of electricity that can be generated at a hydro plant is determined by two factors: head and flow. Head is how far the water drops. It is the distance from the highest level of the dammed water to the point where it goes through the power-producing turbine. Flow is how much water moves through 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

WASHINGTON

OREGON

NEW YORK

CALIFORNIA

ALABAMA

Data: Energy Information Administration

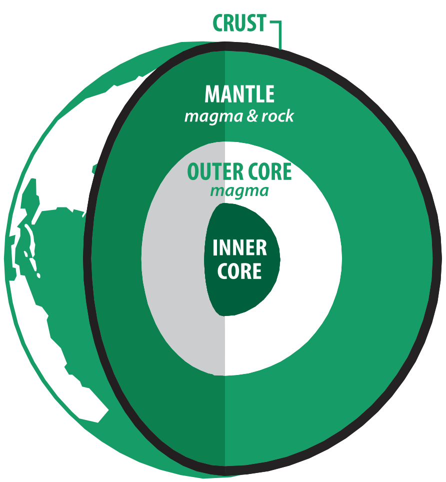
GEOTHERMAL AT A GLANCE

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.

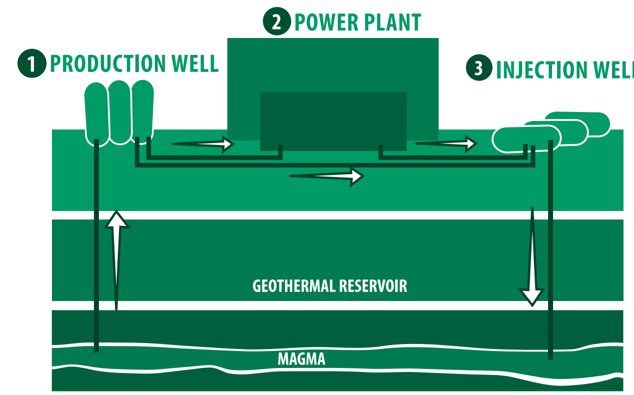
HOT SPRING BATHING AND SPAS

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?

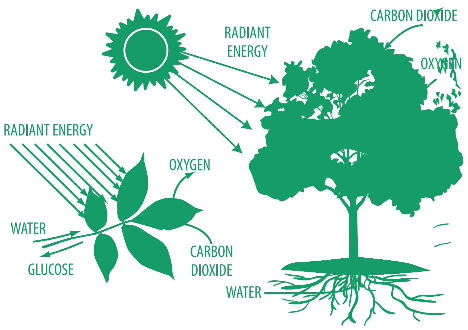
Biomass is any organic matter—wood, crops, seaweed, animal wastes—that can be used as an energy source. Biomass is probably our oldest source of energy after the sun. For thousands of years, people have burned wood to heat their homes and cook their food.

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

$6H_2O + 6CO_2 +$ radiant energy ⟶ $C_6H_{12}O_6 + 6O_2$

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.

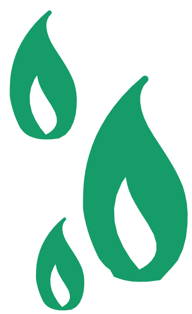
Wood and wood waste are used to generate electricity. Much of the electricity is used by the industries making the waste; it is not distributed by utilities, it is a process called cogeneration. Paper mills and saw mills use much of their waste products to generate steam and electricity for their use. 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 gas can be used to produce electricity, or for cooking and lighting.



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.

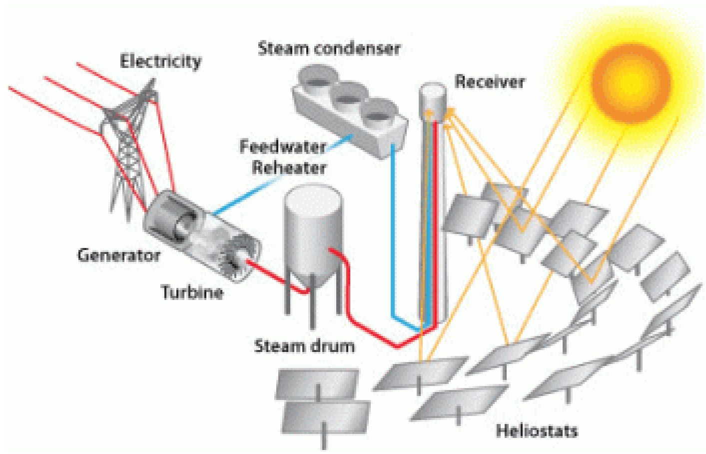


Fig. 1.1 Power Tower Power Plant

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.

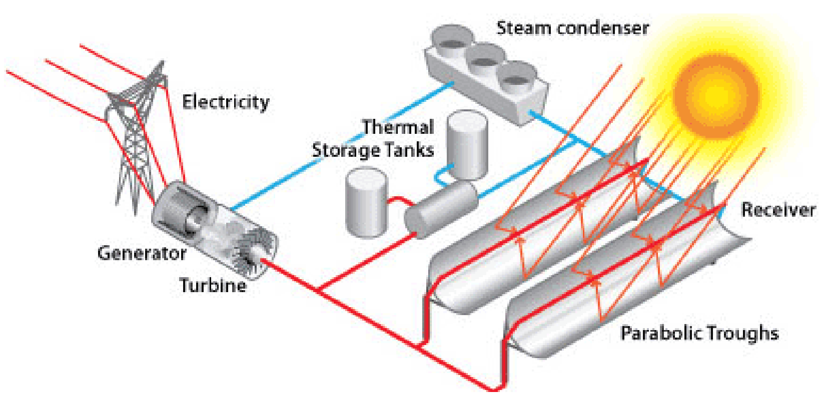


Fig. 1.2 Linear Concentrator Power Plant using Parabolic Tough Collectors

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.

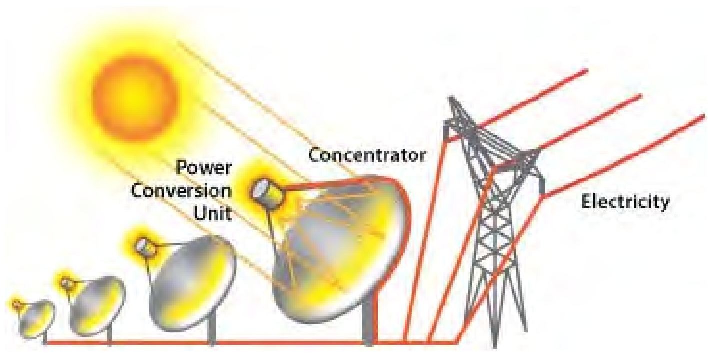


Fig. 1.4 Dish/Engine Power Plant

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

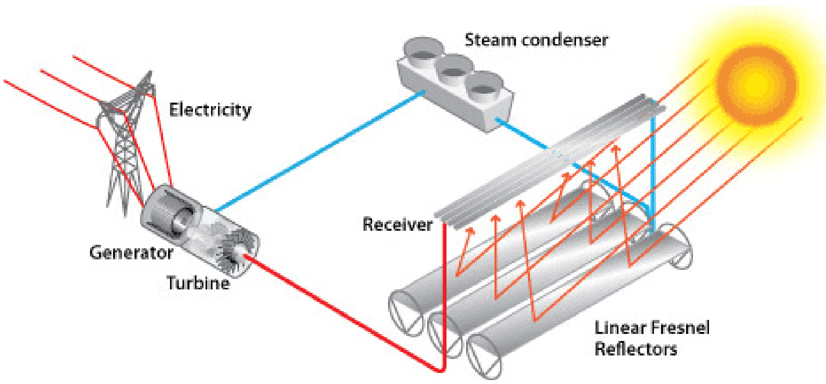


Fig. 1.5 Linear Fresnel Power Plant

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 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.

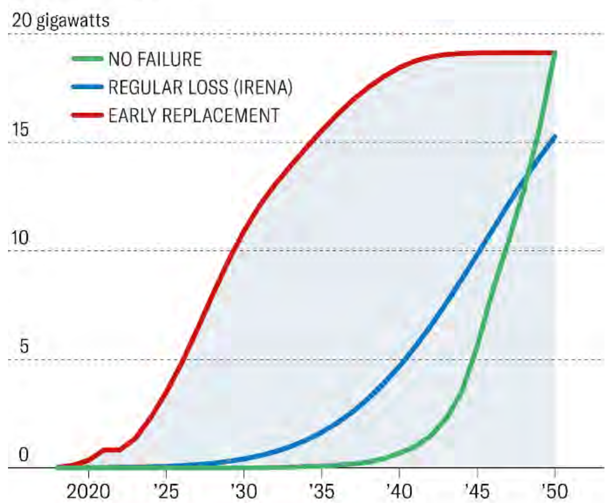
As an example, consider a hypothetical consumer (call her "Ms. Brown") living in California who installed solar panels on her home in 2011. Theoretically, she could keep the panels in place for 30 years, i.e., until 2041. At the time of installation, the total cost was $40,800, 30% of which was tax deductible 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.

. . .

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.

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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.

HYDROPOWER INDUSTRY SUPPLY CHAIN DEEP DIVE ASSESSMENT

1 Introduction

1.1 Role of hydropower in the energy industrial base sector

Hydropower is an important part of the U.S. Energy Sector Industrial Base, including the set of companies that research and develop, manufacture, and operate energy generation, storage, transmission, and distribution assets.

At the end of 2019, the U.S. conventional hydropower fleet (80.2 GW) was the fourth largest in the world by individual countries (after China, Brazil, and Canada) and the U.S. pumped storage hydropower (PSH) fleet (21.9 GW) was the third largest (after China and Japan). However, only 1.7 GW of conventional hydropower and 1.4 GW of PSH capacity were added in 2010–2019 (Uría-Martínez et al, 2021). Of this added capacity, the fraction that resulted from new builds was 33% for conventional hydropower and 3% for PSH; the rest resulted from upgrades to existing facilities. The average age of the U.S. fleet is 64 years for conventional hydropower and 45 years for PSH.[3] New capacity expansion is not anticipated to be the primary driver for the activity of domestic industrial companies supporting the U.S. hydropower fleets. Instead, the primary driver is expected to be the maintenance and modernization of the existing fleets. The exceptions could be PSH builds and some limited new small conventional hydropower plants.

In 2020, hydropower accounted for 36.7% of renewable electricity generation and 7.3% of total electricity generation in the United States (Johnson and Uría-Martínez, 2021). In some U.S. states (Washington, Idaho, Oregon, and Vermont), more than 50% of electricity generated in 2017–2019 was hydroelectric. Hydropower also provides flexibility and grid services that are essential to enable high penetrations of variable renewables and enhance grid reliability. U.S. PSH plants provide a higher percentage of many grid services than the percentage of capacity they represent in the electricity generation fleet. For instance, Gracia et al. (2019) report that hydropower provides approximately 40% of black start resources (vs. less than 10% generation capacity). The 2021 edition of the U.S. Hydropower Market Report (HMR) presents other examples of the U.S. hydropower fleet providing a larger share of ancillary services (such as frequency regulation and reserves) than the share of generation capacity it represents in several independent system operator (ISO) regions. The large shares of ancillary services provided by hydropower relative to its installed capacity are indicative of the flexibility offered by this generation technology. Additionally, PSH has been to date the preferred least-cost technology for long-duration energy storage and the demand for this type of storage asset is expected to grow substantially in the next few decades.

A robust supply chain is necessary to maintain and modernize the existing hydropower fleets and to support the grid in reliably integrating the additional variable renewable capacity needed to achieve the objective of a carbon pollution-free electricity grid in the United States by 2035. The National Hydropower Association (NHA) has compiled a list of more than 2,500 companies that report being part of the U.S. hydropower supply chain, including turbine manufacturers, machine shops, and engineering and consulting companies, among others.[4] In 2018, the number of jobs supported by the U.S. hydropower industry was estimated at 66,500 (Keyser and Tegen, 2020). The manufacturing and utilities sectors accounted for 27% and 26% of those jobs, respectively. The rest were distributed among professional and business services, trade and transportation, and construction sectors. Using a combination of data and input from stakeholder interviews, this report identifies vulnerabilities, challenges, and opportunities for the U.S. hydropower supply chain.

[3] This age calculation is based on plant age rather than unit age. Individual units within a plant can be younger if they have undergone a major refurbishment or modernization.
[4] https://www.hydro.org/map/supply-chains/

1.2 Power and non-power benefits of hydropower dams

Hydropower provides multiple electricity-related value streams to the national power grid. In addition to clean, low-cost electricity services, hydropower dams can provide valuable non-power benefits to the nation. Based on data from the National Inventory of Dams (NID), approximately 60% of the dams connected to hydropower plants in the United States are also authorized for other purposes. Large hydropower plants are more likely to provide multiple non-power services among the 12 categories listed in the NID: hydropower, irrigation, flood control and storm water management, navigation, water supply, recreation, fire protection, fish and wildlife, debris control, tailing, grade stabilization, and “other”.[5] In many cases, the hydropower purpose is secondary to one or several non-power purposes.

Of all the purposes served by dams, hydropower is the one with the best-defined method for value quantification. The value of hydroelectricity is the electricity market energy price. In addition, several ISOs and regional transmission organizations (RTOs) have centralized capacity markets and conduct capacity auctions that can be an additional source of revenue for hydropower plants in those regions. In ISO/RTO regions, markets are also cleared for several of the ancillary services that hydropower provides such as frequency regulation and various types of reserves. For other services like black start, the plant owners receive payments from the ISO/RTO or balancing authority that are meant to cover the costs of providing the service.

The value of the non-hydropower uses of hydropower dams can be substantial and is estimated with valuation methods such as avoided damage costs of floods (flood control) and alternative transportation (navigation) or revenues from irrigated crops (irrigation) and water use (water supply). However, most of these economic benefits are not monetized. Applying these methodologies to federal multipurpose hydropower reservoirs (excluding PSH plants), Bonnet et al. (2015) produce estimates of the distribution of economic benefits per use for each federal agency. In the Tennessee Valley Authority (TVA) and U.S. Army Corps of Engineers (USACE) fleets, recreation is the purpose with the highest economic benefit (35%–40% of the total). Hydropower (energy revenue only) is the second most valuable purpose in the TVA fleet (~23%), and the third most valuable purpose in the USACE fleet (~17%). Irrigation is not an authorized purpose for reservoirs owned by TVA or USACE. In contrast, irrigation is an authorized purpose in most of Bureau of Reclamation’s reservoirs and it accounts for 60% of the economic benefit for their fleet. The energy revenue from the hydropower purpose accounts for 10% of total economic benefit in Reclamation’s fleet.

Although payments are made for some non-power services, the hydropower purpose is often the main source of revenue for financing the maintenance of the dam and enabling the provision of non-power services. Thus, indirectly, the hydropower supply chain also supports those other valuable services.

1.3 Growth potential of hydropower

This section discusses multiple estimates of growth potential for conventional hydropower and PSH, for the United States and globally. First, Section 1.3.1 presents estimates of the remaining resource potential which provide an upper bound to the additional conventional hydropower capacity that could theoretically be added given historical data on water flows and site topography. Second, Section 1.3.2 summarizes data on the capacity from projects that have been announced and are being actively pursued. Of those, only a fraction will make it to construction stage after completing all necessary feasibility evaluation studies, obtaining permits, and securing

[5] Tailing dams do not store water but the by-products from mining operations.

financing. Finally, Section 1.3.3 provides estimates of the additional global hydropower capacity that could be needed to meet selected global decarbonization objectives.

1.3.1 Technical potential

In addition to the importance of modernizing the existing conventional hydropower and PSH fleets to maintain or enhance the power and non-power values listed above, several studies conducted within the last decade on resource assessment show that significant potential remains to build new capacity, both in the United States and globally, through retrofits of non-powered dams (NPDs) and conduits, new stream-reach developments (NSD), and PSH.

For the United States, Hadjerioua et al., (2012) found a potential capacity of 12.1 GW from the retrofit of NPDs with the top three basins being the Ohio, the Upper Mississippi, and the Arkansas-White-Red. For NSDs, Kao et al., (2014) identified a resource potential of 65.5 GW after excluding national parks, wild and scenic rivers, and wilderness areas. These studies are estimates of potential energy generation based on the river flows at the selected sites; further technical and economic feasibility studies would be required to determine which sites to develop. The Hydropower Vision study produced estimates of growth potential based on results from the ReEDS model that solves for the optimal (minimum cost subject to other constraints) set of resources to meet projected electricity demand out to 2050 (DOE, 2016). Given the set of policies enacted as of December 2015 and the resource assessment potentials identified in the aforementioned studies, the ReEDS model finds a potential of 13 GW of new conventional hydropower capacity and 36 GW of PSH capacity by 2050.[6] If those potentials were realized, they would represent a 16% increase in conventional hydropower capacity and more than double the existing PSH capacity. Most of the new conventional hydropower would come from upgrades to existing facilities (6.3 GW) and NPD retrofits (4.8 GW).

For global potential, the International Hydropower Association (IHA) presents regional estimates derived from a review of three recent studies. The estimated capacity potentials range from 350 GW in Europe to 1,100 GW in East Asia and Pacific (IHA, 2021). These are very large numbers when compared with the global installed hydropower capacity of 1,330 GW—1,171 GW of conventional hydropower and 159 GW of PSH—at the end of 2020 (IHA, 2021b). For PSH, several recent studies conducting global searches of potential sites worldwide point to an abundance of candidate locations (Stocks et al., 2021; Hunt et al., 2020).

[6] The study assumed implementation of the Clean Power Plan which was being discussed at the time but was ultimately not enacted.

1.3.2 Development pipeline

1.3.2.1 United States

1.3.2.1.1 New projects

Studies that estimate remaining technical potential for additional hydropower capacity provide a useful upper bound, but a more informative outlook for the short to mid-term potential of new builds emerges from analyzing the project development pipeline.[7] Figure 1 and Figure 2 offer details about the composition and status of conventional hydropower and PSH projects in the U.S. development pipeline at the end of 2020.

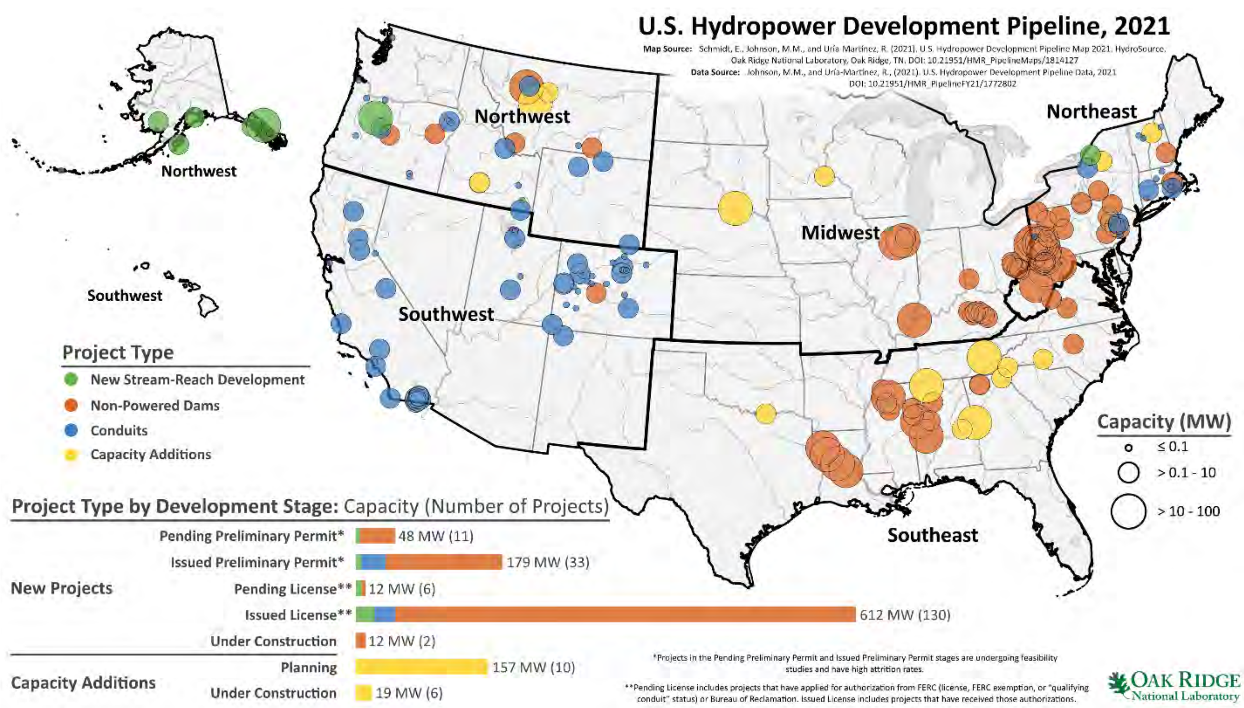


Figure 1. US. conventional hydropower project development pipeline by project type, region, size, and development stage (as of December 31, 2020).

Source: Schmidt et al. (2021)

Note: This map is available for download at https://hydrosource.ornl.gov/map/us-hydropower-development-pipeline-2021

[7] The development pipeline numbers presented here include projects that have formally expressed interest in developing a conventional hydropower or PSH project that would require a FERC authorization (license, exemption, or approval as qualifying conduit) or a Bureau of Reclamation's lease of power privilege (LOPP). For the FERC pipeline, the following development stages are included: pending preliminary permit, issued preliminary permit, pending license (or exemption), issued license (or exemption), and projects under construction. For the LOPP pipeline, the following development stages are included: pending preliminary lease, issued preliminary lease, issued LOPP. To limit the number of categories shown in Figure 1, the stages of the LOPP process are presented under the most similar stage of the FERC development process. Pending preliminary lease is shown as Pending Permit, issued preliminary lease is shown as Issued Permit, and issued LOPP is shown as Issued License.

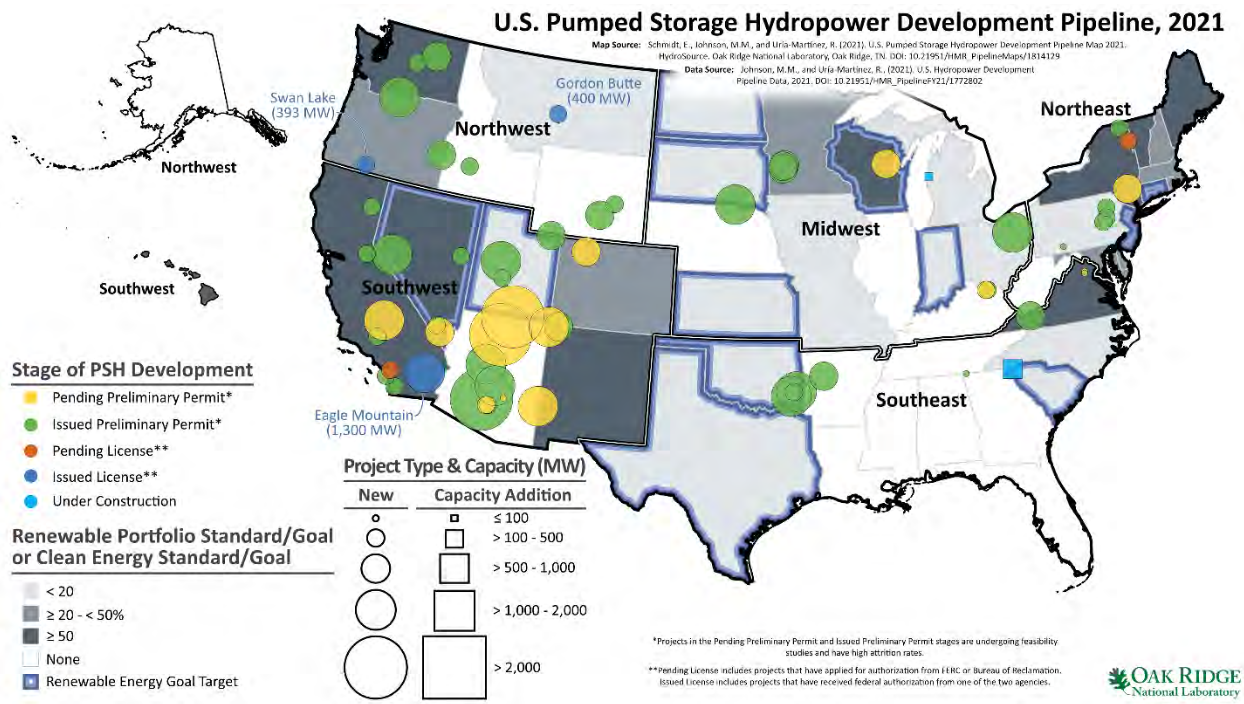


Figure 2. PSH project development pipeline by region and status in relation to state-level renewable energy targets (as of December 31, 2020)

Source: Schmidt et al. (2021b)

Note: This map is available for download at https://hydrosource.ornl.gov/map/us-pumped-storage-hydropower-development-pipeline-2021

At the end of 2020, there were 183 new projects (80 NPD retrofits, 94 conduit retrofits, and 9 NSD projects) in the U.S. conventional hydropower development pipeline, which is 15% lower than the average number of projects in the pipeline in 2016–2020. These 183 projects have a combined proposed capacity of 863 MW. The median capacity varies significantly across project types, from 89 kW for conduit retrofits to 4.5 MW for NPDs. The largest conventional hydropower project in the pipeline is the Uniontown Hydroelectric project in Indiana (66.6 MW). Most conduit retrofits are proposed in the Western half of the country and most NPDs are in the Eastern half. Eight of the nine NSD projects are either in Alaska or the Pacific Northwest. Over 70% of proposed capacity already has an issued Federal Energy Regulatory Commission (FERC) license; only two projects (two NPDs with combined capacity of 12 MW) were under construction at the end of 2020. Most other projects are at a much earlier stage of feasibility evaluation in which attrition rates have typically been very high.

The U.S. PSH development pipeline included 63 projects with combined proposed capacity of 46.7 GW at the end of 2020 (see Figure 2). This number is 17% higher than the average number of PSH projects in the pipeline in 2016–2020. Project sizes range from 10 MW to 3,600 MW and the median size is 500 MW. Twenty-two states had at least one PSH project in the pipeline at the end of 2020, with the greatest number of PSH projects in California, Nevada, and Arizona. Seventy percent of these PSH projects have preliminary permits to conduct feasibility evaluation studies. At the feasibility evaluation stage, just like with conventional hydropower, the attrition rate is very high. Three projects—Eagle Mountain (California, 1,300 MW), Swan Lake (Oregon, 393 MW), and Gordon Butte (Montana, 400 MW) already have a FERC license. No new PSH projects are currently under construction.

Aside from new projects in the development pipeline, 18 ongoing upgrades would add 176 MW to the existing conventional hydropower fleet and 250 MW to the existing PSH fleet.

1.3.2.1.2 Refurbishments and upgrades

The project development pipeline is only one dimension of U.S. demand for hydropower components, with substantial uncertainty as to the fraction of projects that will eventually be constructed. Since 1990, new construction has added 2.4 GW of conventional hydropower and 2.9 GW of PSH—3% and 13% of total installed capacity as of 2021, respectively. Most of the domestic activity for the U.S. hydropower supply chain in the past 30 years has been geared toward maintaining, refurbishing, modernizing, and upgrading the existing fleet.

Uría-Martínez et al. (2021) report that at least $7.8 billion were invested in refurbishing and upgrading the U.S. conventional hydropower and PSH fleets during the 2010s. Turbine runner replacement or refurbishment, generator rewinds, installation of digital governors, and replacement or upgrades of floodgates or transformers were the most common items in the scope of the 339 tracked projects.

At the end of 2020, Industrial Information Resources reported planned new refurbishment and upgrade investments for 62 hydropower plants in the United States to start from 2021 to 2024. The estimated capital investment from these projects adds up to $4.4 billion. Sixty percent of this investment is in the early stages of developing a project justification, conducting preliminary design, and submission of authorization for expenditures. The most common scope items in these planned projects continue to be turbine modernization and generator rewinds. There are also several instances of governor and controls upgrades, and gate and crane refurbishments.

1.3.2.2 Global

Data on global hydropower development activity are of interest to U.S. supply chain participants for multiple reasons. First, U.S. manufacturers of hydropower components export part of their production to the global market and information on which world regions have most planned new projects can help them identify key target export markets. Second, given the interconnected nature of the global supply chain for hydropower components, the volume of hydropower development activity worldwide must be considered for an analysis of potential supply chain bottlenecks for the United States. This is especially the case for large turbines and generators where the number of suppliers is very limited.

The map in Figure 3 introduces the nine world regions considered through this report and shows where major conventional hydropower clusters are located.

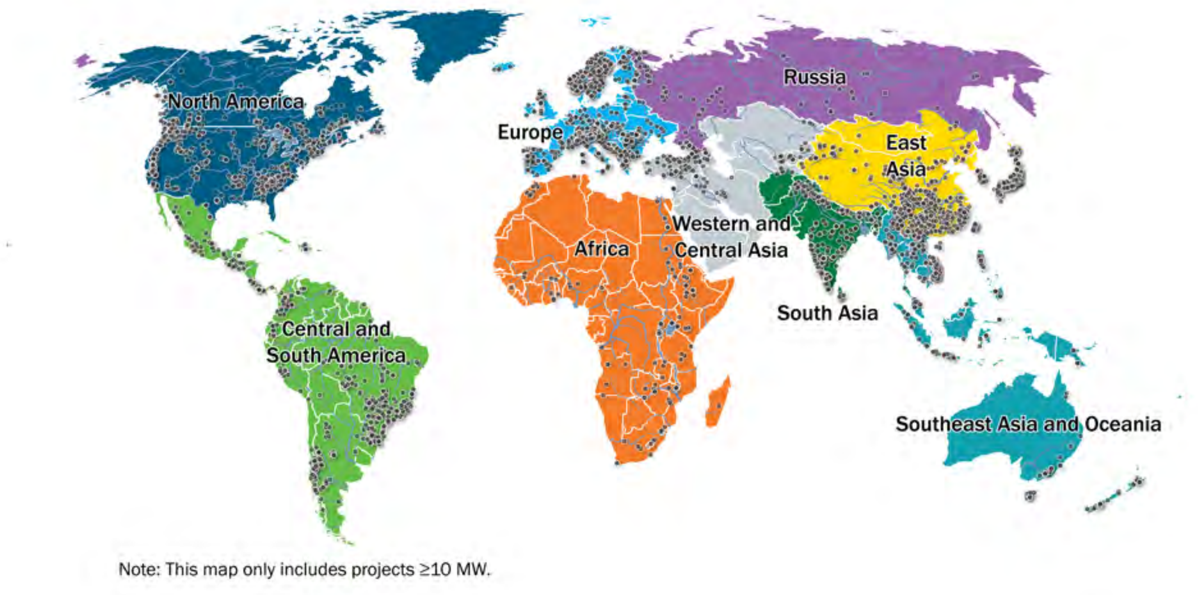


Figure 3. Map of operational conventional hydropower plants by world region

Source: Industrial Info Resources

Note: The dots represent the location of operational conventional hydropower plants

Based on data from GlobalData, a commercial provider of intelligence on key world industries, 151 GW of conventional hydropower and 30 GW of PSH were either under construction or had completed permitting and reached financial closure around the world at the end of 2020. An additional 188 GW of conventional hydropower and 49 GW of PSH were in the permitting phase. At an even earlier stage, plans have been announced for 268 GW of conventional hydropower and 53 GW of PSH without significant progress toward permitting or financing them. If 100% of projects in the Announced, Permitting, Financed, and Under Construction stages were built, they would result in a 57% increase in global conventional hydropower capacity and an 84% increase in global PSH capacity. Figure 4 and Figure 5 show the regional distribution of capacities at the various stages.

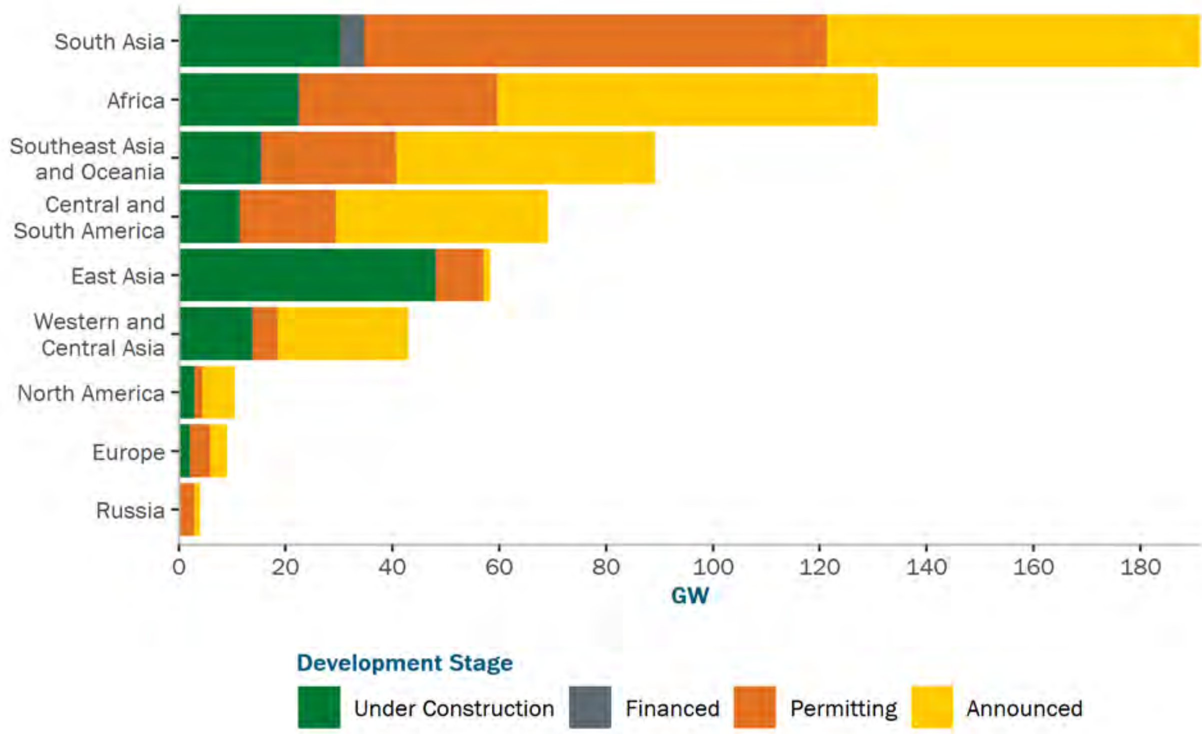


Figure 4. Global conventional hydropower development pipeline by region and development stage

Source: GlobalData

South Asia and Africa are the only two regions with more than 100 GW of conventional hydropower in the pipeline. East Asia leads the ranking in terms of conventional hydropower under construction (48 GW). North America, Europe, and Russia—the regions with the oldest conventional hydropower fleets—are the regions with the least amount of new capacity in the pipeline. For North America, 86% of the capacity shown in Figure 4 corresponds to projects located in Canada.

For conventional hydropower, given the size of the U.S. development pipeline relative to the global development pipeline, it should be expected that U.S. hydropower supply chain participants will pursue export opportunities in addition to supporting the domestic fleets.

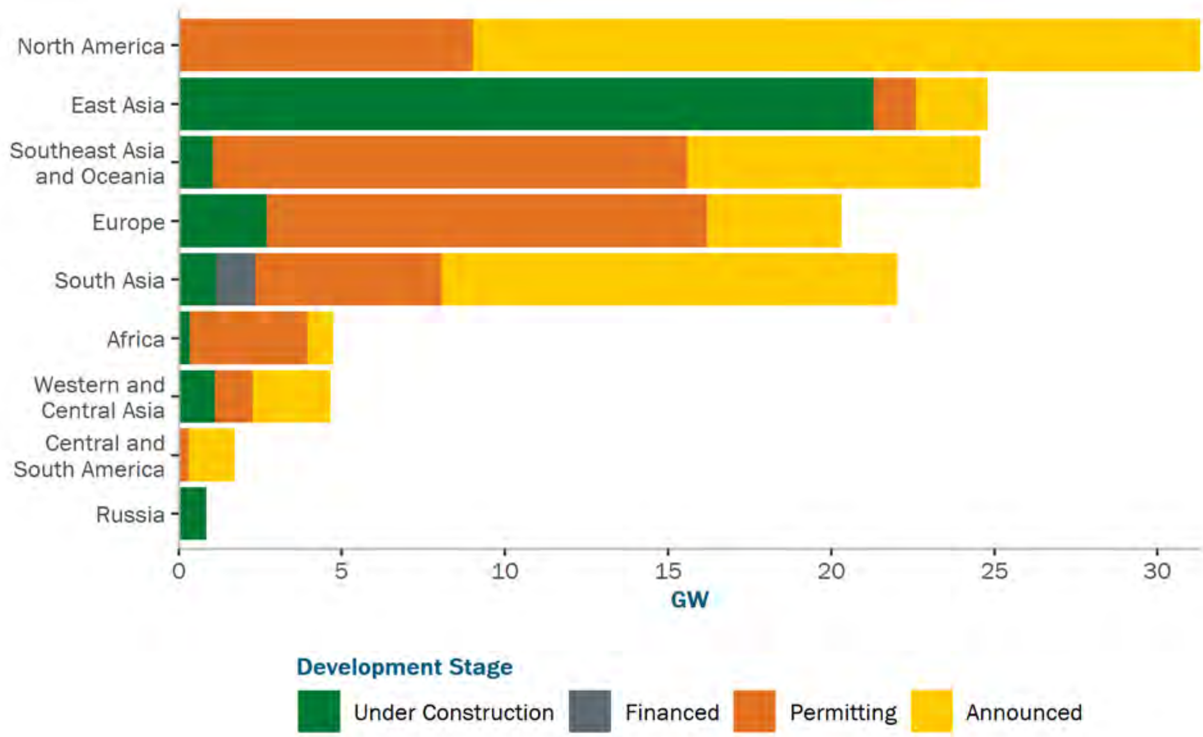


Figure 5. Global pumped storage hydropower development pipeline by region and development stage

Source: GlobalData

North America (defined here as the United States and Canada) leads the PSH pipeline and 45 of the 48 projects tracked by GlobalData in this region are in the United States.[8] However, none of the projects are under construction. North America and Central and South America are the only two regions with no PSH construction currently underway. In contrast, the region with the second largest PSH pipeline (East Asia), has 86% of the 25 GW in its pipeline under construction. Of the 23 PSH plants in the pipeline in that region, 18 are in China, 2 in Japan, and 3 in Mongolia. Europe and North America are the only two regions with more PSH capacity than conventional hydropower capacity in their development pipelines.

1.3.3 New hydropower required to meet decarbonization objectives

Figure 6 compares global hydropower installations in 2000–2018 with the estimated average annual global installations needed out to 2050 to meet different decarbonization objectives. IHA (2021) provides estimates of total hydropower capacity needed by 2050 for a scenario in which global warming is kept under 2 °C (850 GW) as well as the forecasted new hydropower needed based on the IEA's Net Zero Roadmap (1,300 GW).

[8] GlobalData covers projects in all world regions, but its coverage of the U.S. development pipeline is not as complete or up-to-date as that in the U.S. dataset presented in Section 1.3.1.1. leading to some differences in the number of projects and capacity for the United States across the two datasets.

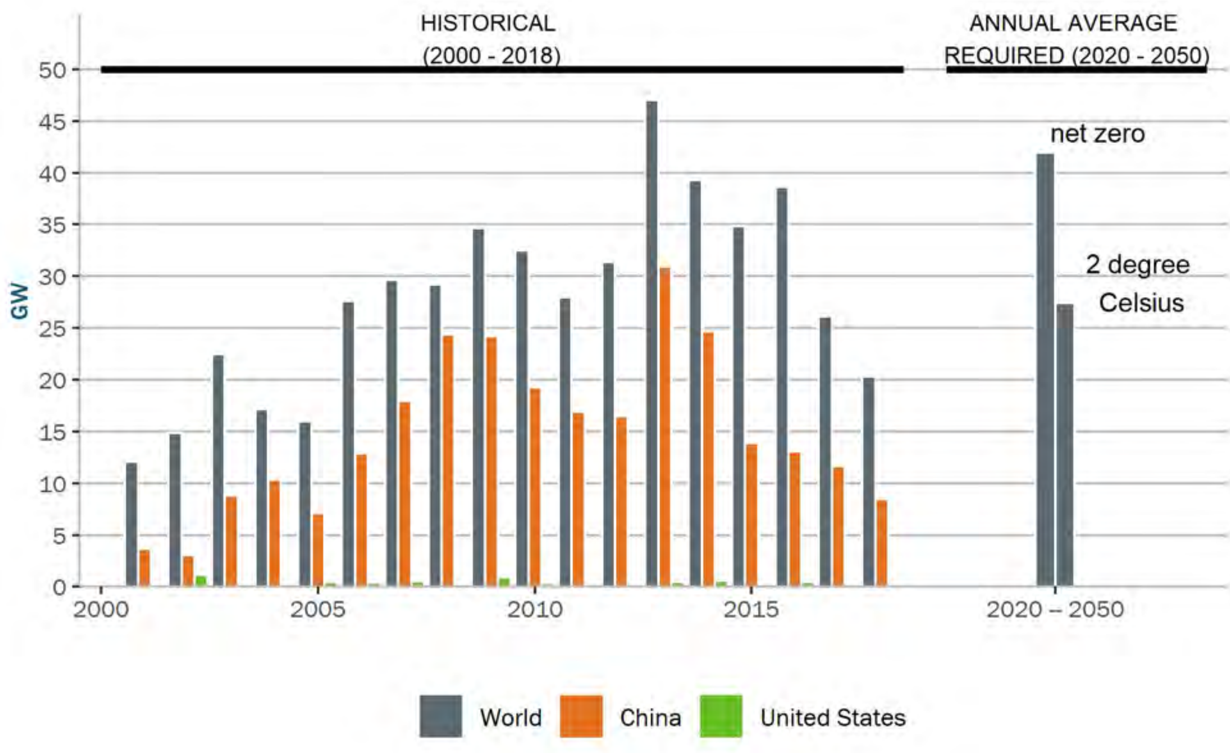


Figure 6. Recent hydropower (including PSH) installations versus average annual needs to 2050 to meet alternative decarbonization objectives.

Source: EIA, IHA (2021)

On average, from 2000 to 2018, 27 GW of hydropower (including PSH) were added globally per year. Maintaining that annual average from 2020 to 2050 would add 810 GW, very close to the estimated 850 GW needed by 2050 to keep global warming below 2°C. However, a substantial scale-up in construction would be required to construct the 1,300 GW estimated as necessary for a net zero energy sector by 2050. For comparison, the total capacity (conventional hydropower plus PSH) in the development pipeline at the end of 2020, presented in Figure 4 and Figure 5, would add 739 GW of which 321 GW are at a very early stage of development with substantial uncertainty about their progressing to construction.

Of the global capacity added from 2000 to 2018, 51% has been in China. If decarbonization-driven development substantially changes the regional fractions of new construction going forward, the supply chain might need to adjust accordingly in terms of manufacturing locations, workforce etc.

The manufacturing capacity required to service global demand for hydropower-specific components in the next three decades does not depend on greenfield projects alone. Figure 6 shows capacity added in new projects as well as through installation of additional turbine-generator units at existing plants and uprates (i.e., power rating increases) of existing units. However, Figure 6 does not include refurbished capacity. In some regions, most of the demand for hydropower components results from refurbishment or modernization of existing plants without adding significant new capacity. This is especially true for the United States where turbine manufacturers stated that refurbishments and upgrades have accounted for 90% or more of the domestic demand in recent years. On the other hand, globally, one major turbine manufacturer mentioned that their work has typically been in a ratio of one brownfield project to two greenfield projects. To reach a net zero energy sector, the hydropower supply chain would need to be scaled so that it can meet the demands for refurbishments, upgrades, and new construction.

2 Supply Chain Mapping

2.1 Technology Overview

The following is a brief description of hydropower energy generation to illustrate the key components. A hydropower plant converts potential energy, in the form of an elevated body of water, into kinetic energy through water flow, into mechanical energy by rotating the turbine, and then into electrical energy by rotating the generator. As the turbine spins so does the generator rotor whose outer surface is covered in electromagnets (field poles). As those electromagnets move past the copper windings covering the surface of the generator stator, alternating current is generated. A step-up transformer converts the alternating current to high voltage current that can be transported over the electric transmission grid. Water flow into the turbine is controlled through gates and valves, which allows for isolation of the turbine-generator units during maintenance or emergencies.

A hydropower plant often has multiple turbine-generator units which limits the number of single points of failure to plant operations. Figure 7 shows the major components of a Kaplan type turbine-generator unit. The configuration of hydropower plants is highly site-specific, with multiple custom components that require long lead times for their replacement. This section describes in more detail the characteristics and function of a list of hydropower plant components. All of them are critical to turbine-generator unit operations making their supply chains the focus of this study. Hydropower facilities contain highly customized components combined into systems that are designed to fit the specifics of their environment. This environment is dictated by water availability in terms of head and flow. Since components and overall facilities are unique, general arrangements will be similar, but interchangeability of components is limited.

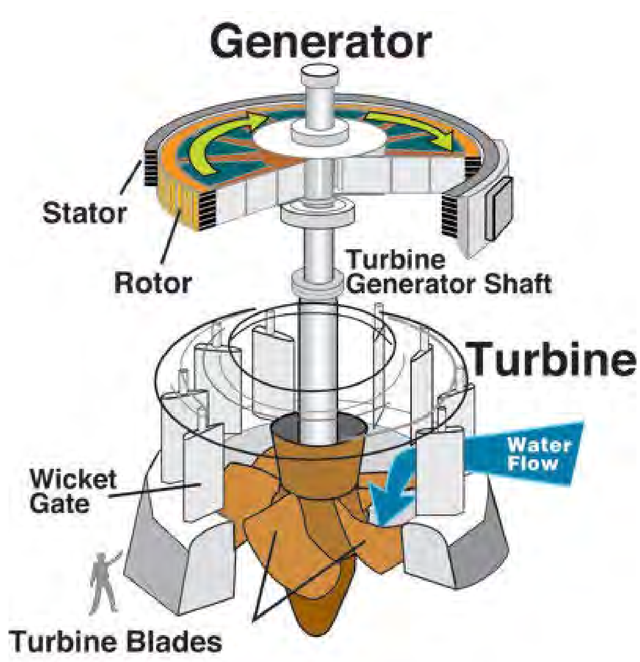


Figure 7. Diagram of a Kaplan-type hydroelectric turbine-generator unit

Source: Courtesy of U.S. Army Corps of Engineers. Wikimedia: Creative Commons License.

2.1.1 Turbine

There are multiple types of turbines and selection depends on the combination of water flow and head—the difference in elevation between the water intake point and the water discharge point—available at the site, among other factors. The two major families of turbines are impulse and reaction turbines. Reaction turbines, such as Francis and Kaplan, are fully immersed in water and are ideal for low-head, high-flow systems. Impulse turbines, such as Pelton, operate in air and driven by high-velocity jets of water and are the typical choice in high-head sites (Canyon Hydro, n.d.). Selecting the appropriate curvature for the turbine blades and high-quality casting materials are among the choices that help maximize the generation efficiency of the resulting unit.

The hydropower turbine has several components, mostly made of steel (carbon or stainless), that require custom design and fabrication:

- Scroll case: It is a custom-made, steel spiral casing that surrounds the turbine runner. It is the first component reached by the water flow as it exits the penstock. These are typically made of fabricated carbon steel plate.
- Runner: Blades (in reaction turbines) or buckets (in impulse turbines) designed to capture the maximum energy from the water passing through. Runners and blades are custom-made from steel (carbon or stainless) castings, forgings, and in some cases, plate.
- Wicket gates: Adjustable gates/vanes to control the flow of water through the turbine, made of steel (carbon or stainless) castings or forgings.
- Draft tube (only applies to reaction turbines): It connects the turbine outlet to the tailrace. They are custom-designed civil structures made of cemented concrete with a cast steel lining to avoid cavitation. The draft tube brings the pressure of the water flowing out of the turbine back to atmospheric pressure. Draft tubes are typically fabricated from carbon steel plate.
- Headcover: It provides separation of the wet turbine elements, including runner and wicket gates, from the dry powerhouse elements, including the generator and wicket gate operating servomotors. Headcovers are engineered to be pressurized on the water side and to support wicket gate elements. Components of the headcover may be constructed from steel plate, castings, and forgings.
- Bearings: Turbine guide bearings are typically bushings, made of babbitt, composite, or Polytetrafluoroethylene (PTFE), a Teflon-type material.

2.1.2 Generator

The description in this section draws primarily from a design manual for hydropower generators published by Bureau of Reclamation (Bureau of Reclamation, 1992). Generators, particularly for large units such as those with power rating greater than 100 MW, require custom design and fabrication. The major parts of a generator are:

- Shaft: It connects the generator with the turbine. It is typically made of forged steel.
- Rotor: It is the rotating part of the generator. It rotates at a fixed speed determined by the turbine. The rotor is connected to the shaft and its outer surface is covered with field poles.
    - The field poles are built from thin laminations of magnetic material.
    - The rotor spider transmits torque and rotation from the shaft to the rotor rim and poles and provides supporting structure for the poles. It is often made of forged and fabricated steel.
- Stator: It concentrates the magnetic field from the rotor to produce the induced voltage in the armature.

  - The stator frame provides the structure to support the stator core and windings. It is made of thick fabricated steel plates.
  - The stator core is made of stacked thin laminations of electrical grade steel and coated on each side with insulation. It is built inside a cage which is then attached to the stator frame (GE Energy, n.d.).
  - The stator windings are coils made of copper and insulating material and they are wedged into stator core slots. They are custom-made for each installation and spares must be acquired when the generator is first purchased to ensure availability when the need for repair arises.
    - Insulation materials for stator windings have changed over time and the standard base materials are now glass fibre, mica dust, or polyester fiber. There are also multiple options for the insulation binder materials. The standard used to be asphalt before the 1960s and since then polyester-vacuum pressure impregnation (VPI) hybrids and several kinds of epoxy have also been introduced (BBA, 2019).
- Bearings: Generator bearings may be roller type or journal type bushings. Thrust bearings are used to support the generator in vertical units, or to resist the hydraulic forces imparted by water on the turbine in horizontal reaction turbines. Typical bearing material is babbitt, composite, or PTFE material. Roller type bearings are used in some applications as well.

2.1.3 Governor

The governor regulates the rotational speed, power output, and system frequency of the turbine-generator units by controlling the flow of water through opening/closing of the wicket gates. It involves control and actuating components. Governors are hydraulic systems with common components across many industries. The below summary discusses how these hydraulic systems have changed over time.

- Speed sensing devices have changed over different generations of governors. Early mechanical-hydraulic governors had a fly-ball type pendulum. The second generation of electro-hydraulic governors had a frequency transducer as speed sensing device (Vu and Agee, 1998). In modern digital governors, the speed signals are provided by a digital control algorithm and electronic circuits.
- Hydraulic pressure units (HPUs) include a pressure oil tank, oil sump, air compressor, oil filtration system, oil pump or motor, and piping. Their function is to supply pressurized oil to a servomotor to adjust the position of the wicket gates. For emergency shutdowns (i.e., loss of station power or grid), systems will be equipped with an air-over-oil pressure tank or a bladder accumulator to stop water flow through the turbine.
- Controls can be mechanical, analog, or digital.
  - Digital governors help increase plant automation, include built-in diagnostic tools for better fault detection, and allow more precise turbine control. A digital governor is required by system operators for a plant to qualify for provision of certain ancillary services. A potential downside from digital governors is their frequent obsolescence that forces replacement of the programmable logic controllers (PLCs) every five to 15 years despite not having experienced any failures. Also, at least in some cases, a digital governor eliminates the option for manually controlling a unit.

2.1.4 Excitation system

The excitation system, consisting of electronic circuitry and components, supplies and regulates the amount of direct current (DC) needed by the generator rotor windings. Hydropower exciters are typically shaft-mounted rotating systems energized through contacting brushes. These are being replaced with modern equivalents, including:

- Static exciter: Static excitation systems can be of two types (inverting and semi-inverting) depending on the speed of generator field suppression required.
- Brushless or rotating rectifier exciter: It uses rotating rectifiers that are directly connected to the generator field poles, eliminating the need for brushes. It is used in smaller hydropower generators where large excitation current is not needed.

2.1.5 Switchgear

The generator switchgear is located between the generator and the step-up transformer and serves to synchronize the frequency, voltage, and phase of the electricity exiting the generator with those of the grid.

- Circuit breakers: There are four types depending on the medium they use for arc interruption: air, oil, sulfur hexafluoride (SF6), or vacuum.
- Surge arresters: They protect the generators from overvoltage.

2.1.6 Emergency closure systems

When closed, intake gate closure systems stop water from the dam reservoir from reaching the turbine. They are made of fabricated steel. For emergency deployment, they can be operated via accumulators on the hydraulic system, gravity deployment, or automated cranes. For normal operation, they can be operated with a hydraulic system, a wire rope hoist system, or a crane (Gore et al., 2001).

2.1.7 Penstock

The penstock is the conduit transporting water flow from the intake point to the turbine. A hydropower plant can have multiple penstocks to convey water to different units. Alternatively, a single penstock can be bifurcated or trifurcated to distribute the flow to multiple turbine-generator units.

Steel is the most common raw material for penstocks, but they can also be made from other materials, including wood stave (largely out of use for new installations but still present in some old projects), fiberglass, and high-density polyethylene plastic. Multiple materials and various wall thicknesses (as pressures increase) may be utilized in a single installation.

2.1.8 Bypass systems

In the event of inflow greater than turbine capacity, or turbine(s) being offline, alternative passages of water are required at hydroelectric generation plants.

- Spillways: Gated concrete structures having ideal shapes to pass flow. These are typically gated with large steel structures that operate using wire rope hoists or hydraulic hoists.
- Overflow spillway: These spillways are unregulated, meaning water is not controlled as it passes. Water will reach a specific elevation, then overflow this type of spillway. It is constructed of concrete.

- Turbine bypass: In facilities where the powerhouse is a significant distance away from the dam or spillway, a bypass system is required. These are typically valve-controlled systems within the penstock where a turbine inlet valve will be closed and a bypass valve opened on a parallel water passage route. A dissipation valve or structure will be placed at the bypass outlet to minimize energy in the water jet being discharged. The bypass and valve structures are largely made of steel, cast steel, and stainless steel.

2.1.9 Balance of plant

This category includes auxiliary systems such as compressed air systems, oil delivery and storage, plant temperature control, hoists, and components that are not hydropower-specific but still critical to plant operation such as batteries, transformers, and cranes.

2.2 Industry Structure

Along with a whole range of mechanical, electrical, and electronic components associated with moving water and operating the powertrain, consisting of the turbine and generator, a hydropower plant often includes extensive civil works and other supporting structures. Most of the materials and services for the construction of civil works and other structures in the United States are met by domestic companies.

Turbines and large generators are the key hydropower-specific components built by companies (or company divisions) exclusively dedicated to serve the hydropower sector. Thus, the industry structure discussed in this section focuses largely on the turbine-generator manufacturing supply chain.

Steel, stainless steel, and copper are the main raw materials needed to build many of the components listed in the previous section; they are the raw material industries most important for hydropower supply chains.

Even though turbines and generators operate as a unit, they are sometimes produced by separate companies. In the past, there was a greater separation between companies that supply turbines and generators as they require different types of expertise. The Bureau of Reclamation (1992) explains that, during the decades in which most of its fleet was constructed, there was only one U.S. manufacturer and a few international manufacturers that could provide both the turbine and the generator. To increase their procurement options, they typically announced requests for bids separately for turbines and generators. Nowadays, the major turbine manufacturers also provide generators either through self-production, where turbine manufacturers have acquired or merged with generator manufacturers to enhance their ability to supply the entire powertrain, or through joint ventures with generator manufacturers. For small units, several manufacturers offer "water-to-wire" packages where the turbine and generator are supplied as a set along with other components such as automated controls, turbine inlet valve, and switchgear.

The manufacturing process for a new turbine or turbine runner takes multiple years and involves many steps as designs are dictated by the water flow and head criteria of the specific site. The unit is first designed and tested computationally using Finite Element Analysis and Computational Fluid Dynamics methods. Then, for a new turbine runner design, a prototype might be produced and further tested, a step that can add one year to the process. The manufacturing process traditionally starts by ordering a steel casting from a foundry. The casting process involves heating up the material to its melting point and pouring it into a mold to obtain the desired shape. The resulting casting is then machined to introduce features that cannot be produced during the casting process. It has become standard to use computer numerical control (CNC) machining rather than conventional machining. CNC machining is a subtractive manufacturing process, where a tool chips away steel shavings from the initial single piece to achieve the desired shape, guided by computer-aided design (CAD) software (Formlabs, n.d.). Finally, turbine runners are manually polished to achieve a smooth finish.

The manufacturing process described in the previous paragraph follows subtractive manufacturing principles where the starting point is a solid block from which material is removed until the desired shape is achieved. In contrast, additive manufacturing (AM) is characterized by the absence of a mold, die, machine (e.g., mill, grinder), or other tool designed to produce the target geometry. Instead, AM processes involve depositing layers of materials and consolidating them to create a solid object. A wide range of metals or polymers are used in these processes and some final machining is often needed to achieve the exact dimensions required. This can be accomplished via post-build machining or with the use of a hybrid system in which there is a subtractive function available, along with the additive process, to provide more accurate geometry. AM processes are mostly still in the research and development (R&D) phase for applications in the hydropower industry, but some manufacturers have started applying them to the manufacturing of hydropower turbines either to produce components like blades in small turbines or to 3D-print casting molds.

Other turbine components such as the scroll case, head cover, wicket gates, or draft tube are also made of steel using manufacturing processes such as turning, forging, rolling, and bending. The various turbine components are finally welded together (Kafle et al., 2020).

For generators, many of the parts are made of steel using similar processes and tooling as discussed for turbine components. However, the stator winding coils require an entirely different manufacturing process. At a coil manufacturing facility, strands of copper to manufacture the copper windings are drawn from copper reels. The two main coil structures typically used in hydropower generators are single-turn bars or multi-turn coils. In multi-turn coils, strands are insulated. Multiple strands form a turn and additional insulation is applied at the turn level. Then, the turns are assembled into full loops and a spreading machine is used to create the basic coil shape. Next, ground wall insulation tapes are applied and the coils are cured. Single-turn bars do not make a full loop; they are “half-coils”. For small units, the coils are placed into the stator slots at the factory; for large units, placement into the stator slots takes place at the plant site.

Specialized machining shops are also key components of the hydropower supply chain to serve the needs of plant owners facing extinct supply chains for some of their plant components (e.g., some machine shops are able to reverse engineer old mechanical governor components) or needing refurbishment of custom components such as gates.

Once manufactured, transportation of the turbine and generator components within the United States can be by barge, rail, and/or truck depending on the size and weight of the components as well as the plant site location. Transportation logistics are considered by manufacturers in deciding whether the product can be shipped fully assembled or broken into multiple parts that can more easily be transported via truck for final assembly at the plant site. Barge transportation is used frequently for transporting large components to plants that are located on navigable main river stems. When manufacturing takes place overseas, ocean shipping is almost always the chosen transportation mode. However, there are also instances of air shipping when the dimensions of the component allow it and it is especially urgent for the plant owner to receive it.

The turbine-generator package is typically designed first, with the conveyance system and powerhouse designed around it. The turbine production and civil construction are typically parallel efforts. As the turbine and generator are being manufactured, there is significant back and forth between the turbine designers, facility design engineers, and construction companies. The foundation of the turbine-generator system is critical for alignment with the conveyance system, discharge system, and bypass system. The design and construction of the powerhouse will occur on a timeline to accept the turbine-generator package when it is shipped to the site. Climate-controlled shipping and storage may be considerations for the generator due to its sensitivity.

At the end of its operational life, hydropower plant materials for which there is an active market (steel, copper) are typically recycled. The value of these materials is often factored in as a credit in contractor bids. Some of the stakeholders interviewed acknowledged not giving much thought to other initiatives to avoid landfilling given the long operational life of most hydropower plant components and the recycling practices already in place. Some examples were mentioned where old turbine runners are used by the manufacturers for training schools or testing purposes.

Disposal of hazardous substances also receives special attention. The list of hazardous substances in a hydropower plant may include oil, asbestos (typically found on generator windings and insulations for units constructed from the 1930s to the 1980s), and lead (found sometimes in old turbine runners). Presence of hazardous substances associated with the copper or steel components can make their recycling more difficult.

2.3 U.S. Production Capabilities

NHA's inventory of U.S. hydropower supply chain companies contains more than 2,500 entries but no easy way to categorize the goods or services provided by each company. Table 1 shows the top 10 states by number of companies in NHA's inventory; together they account for more than 60% of the total number of companies.

Table 1. Top 10 States by Number of Companies in the U.S. Hydropower Supply Chain

State	Number of Companies
Pennsylvania	324
California	247
Washington	202
Wisconsin	147
Ohio	133
Illinois	129
Alabama	121
Oregon	109
Michigan	83
Massachusetts	80

Source: NHA

The ten states in Table 1 include the three with the largest installed hydropower capacities (Washington, California, and Oregon) but also others that have small hydropower fleets. For states like Pennsylvania (by far the one with the largest number of companies), Wisconsin, Ohio, and Michigan, it is their proximity to steel mills and related manufacturing that made them attractive. In fact, a large fraction of the companies that serve the hydropower supply chain are not exclusively dedicated to it. For instance, machine shops serve a variety of industries as do companies producing pipes or even those manufacturing small generators or industrial controls.

Why Aren’t We Looking at More Hydropower?

By Lindsay Fendt – Ask MIT Climate – March 2, 2021

Hydropower is already a major source of power globally—it’s the largest source of renewable electricity and one of the fastest growing—but there are limited places to build hydropower, and large dams carry a number of social and environmental concerns.

While wind and solar often dominate conversations about low-carbon electricity, hydropower provides much more electricity worldwide than any other low-carbon energy source—nearly eight times more than solar power and 1.5 times more than nuclear. And it’s one of the fastest-growing sources of renewable energy: according to the International Energy Agency, hydro saw more growth between 2008 and 2018 than any other source of renewable electricity other than wind power.

"If you look at some of the most dramatic proposals for a pathway to zero carbon electricity system, they all need to incorporate a significant build out of hydropower," says John Parsons, an energy economist with MIT's Center for Energy and Environmental Policy Research.

However, large hydroelectric dams can’t be built just anywhere. Hydro plants need a consistent supply of water and a large amount of land. Some countries have plenty of these resources; others do not.

Poorly planned hydropower can also cause more problems for the climate than it prevents. Hydro plants need large reservoirs to provide a steady stream of water. When these reservoirs are built, plants and other organic matter get flooded. This material decays over time, releasing greenhouse gases like carbon dioxide and methane. According to Parsons, there hasn't been much research measuring these emissions, but the studies that have been done have found huge differences from reservoir to reservoir.

"People are right to think of hydro as a low-carbon resource, but the variability is very high and there are some reservoirs that have lifecycle emissions of greenhouse gases that are higher per unit of electricity produced than a fossil plant," he says. "You don't want to just be advocating hydro everywhere."

Many wealthy countries, including the U.S., have already built out most of their suitable hydro resources. The countries adding large amounts of hydro are mainly growing economies in East Asia and South America. Places like China and Brazil have large planned hydro projects that will come online in the next few years, but rather than replace fossil fuel resources, these dams will be used to expand electricity access to areas that don't have it. These enormous projects generate large amounts of electricity and cost billions of dollars.

"Hydro resources often require a very long-term investment horizon," Parsons says. "When you invest in building out a hydro reservoir, it's usually as a part of a very big economic development strategy over a couple of decades."

Hydropower can also cause environmental and social problems. Reservoirs drastically change the landscape and rivers they are built on. Dams and reservoirs can reduce river flows, raise water temperature, degrade water quality and cause sediment to build up. This has negative impacts on fish, birds and other wildlife.

These environmental impacts often spill over to humans as well. The World Bank estimated in 2000 that between 40 and 80 million people had been directly displaced by dams and reservoirs.2 Another study from 2010 estimated that 472 million people downstream from large dams suffer from reduced food security, regular flooding or impacts on their livelihood.3

So while hydropower is a good source of low-carbon electricity, even countries with plenty of untapped water need to weigh the benefits of hydro against the environmental and social costs of dam projects. There’s still room for hydro to grow, but most countries will not build out as much hydropower as they theoretically could—and that may be for the best.

Do We Have the Technology to Go Carbon-Neutral Today?

By Kathryn Tso – Ask MIT Climate – September 28, 2020

We still need new breakthroughs to decarbonize many parts of our modern economy, especially if we don't want to drive up the price of energy and goods. But we can make real progress with today's technology, and invest in good ideas for the next generation of low-carbon solutions.

What would our world look like if we became completely carbon neutral? Could we still enjoy today's electricity, transportation, heat and manufacturing if we put no more greenhouse gases into the atmosphere than we take back out? "Unfortunately, these are not solved problems," says Desiree Plata, MIT Professor of Civil and Environmental Engineering. "While we do have the technology to make a lot of systems nearly carbon neutral, none of these systems can run the same way they do today and the cost to implement [some of today's solutions] is prohibitively high."

First, the good news. We've gotten pretty good at making low-carbon electricity. Today, solar panels and wind turbines can make electricity at a similar price to coal or natural gas. And we can also use that clean electricity to drive (like with electric cars) and to heat our homes and water (like with electric furnaces and hot water heaters): things that today mostly run on oil or gas.

However, says Plata, it's not so simple to switch out the old, fossil fuel technologies for the new, low-carbon ones. Solar and wind power aren't always there when we need them, the way coal and gas are. "For example," Plata says, "solar energy is best captured and stored during the middle of the day, but is least accessible at night when the demand increases. One of the only technologies to meet that rapidly accelerating demand is fossil-derived carbon." In other words, we still need fossil fuels to fill the gap when we don't have enough sun or wind. To get more of our electricity from wind and solar, we first have to change the way we use and distribute electricity, or come up with better ways to store energy that can work on a large scale and at low cost.

Then there are areas where today's carbon neutral technologies can't match the performance of fossil fuels. "Transportation would have to change drastically, as carbon neutral energy cannot provide as much power for large vessels as fossil fuels," says Plata. "Think about air travel. Solar planes have to be very lightweight. So, passenger jets have to be shrunken down from the traditional form to much smaller units. Instead of an Air Bus, you need an Air Car." Heavy trucks and rail transport have similar limitations.

Finally, there are areas where our technology isn't ready to support a switch to cleaner energy sources at all. The steel and concrete manufacturing sectors in particular don't yet have options to stop using fossil fuels to generate the high amount of heat they need. So, the next best method is to capture and store the carbon dioxide these facilities emit when they burn fossil fuels. Some factories around the world, making everything from fertilizer to steel to gas, have been adding carbon capture technologies in recent years, effectively keeping their carbon emissions out of the atmosphere. And some coal- and gas-fired power plants have started to follow suit.

“This has grown appreciably in the last decade,” says Plata. However, “there is a significant cost to implement these technologies, measured in millions of dollars to stand up the needed infrastructure. This is not currently economical for most plants, and it only becomes economical if you put a price on the carbon to incentivize its trapping.” That’s one example of a political solution that could work alongside technological ones: if companies had to pay for the greenhouse gases they emit, they would have an incentive to become carbon neutral even with today’s technologies.

Just because we don’t have all the technology we need to overcome the climate crisis today doesn’t mean there’s nothing to be done. We are far from using today’s technologies to their full potential. Wind and solar power, carbon capture, and electrified heat and transportation all have lots of room to grow. And for those sectors where we still need new options, scientists and engineers are working on innovative approaches to energy storage, manufacturing, new transportation fuels, automated and low carbon air travel, and everything in between. “It’s a great time to be a technologist,” says Plata. “There are so many ways young scientists, engineers, and policy architects can contribute to solve these important problems.”

INTRODUCTION

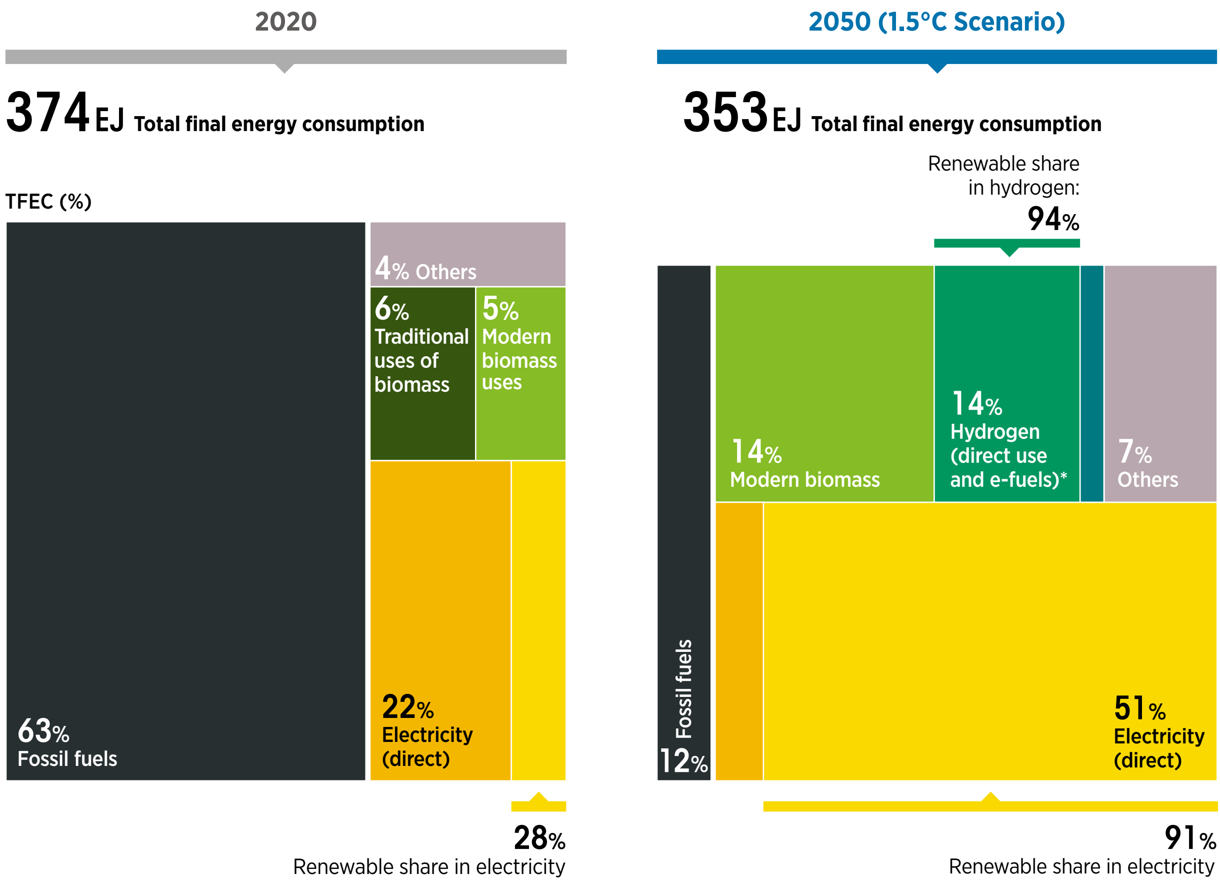
Systemic innovation is needed to achieve smart electrification of end-use sectors

The world has already begun a historic shift towards cleaner sources of energy. Rapid reductions in the cost of solar and wind technologies have led to widespread adoption of these technologies, which are now dominating the global market for new power generation capacity.

But the pace of change must accelerate if we are to meet sustainability and climate goals. We need an even faster expansion of renewables, along with a smarter, much more flexible electricity grid. Equally important is the need for significant increases in the range of products and processes that run on clean electricity in major end-use sectors, notably industry, buildings and transport.

Because the electrification of end uses enables the use of efficient technologies, widespread electrification – combined with efficiency measures – will decrease total global energy consumption. In IRENA's analysis, meeting the goals of the 2015 Paris Agreement on Climate Change will require the share of electricity in the energy mix to rise from 22% in 2020 to 51% in 2050, as shown in Figure I.1.

FIGURE I.1 | Final energy mix in 2018 and 2050



Source: (IRENA, 2023).

But the electrification of end uses alone is not enough. Electrification must be done in a "smart" way, both by interconnecting the power sector with other energy sectors, such as heat and mobility, and by enabling flexible sources across all energy sectors. Electric vehicles, for example, not only cut greenhouse gas emissions dramatically, they can also feed electricity to the grid, reducing the need to build additional generation capacity. Smart electrification, through sector coupling, flexibility and energy efficiency, thus prevents a higher electricity load for the power system and is a tremendously powerful tool for decarbonising the energy sector, including end uses.

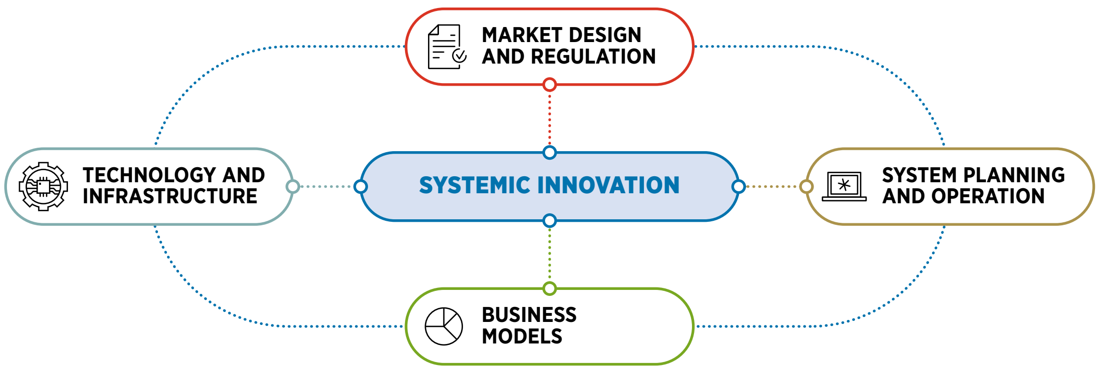
Smart electrification enables the power system to accommodate new loads in a cost-efficient manner. It also builds flexibility into the power system, thereby permitting the integration of a higher share of renewables and making the power system more robust and resilient. Smart electrification is the most cost-effective solution for decarbonising major end uses such as transport and heating.

Moreover, smart electrification with renewables creates a virtuous cycle. Electrification drives new uses and markets for renewables. That, in turn, accelerates the switch to electricity for end uses, creating even more flexibility and driving further growth in the use of renewables and continued technological innovation. Growth and innovation also cut costs and create additional opportunities for investment and business.

Innovation is the foundation for smart electrification and the global energy transformation. Most innovations cannot be implemented in isolation, nor are they limited to technology-based solutions. Along with innovation in technology and infrastructure, innovations are also needed in market design and regulation, system planning and operation, and business models. Innovative solutions will consequently emerge from the complementarities of advances across multiple components of energy systems and leveraging the synergies of these innovations in a process called *systemic innovation.*

The 100 key innovations identified in this report are spread across four dimensions: (1) technology and infrastructure, (2) market design and regulation, (3) system planning and operation, and (4) business models (Figure I.2). It is only by matching and leveraging synergies in innovations in all parts of the power system and end-use sectors and including all relevant actors and stakeholders that successful solutions can be implemented on the ground.

FIGURE I.2 | Dimensions of systemic innovation



Smart electrification cannot be pre-packaged. Optimal strategies for power system design and the application of innovation will vary among countries and their specific attributes, including both the technical and economic aspects of a given power system and its social and cultural context.

Electricity will be the main energy carrier in future energy systems

Achieving the Paris Agreement goal of limiting the increase in the global average temperature to 1.5°C relative to pre-industrial levels is the unifying principle behind IRENA's 1.5°C Scenario. To achieve that scenario, the share of electricity in total final energy consumption (TFEC) will have to grow from 21% in 2019 to 29% by 2030, and to 51% by 2050; this can be achieved through tremendous growth in technologies that operate on electricity, many of which are already available (IRENA, 2023). These include electric vehicles (EVs) and heat pumps, which provide heat for buildings and many industrial processes. In addition, end uses that are difficult to electrify directly, such as other industrial processes, can be electrified and decarbonised indirectly with "green" hydrogen produced using renewably generated electricity.

By 2050, global electricity demand is set to be 3 times what it was in 2020, posing challenges for power systems and raising the importance of energy efficiency. However, given the enormous benefits of electrification and decarbonisation, governments around the world should not see rapid, smart electrification as a threat or onerous task but rather as a golden opportunity to accelerate economic growth, improve energy security (Box I.1), reduce the growing impacts of climate change and achieve other important sustainability goals.

Table I.1 summarises the levels of electrification needed to reach the Paris Agreement targets.

TABLE I.1 | Electrification progress towards 2050 based on IRENA's 1.5°C Scenario

	Recent years	2030	2050
Share of direct electricity in total final energy consumption	22% (1)	29%	51%
Share of electricity in transport sector TFEC (%)	1% (2)	7%	52%
Share of electricity in the buildings sector (in TFEC terms)	34% (3)	53%	73%
Share of electricity in industry (TFEC)	20% (4)	25%	27%
Electric and plug-in hydrid light passenger vehicles stock (millions)	10 (5)	359	2 182
Passenger electric cars on the road (millions)	10.5 (6)	360	2 180
Electric vehicle chargers (millions)	1 (7)	372	2 300

	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

Innovation landscape for smart electrification of end-use sectors

This report presents a landscape of innovations to help policy makers formulate smart electrification strategies. As noted, it includes 100 key innovations for both direct and indirect electrification of end uses (Figure I.3 and Table I.2). The innovations were selected based on analysis of hundreds of real-world projects in consultation with more than 150 external experts from across the world. The report also provides a list of important topics often overlooked when developing smart electrification strategies.

The report is divided into three parts corresponding to three main power to X routes for smart electrification:

- **Power to mobility** maps 35 key innovations for smart electrification of the transport sector.
- **Power to heat or cooling** maps 35 key innovations for smart electrification of the heating and cooling sector across three segments: buildings, industry, and district heating and cooling.
- **Power to hydrogen** maps 30 key innovations for smart indirect electrification to produce green hydrogen with renewable electricity via electrolysis. This section is limited to green hydrogen production and infrastructure and does not cover further uses and processing of hydrogen.

Each of the avenues illustrated in Figure I.3 includes guidelines on how to implement key innovations.

FIGURE I.3 | Direct and indirect avenues for smart electrification

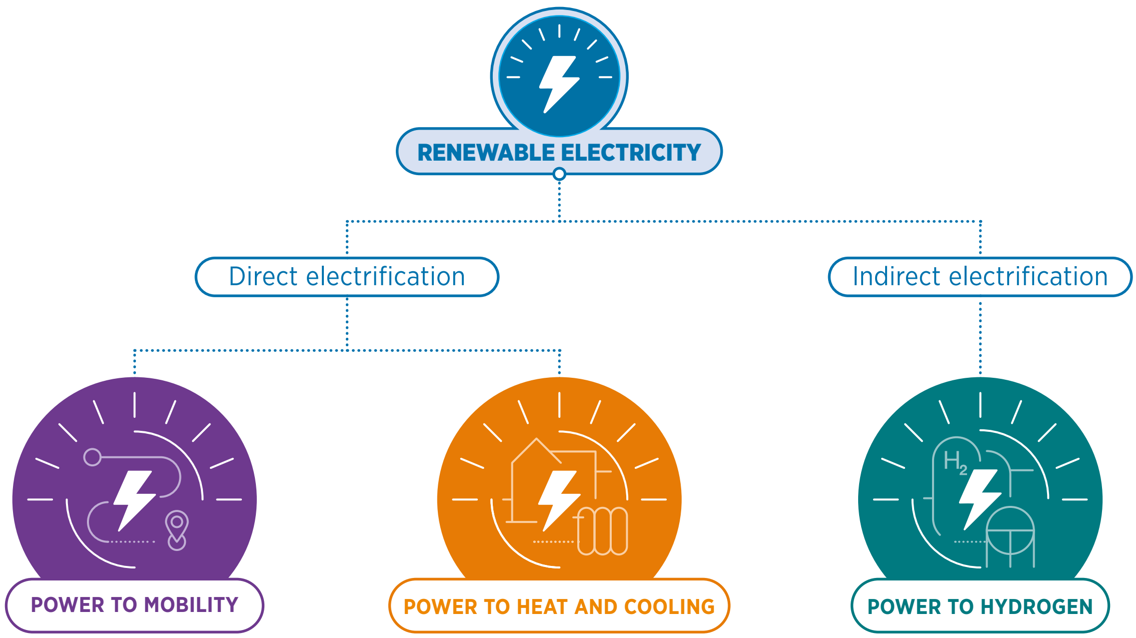


TABLE I.2 | A hundred innovations for smart electrification of end uses spread across the four dimensions of systemic innovation

POWER TO MOBILITY

35 INNOVATIONS

TECHNOLOGY AND INFRASTRUCTURE

- **1** EV model evolution
- **2** EV battery
- **3** Battery recycling technology
- **4** Diversity and ubiquity of charging points
- **5** Wireless charging
- **6** Overhead charging
- **7** Portable charging stations
- **8** V2G systems
- **9** Digitalisation for energy management and smart charging
- **10** Blockchain-enabled transactions
- **11** Smart distribution transformers
- **12** Smart meters and submeters

MARKET DESIGN AND REGULATION

- **13** Dynamic tariffs
- **14** Smart charging: local flexibility provision
- **15** Smart charging: system flexibility provision
- **16** "Right to plug" regulation
- **17** Streamlining permitting procedures for charging infrastructure
- **18** Standardisation and interoperability
- **19** V2G grid connection code

SYSTEM PLANNING AND OPERATION

- **20** Cross-sectoral co-operation and integrated planning
- **21** Including EV load in power system planning
- **22** Grid data transparency
- **23** Clean highway corridors
- **24** Operational flexibility in power systems to integrate EVs
- **25** Management of flexible EV load to integrate VRE
- **26** Management of flexible EV load to defer grid upgrades
- **27** EV as a resilience solution

BUSINESS MODELS

- **28** EV aggregators
- **29** EV load peak shaving using DERs
- **30** Battery second life
- **31** EV charging as a service
- **32** Electric mobility as a service
- **33** Ownership and operation of public charging stations
- **35** A single bill for EV charging at home and on the go
- **35** Battery swapping

Notes: AEM = anion exchange membrane; AI = artificial intelligence; ALK = alkaline; DER = distributed energy resources; DHC = district heating and cooling; EV = electric vehicle; IoT = Internet of Things; PEM = polymer electrolyte membrane; PPA = power purchase agreement; P2P = power-to-power; SOEC= solid oxide electrolyser cell; TES = thermal energy storage; TSO = transmission system operator; VRE = variable renewable energy; V2G = vehicle to grid.

POWER TO HEAT AND COOLING

35 INNOVATIONS

TECHNOLOGY AND INFRASTRUCTURE

- **1** Low-temperature heat pumps
- **2** Hybrid heat pumps
- **3** High-temperature heat pumps
- **4** Waste heat-to-power technologies
- **5** Medium- and high-temperature electricity-based applications for industry
- **6** Low-temperature TES
- **7** High-temperature TES
- **8** Fourth-generation DHC
- **9** Fifth-generation DHC
- **10** IoT for smart electrification
- **11** AI for forecasting heating and cooling demand
- **12** Blockchain-enabled transactions
- **13** Digitalisation as a flexibility enabler

MARKET DESIGN AND REGULATION

- **14** Dynamic tariffs
- **15** Thermal load flexibility
- **16** Flexible PPAs
- **17** Standards and certifications for improved predictability of heat pump operation
- **18** Energy efficiency programmes for buildings and industries
- **19** Building codes for power-to-heat solutions
- **20** Streamlining permitting procedures and regulations for thermal infrastructure

SYSTEM PLANNING AND OPERATION

- **21** Holistic planning for cities
- **22** Heat and cold mapping
- **23** Coupling cooling loads with solar generation
- **24** Smart operation with thermal inertia
- **25** Smart operation with seasonal thermal storage
- **26** Smart operation of industrial heating
- **27** Combining heating and cooling demand in district systems

BUSINESS MODELS

- **28** Aggregators
- **29** DERs for heating and cooling demands
- **30** Heating and cooling as a service
- **31** Waste heat recovery from data centres
- **32** Eco-industrial parks and waste heat recovery from industrial processes
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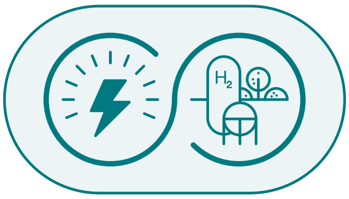
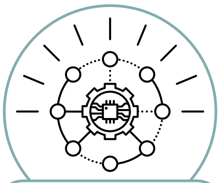
Notes: AEM = anion exchange membrane; AI = artificial intelligence; ALK = alkaline; DER = distributed energy resources; DHC = district heating and cooling; EV = electric vehicle; IoT = Internet of Things; PEM = polymer electrolyte membrane; PPA = power purchase agreement; P2P = power-to-power; SOEC= solid oxide electrolyser cell; TES = thermal energy storage; TSO = transmission system operator; VRE = variable renewable energy; V2G = vehicle to grid.



POWER TO HYDROGEN

30 INNOVATIONS



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- **7** Hydrogen-ready equipment
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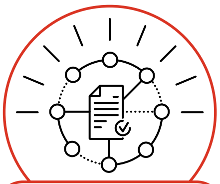
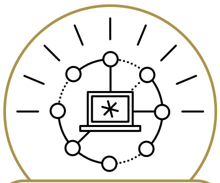


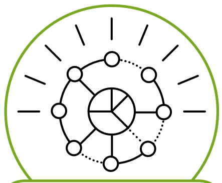
MARKET DESIGN AND REGULATION

- **10** Additionality principle
- **11** Renewable PPAs for green hydrogen
- **12** Cost-effective electricity tariffs
- **13** Electrolysers as grid service providers
- **14** Certificates
- **15** Hydrogen purchase agreements
- **16** Carbon contracts for difference
- **17** Regulatory framework for hydrogen network
- **18** Streamlining permitting for electrolyser projects
- **19** Quality infrastructure for green hydrogen
- **20** Regulatory sandboxes



SYSTEM PLANNING AND OPERATION

- **21** Electricity TSOs including hydrogen facilities in their planning
- **22** Co-locating electrolysers with renewable generators (onshore and offshore)
- **23** Smart hydrogen storage operation and P2P routes
- **24** Long-term hydrogen storage
- **25** Co-operation between electricity and gas network operators



BUSINESS MODELS

- **26** Local hydrogen demand
- **27** Hydrogen trade
- **28** Hydrogen industrial hub
- **29** Revenues from flexibility provided to the power system
- **30** Sale of electrolysis by-products (oxygen and heat)

Notes: AEM = anion exchange membrane; AI = artificial intelligence; ALK = alkaline; DER = distributed energy resources; DHC = district heating and cooling; EV = electric vehicle; IoT = Internet of Things; PEM = polymer electrolyte membrane; PPA = power purchase agreement; P2P = power-to-power; SOEC= solid oxide electrolyser cell; TES = thermal energy storage; TSO = transmission system operator; VRE = variable renewable energy; V2G = vehicle to grid.

Renewable Energy to Support Energy Security

Background

Renewable energy plays an important role in supporting energy security[1] through contributing to the protection and continued provision of energy services when a disruption occurs (DOE 2017). Sources of disruption to energy services can be natural, technological, and human-caused—such as weather events, cyberattacks, and global market disturbances.

Although energy systems have always been subject to disruption, potential threats are increasing in relation to reliance on energy for economic growth; intensifying weather events; and the growing potential of large-scale cyberattacks on increasingly networked energy systems. Such evolutions give urgency to understanding trends and vulnerabilities in emerging energy technologies, planning, and practices.

Institutions and governments around the world define energy security in different ways. The International Energy Agency (IEA) defines energy security as "the uninterrupted availability of energy sources at an affordable price." IEA also makes a distinction between long-term energy security for future economic development and short-term energy security that ensures energy systems will react quickly to sudden changes in the supply-demand balance (IEA). The U.S. Department of State defines energy security as "access to diversified energy sources, routes, suppliers [in order to limit] the influence of a single dominant buyer, seller, or investor and guards against those who would use energy for coercive ends" (DOE 2017).

Energy security is vital to many sectors of the economy. Examples include, but are not limited to, the following:

Industry: Nearly all modern industries depend on reliable and affordable power supplies. Power outages and poor power quality can cause damage to manufacturing equipment and impact production. Unstable energy prices can impact the economics of producing goods and services.

Food: The globalized industrial food system is largely dependent on fossil fuels to power farming equipment, produce pesticides and fertilizer, and transport goods. To prevent food from spoiling, reliable power is needed to keep produce cool in refrigerated warehouses or transportation containers. Rising fuel and energy prices can impact food prices and affordability (Neff, Parker, Kirschenmann, Tinch, and Lawrence 2011).

Health Care: Interruptions to power supplies can impact medical centers and hospitals. Certain treatments or medical care protocols rely on dependable power (e.g., dialysis centers and operating rooms). Vulnerable patients can die from heat or cold exposure. The blackouts in Puerto Rico after Hurricanes Maria and Irma in 2017 greatly impacted the chronically ill who relied on electricity to power health care machines. Deaths due to chronic illness after the hurricanes surged in comparison to the same period in 2016 (Hernandez, Learning., and Murphy 2017).

Other Critical Services: Power is also essential in providing other critical services related to water and sanitation and telecommunications, among others. Provision of these services is especially critical in the aftermath of a disaster to avoid cascading negative impacts and enable recovery.

Threats to Energy Security

Threats to the energy sector can be natural, technological, or human-caused—and can damage, destroy, or disrupt energy systems (Resilient Energy Platform). A community that is energy-secure will incorporate resilient systems and approaches that can prevent, mitigate, or allow for adaptation to threats and changing conditions. Examples of threats to the energy sector include:

1 It is important to note that energy security is not the same as energy sovereignty. Energy sovereignty refers to the ability of a community or nation to internally produce all necessary energy; however, energy sovereignty does not mean a community is energy secure. As an example, a jurisdiction that internally produces 100% of its energy from solar power may not be energy secure if they experience natural disasters that threaten solar photovoltaic (PV) systems.

Natural Disasters: Severe weather events like droughts and storms are projected to become more intense and destructive (IPCC 2012). These events can decrease or disrupt supplies and negatively impact energy infrastructure (Rudnick 2011). In the United States, severe weather is the number one cause of power outages (Executive Office of the President 2013).

Cyberattacks: The energy sector is becoming more automated, digitized, and interconnected. Cyberattacks are becoming more common and could pose a greater threat as the energy sector becomes more modern and connected (IEA).

Geopolitics: Interstate conflicts can threaten energy security. For example, the 1973 oil crisis resulted from an embargo by the Organization of Petroleum Exporting Countries on the United States (U.S. Department of State). Political instability in fuel producing nations can impact energy prices.

Fuel Price Fluctuations: Changes in fuel prices (e.g., related to market or other factors) can threaten energy security through impacting a nation's or community's ability to purchase fuels.

Long-Term Climatic Changes: Changing environmental conditions like air temperature, water temperature, and water availability can cause stress to energy systems.

- Rising temperatures increase the demand for air conditioning, most significantly impacting summer peak energy demands (Zamuda, Bilello, Conzelmann, Mecray, et al. 2018).
- Water is necessary for energy production. Hydroelectric systems depend on flow, and some electricity production systems need water for cooling. Reduced precipitation or increased water temperatures can impact supply by limiting power plant capacity. Snowpack melt changes (i.e., the timing of melt and runoff in the spring or summer) changes peak production for hydroelectric systems (Zamuda, Bilello, Conzelmann, Mecray, et al. 2018).
- Changes in sea levels or storm surges can impact energy infrastructure close to shorelines, due to flooding (EPA).

The Connection Across Energy Security and Resilience

Energy security and resilience are related and, in many cases, interlinked. Countries and jurisdictions think about the relationship between energy security and resilience in different ways. For example, the Government of Laos recently undertook a power sector vulnerability assessment that fed into a resilience action plan. This plan is seen as supporting a broader country objective to enable energy security. In most cases, energy security is seen as an overarching objective, and resilience is seen as an energy system characteristic that can contribute to energy security through enabling adaptation to changing conditions and recovery from disruptions. Figure 1 presents one perspective for considering the interlinkage across energy security and energy resilience.

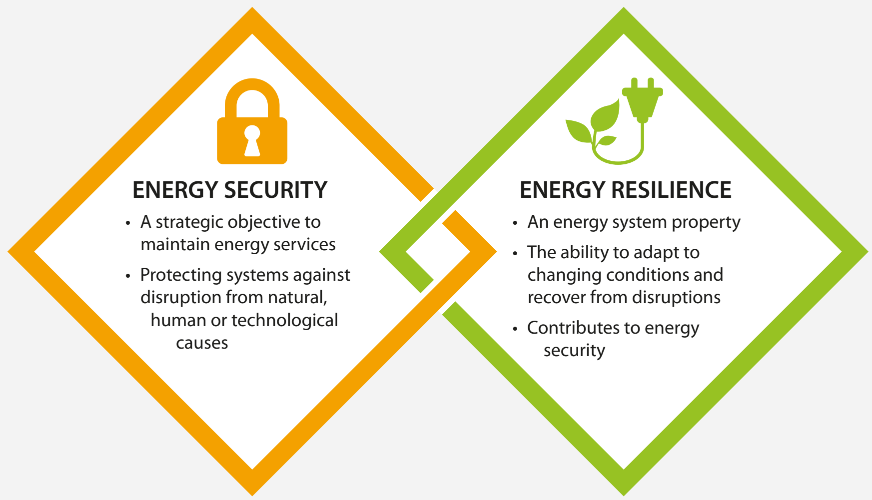


Figure 1. Interlinkage of Energy Security and Energy Resilience.
Illustration by Brittany Conrad, NREL

How Can Renewable Energy Support Energy Security?

Energy security remains a key objective of many countries around the world. Deploying renewable energy technologies supports the goal of energy security and supports the realization of additional benefits.

Diversifying the Generation Mix: Renewable energy can support energy security by adding diversity to an overall electricity generation portfolio. Diversity of a power generation portfolio can relate to the spatial location, types of generation resources, and fuel sources or supply.

- Spatial diversity—A more spatially diverse generation and storage energy portfolio can better withstand shocks to the system. With more resources across different geographic areas, such diversity could power infrastructure during disasters, cyberattacks, or other extreme events. Spatially diverse energy generation portfolios can also provide a smoothing effect across variable generation resources, allowing for improved reliability and integration of variable renewables (Cox, Hotchkiss, Bilello, Watson, et al. 2017).

What is a Power System Threat?

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

Learn more at: https://resilient-energy.org/guidebook

- Resource and fuel diversity—Having a majority reliance on one specific fuel type makes the power system vulnerable to fuel supply constraints or price fluctuations. Diversifying energy portfolios with renewable energy can help communities reduce dependence on fuel imports, especially in island nation settings. Further, renewable electricity prices are often stable, in contrast to regularly shifting fossil fuel prices due to geopolitical, market, or other factors (Olz, Sims, and Kirchner 2007).

Reducing Water Use: Technologies with high water requirements are vulnerable to drought or other climatic events. Deploying renewable energy can reduce potential fluctuations or uncertainty in power generation portfolios that depend on hydro or require significant amounts of water for generation or cooling.

Modularity and Rapid Deployment: According to Cox et al. "Modularity [of distributed renewable technologies] allows for locational flexibility and for new generation systems to be put in place at a faster pace than large-scale systems as electricity demand grows and understanding of climate risks improves." Modularity can support energy security through rapid deployment of more modular, distributed energy systems in response to changing threats. In addition, modularity can support the diversification of energy generation, as distributed systems have greater locational flexibility and can be deployed in diverse settings. Finally, when a part of a modular system is damaged or fails it is typically easier to repair than a larger system failure. In some cases, the section that is damaged can be removed while the rest of the system continues to function, or the part replacement can occur quickly.

Islanding: Renewable distributed generation technologies can be equipped with control mechanisms to support "islanding" of on-site power sources in the event of a disaster. Islanding controls can isolate a distributed power source from other systems, allowing them to continue to provide power locally even if the main grid is compromised or disrupted. Importantly, islanded distributed energy systems (especially when combined with storage) can provide power to critical facilities, such as hospitals, water treatment facilities, or vulnerable communities, in a safe manner.

Coupling with Storage: A renewable based energy system, utility-scale or distributed, can further support energy security when coupled with energy storage technologies. Storage allows for fluctuations of a generation technology (e.g., solar PV or wind), while providing power to a site through stored power (e.g., a charged battery system). In addition, storage can provide backup power in the event of an outage and potentially allow for black start recovery[2] when the system is designed to do so. In alignment with energy security objectives, energy storage can also support stabilization of electricity prices, management of demand changes, and mitigation of curtailment.

Deploying renewable energy technologies supports the goal of energy security and supports the realization of additional benefits. *Photo by Dennis Schroeder, NREL 58004*

Resilient Energy Platform

The Resilient Energy Platform helps countries to address power system vulnerabilities by providing strategic resources and direct country support, enabling planning and deployment of

2 "Black Start is the procedure [used] to restore power in the event of a total or partial shutdown of [a] national electricity transmission system" (National Grid ESO).

resilient energy solutions. This includes expertly curated reference materials, training materials, data, tools, and direct technical assistance in planning resilient, sustainable, and secure power systems. Ultimately, these resources enable decision makers to assess power sector vulnerabilities, identify resilience solutions, and make informed decisions to enhance energy sector resilience at all scales (including local, regional, and national scales). To learn more about the solutions highlighted in this fact sheet, please visit the Platform at: resilient-energy.org.

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

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

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Current Issue Part A Study Resources

Key Topic #3: Renewable Energy and Natural Resources

12. Describe the impact renewable energy projects have on natural resources and the environment on both local and global scales.
13. Identify actions or innovative approaches to address negative impacts from renewable energy on natural resources and the environment.
14. Explain the benefits and limitations of concurrent use of renewable energy projects on agricultural lands.

Study Resources

Study Resources begin on the next page! →

Agrivoltaics: Coming Soon to a Farm Near You?

US Department of Agriculture Northeast Climate Hub, 2023

In 2020, U.S. renewable energy production (and consumption) hit a record high. The increase was mainly driven by more solar and wind.

Despite this, renewable energy still only accounts for 12% of total U.S. energy consumption. Meeting the goal of “a net-zero emissions economy by 2050”, will require much more. According to a recent U.S. Department of Energy report, Solar Futures Study, “it is now possible to envision—and chart a path toward—a future where solar provides 40% of the nation’s electricity by 2035.” In that future, farmers and farmland will play a key role. One issue with renewable power is that it requires far more land per unit of power produced than fossil fuels. While many may favor renewable energy in the U.S. – that sentiment often changes when projects are proposed close to home. An energy system built on renewables – like solar or wind – would mean locating sites and infrastructure a lot closer to where those resources are either abundant and/or easily distributed. And, in many cases, this would mean areas that have not yet seen energy production or infrastructure in their own community backyards before.

How much land is needed?

According to the Solar Futures Study, a lot of land will be needed. By 2050, ground-based solar could need about 0.5% of the land in the contiguous U.S. To put this into perspective, about 5% of land is already in urban areas and roads and another 0.1% in golf courses. Agriculture occupies about 43% of the lower forty-eight states surface area. The report points to prioritizing disturbed lands (8% of land) and dual-use land opportunities. Examples of disturbed lands include invasive species-impacted lands, non-vegetated lands such as quarries or gravel pits, and lands identified as contaminated but remediated for some forms of reuse. Agriculture will be an important dual-use case.

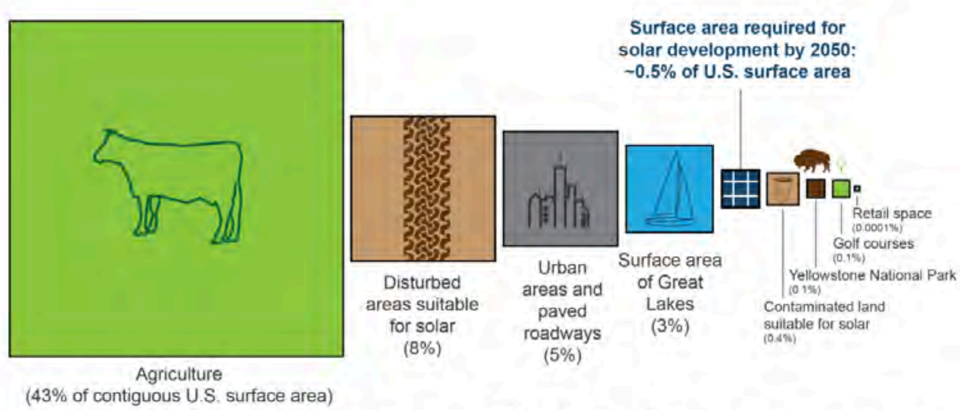


Figure 8 - 7. Maximum land use required for solar in 2050 in the *Solar Futures* scenarios compared with solar-suitable disturbed and contaminated areas and examples of other U.S. areas

Amounts of disturbed and contaminated lands depicted here represent the amounts suitable for solar energy development calculated in the *Solar Futures Study*. Sources: (EPA 2020; USDA 2014; LANDFIRE, n.d.).

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?

Maine's prime farmland is being lost to solar. Is 'dual use' the answer?

By Kate Cough – The Maine Monitor – January 16, 2022

A report urges developers to build dual-use projects with elevated panels that permit farming and grazing beneath. Critics say the approach is not yet affordable.

Maine farmer Michael Dennett of Jefferson stands with his flock of sheep. Dennett has contracts to graze his sheep beneath solar panels, essentially providing a mowing service for developers. Photo by Garrick Hoffman.

On an overcast afternoon in early July, Michael Dennett drove to a paddock near midcoast Maine to check on his sheep. They'd been there for a couple of days, and it was almost time to move them to another section of pasture.

Dennett, who owns Crescent Run Farm in Jefferson with his wife, Ryan, has been a sheep farmer for years. But this pasture was different from where he'd grazed sheep in the past: It was a commercial-scale solar project, and Dennett's sheep were providing the mowing services.

"Ideally we get through a site within 30 days, particularly in the spring when grass is growing really fast," said Dennett. Per his contract with ReVision Energy, Dennett does two grazes annually on several sites not far from the couple's home.

Arrangements like Dennett's — grazing sheep, or growing blueberries under solar panels — are known as "dual-use." As Maine farmers lose prime land to solar developers who want it for panels, dual-use has emerged as a way to keep the land in production, yet also use it to generate energy from the sun.

Farmland, with its open fields, southern exposure and well-drained soils, is typically one of the easiest and cheapest places to put a solar project. But that type of land is also limited in Maine.

A lack of regulations around where solar can be sited has resulted in farms being converted to panels at a rapid clip, an analysis by The Maine Monitor found. Developers outcompete farmers for prime land, or offer working farmers attractive sums to take some land out of production.

In an effort to help stem the conversion, a report expected out this week from the Governor's Energy office stakeholder group encourages farmers considering solar on actively farmed land to prioritize dual-use, to keep as much of that land in production as possible.

Except those systems, solar developers say, are so costly to construct that they aren't viable in Maine on any grand scale.

"That's the technology that we can't afford in this state," Matt Kearns, chief development officer of Longroad Energy and member of the Agriculture Solar Stakeholder Group, told members at a meeting in December.

Sheep are able to graze under traditional ground-mounted systems, and the shade the panels provide is great for the animals, said Dennett. But other kinds of dual-use projects, such as those that allow for vegetable farming or cattle grazing, require elevating panels and spacing them farther apart.

As Maine farmers lose prime land to solar development, dual-use farming has emerged as a way to keep the land in production, yet also use it to generate energy. Photo by Michael Dennett.

That means more materials, like steel and aluminum, and less energy (and thus less revenue) per acre compared to traditional ground-mounted systems, where panels can be placed close together.

"It's very expensive, very hard to do," said Kearns. "If we're encouraging dual-use … that's basically just saying the farmer can't develop solar."

Farmers can't compete

Maine, the most heavily forested state in the U.S., has a finite amount of soil suitable for agriculture. About 10 percent of the state's nearly 22 million acres are considered "soils of statewide importance." Of those soils, 800,000 acres are considered "prime," or land that is "of major importance in meeting the nation's short- and long-range needs for food and fiber," according to the U.S. Department of Agriculture.

Only half of the land suitable for farming in Maine is being farmed, and increasing local food production is one of the goals of Maine Won't Wait, the state's climate action plan. State officials have said they want to triple the amount of food consumed in Maine from state food producers to 30% by 2030.

But amid the state's solar gold rush, much of that land has stopped growing food or fiber altogether. It now produces solar energy.

The state does not track how much farmland has been lost to solar projects, but a recent analysis by the Maine Audubon Society found that of 180 projects waiting to be reviewed by the Maine Department of Environmental Protection, 163 intersected with soils classified as prime or of statewide importance. That number is potentially much higher, since only projects on more than 20 acres go through full DEP review.

“The reality is we’re losing habitats. And the reality is we’re losing farmland,” said Sarah Haggerty, a conservation biologist with the Maine Audubon, in a presentation to the Agriculture Solar Stakeholder group.

The group, convened by the Department of Agriculture, Conservation and Forestry, and the Governor’s Energy Office, was tasked with seeking ways to protect important agricultural land while helping to reach solar generation goals.

While state and local officials have championed building those solar projects on capped landfills, brownfields and land that is otherwise unusable, that’s not where they’re ending up.

“We were pretty disappointed to find that 11 of the 180 projects intersect with gravel pits, and just six of them are uncapped landfills,” said Haggerty.

Solar is not the only threat to farmland, which is also being developed for housing and sold off as older farmers (the average age of a Maine farmer is 57) retire and there is no one to take their place. But what makes for good farmland — southern exposure, well-drained soils — also makes an excellent location for solar panels.

And once there are panels on that land, it’s highly unlikely it will ever be farmland again, at least not for many decades.

“I do not think we should expect large amounts of land to return to other uses from solar at the end of the first generation of life,” said Fortunat Mueller, a managing partner at ReVision Energy, during a recent stakeholder meeting.

Pressure from solar developers makes it more difficult for the roughly 25 percent of Maine farmers who lease their farmland to compete in the market. It also makes it harder for new farmers, many of whom lease land before they’re able to buy.

Younger farmers are “competing with developers who are offering $1,000 an acre on average, when we can maybe offer $200 an acre for row crop quality soil,” said Andy Smith, who participated in the committee and runs The Milkhouse, a dairy farm in Monmouth, with his partner, Caitlin Frame.

Farmers who lease hay fields, where they often pay $50 per acre or less for a lease, have been particularly hard hit by solar development, said Smith. “We’re at a massive disadvantage.”

The ‘wild east’ of solar

One reason Maine has seen such rampant solar development on farmland is that lawmakers have yet to enact rules around siting solar on those soils, or set regulations that would direct projects away from open space.

The state was flooded with proposals after the Legislature, in 2019, put in place incentives aimed at helping meet its renewable energy goals. With few regulations on where projects can be located, companies have typically looked to the cheapest, easiest options.

Other states and countries have grappled with the issue for years. Massachusetts, faced with rapid loss of farmland and open space to solar and housing development, set rules allowing solar development on agricultural land only if panels are raised at least 10 feet above ground and shading from the array covers no more than 50 percent of the field. It also pays companies with such projects more for the energy they produce.

Vermont, responding to a similar issue, enacted rules in 2017 that would pay companies more for putting panels on landfills, sandpits and brownfields, although many of those incentives are ending.

Building solar projects on landfills is 10% to 15% more expensive than siting them on undeveloped land. It requires altering construction practices to keep from compromising the landfill's protective cap, which can increase labor costs. The presence of the cap also means that posts typically can't be driven into the ground but must be stabilized with ballast or mounted on long concrete footings, an additional expense.

Landfills and brownfields, which often have remnants of industrial infrastructure and environmental hazards, may also require more in-depth review than putting posts and panels in an empty field. Landfill projects must be monitored to ensure they do not compromise the site's integrity in the long term. Size is also an issue; many brownfields and landfills aren't large enough for grid scale arrays.

Solar on commercial rooftops is possible, but companies often don't want panels there because they take away from a building's development possibility, Drew Pierson, head of sustainability at BlueWave Solar, told the stakeholder group.

That's why developers say financial incentives are essential for companies to build on those kinds of sites or to put up dual-use projects on farmland.

"This all feels good. It sounds good. But it's not going to get done without additional incentives," said Jeremy Payne, executive director of the Maine Renewable Energy Association, in a December meeting.

Anything that increases costs to ratepayers will be a non-starter politically, the stakeholder group agreed.

"Massachusetts, sure. Big, big economy, a lot of ratepayers. Maine has a million and a half ratepayers," said Kearns of Longroad Energy. "I don't think we can afford that here."

Solar can keep land in agricultural production

Solar can also provide an economic cushion for farmers, who often operate on thin and unpredictable margins. Many see it as a way to possibly return the land to farming in the future, even if it's taken out of agricultural production in the short term, or as a way to use marginal areas that aren't being actively farmed.

That's the case for Rick Dyer and his family, who run Clemedow Farms in Monmouth. Dyer decided to allow a developer to install ground-mounted panels (Dyer wasn't aware of dual-use at the time) on 45 of the 1,000 acres the family owns in order to help sustain the rest of the farm.

"It provides a buffer by which if all else were to end tomorrow," said Dyer, "the economic value that comes in will pay the taxes on the entire property for the next 20 to 40 years and maybe beyond."

The panels, he said, provide economic support that will help keep the rest of the land in open space and able to be farmed.

"Farming in Maine is difficult at best," Dyer added. "For dairy farmers right now, it's really trying. The same price of milk is getting paid to the dairy farmer today that was getting paid to my grandfather 60 years ago, and the cost of that tractor went from $15,000 to $150,000."

Once the contract on the Clemedow Farms solar project is up, there are decommissioning plans that could allow the land to be put back into agricultural production.

Dyer hopes that will be the case. Had a housing development been built on that 45 acres, it would be nearly impossible to return that land to agricultural use, he pointed out. Putting up panels on one section will keep that hope alive.

Farmers want more evidence about dual-use

Economics aside, several farmers said they want to see more data that dual-use systems can work in Maine before agreeing to put panels on productive land.

"There's a lot of talk about dual-use and working with farmers and all of this, but at the end of the day not much else is ever going to be able to happen under these arrays other than sheep grazing and bees foraging on clover or something," said Smith, of The Milkhouse. Providing pollinator habitat is often counted as dual-use.

"But that to me is kind of greenwashing to call that agriculture," he said. "Not that it's not important, but we're not producing a lot of calories off that land."

Smith and his partner, whose 250-acre farm has a substation in the center, were contacted by more than a dozen companies after the legislation passed in 2019. They have a rooftop array that offsets the farm's energy use and were interested in putting up a dual-use system for their sheep and cattle to graze under. A developer told them it didn't make "economic sense."

While there are examples of crops successfully growing elsewhere under dual-use conditions, including a 24-acre vegetable farm with 3,200 panels in Colorado, it's important to see examples of it working in Maine, said Smith.

Scientists are studying a dual-use array on a 10-acre patch of blueberry field in Rockport to see how many years it takes the berries to begin producing after the array is installed, and also to see how well they do in shade.

Pierson, of BlueWave Solar, told the stakeholder group that globally there are already many examples of this working.

But, he added: “It’s not all roses … (Farmers) are going to need to invest in new equipment, or even business models to figure out how this works.” That could mean learning new methods and departing from long-held philosophies on farming.

Certain pieces of equipment cannot fit between the poles, tractors may not be able to maneuver, and farmers have to be careful not to get chemicals on the panels themselves.

“There are low-impact methods that may not have been on farmers’ minds before that are now actually required because you don’t want to damage the solar project,” said Pierson.

Group recommends changes

The stakeholder group came up with several recommendations that it hopes will ease pressure on farmers while still allowing Maine to meet its renewable energy goals. A dual-use pilot program of at least 20 megawatts was suggested, along with the creation of a database with information on solar projects.

The report also suggests regulators consider streamlining the permitting process by making dual-use and/or co-location (in which panels are installed on a portion of farmland, as at Monmouth’s Clemedow Farms) eligible for permit-by-rule, which essentially allows companies to meet certain criteria and be exempt from full site law of development review.

“If we really are going to go big on clean energy, we want to be careful about, you know, just adding a ton of new restrictions,” said Kearns of Longroad Energy.

The report advocates for allowing farms to keep their agricultural use tax designation even if they put up solar panels, as long as farming remains on the land. Under current rules, farmers typically lose that designation on the portion of the land with panels, which can amount to many thousands of dollars each year.

In public comments, many urged for solar panels to be installed on farmland only as a last resort.

“I am an advocate for solar power, but I believe that panels should be on every rooftop and parking lot and brownfield before we cover farmland,” wrote David Asmussen, a commercial vegetable farmer.

Anything that slows solar implementation, argue developers and advocates, will hold Maine back from meeting its renewable energy goals. But farmers and others point out that a local food system and a biodiverse landscape are also some of the best ways to fight climate change, even if the benefit is harder to quantify financially.

“It’s really important that people understand that this is rapidly changing the landscape of Maine,” Smith added. “We’re talking about the development of tens of thousands of acres of land in the state, just to meet our initial (portion) of renewable energy goals.”

CONSERVATION

Solar Farms Shine a Ray of Hope on Bees and Butterflies

A trend of planting wildflowers on solar sites could maintain habitat for disappearing bees and butterflies

By Jodi Helmer on January 14, 2019 أعرض هذا باللغة العربية

NREL scientist Jordan Macknick and Jake Janski, from Minnesota Native Landscapes survey a pollinator test plot planted underneath the photovoltaic array at the Chisago Solar Site, part of the Aurora Solar Project in Minnesota. Credit: Dennis Schroeder National Renewable Energy Lab *Flickr* (CC BY-NC-ND 2.0)

The tidy rows of gleaming solar panels at Pine Gate Renewables facility in southwestern Oregon originally sat amid the squat grasses of a former cattle pasture. But in 2017 the company started sowing the 41-acre site with a colorful riot of native wildflowers. The shift was not merely aesthetic; similar projects at a growing number of solar farms around the country aim to help reverse the worrying declines in bees, butterflies and other key pollinating species observed in recent years.

Up to $577 billion in annual global food production relies on pollination by insects and other animals such as hummingbirds and bats, according to the United Nations. But more than half of native bee species (pdf) in the U.S. have seen their numbers drop sharply since 2005, with almost 25 percent now at risk of extinction. Meanwhile the North American monarch butterfly population has declined 68 percent over the past two decades, the nonprofit Center for Biological Diversity says. Suspected factors include climate change, pesticide use and parasites—along with shrinking habitat, largely blamed on natural landscapes (such as scrublands or wetlands) being converted for agricultural use.

And as pollinator habitat wanes, solar installations are taking up ever more land. The U.S. is expected to convert six million acres of land to such facilities before 2050, according to the National Renewable Energy Laboratory (NREL). Some researchers see this as an opportunity to reclaim land for pollinating species by replacing the usual grass or gravel at these sites with wildflowers that need insects to pollinate them, and that produce the nectar those insects eat. “If we can create some habitat where there wasn’t habitat before, like on solar farms, we can likely have a positive impact,” says Scott McArt, an entomologist at Cornell University.

A monarch Butterfly feeds on flowers being grown for seed at Minnesota Native Landscapes in Foley, Minn. Credit: Dennis Schroeder National Renewable Energy Lab *Flickr* (CC BY-NC-ND 2.0)

MORE PLANTS = MORE POLLINATORS?

Minnesota-based Great River Energy (pdf) has also introduced pollinator-supporting plants—such as purple prairie clover and wild lupine—at several of its solar sites, as has SoCore Energy at some of its outfits in Wisconsin. In 2018 the NREL identified 1,350 square miles of land near existing and planned utility-scale solar energy facilities around the country that could be similarly converted. Although no national statistics are available, in Minnesota alone it is estimated that half of the 4,000 acres of commercial solar projects installed in 2016 and 2017 included pollinator habitat.

Designing such habitat is not a matter of simply scattering some wildflower seeds, though. The right mix of a broad range of native plants is needed to attract and support the hundreds of pollinator species, from bees to birds, that can be found in some areas. A number of them have adapted to specific plants—such as monarch butterflies that feed on milkweed—or are extremely imperiled, as is the case with native bumblebees, says Sarah Foltz Jordan, a senior pollinator conservation specialist for the nonprofit environmental organization Xerces Society for Invertebrate Conservation. “A common issue with pollinator habitat is that the seed mixes aren’t very diverse," she says. "So they may look pretty, but when you don't have a highly diverse plant community, you don't support a highly diverse pollinator community."

There is some limited evidence (pdf) solar farms with mixed plant life can support a wider array of bee and butterfly communities than those with grass or gravel beds can, but researchers are still investigating just how much this can affect the insects' long-term survival. "We don't have the data to say whether meaningful changes occur at a broad scale just due to solar sites," McArt says. "We don't know if this is going to have a substantial impact." But he hopes to change that. In July, through a partnership between Cornell and North Carolina–based solar developer Cypress Creek Renewables, McArt launched a three-year study to determine whether—and how much—establishing habitat on solar sites benefits pollinator populations.

The team will compare the abundance and diversity of wild bee species at a solar site planted with native wildflowers with an installation that has turfgrass growing beneath its panels. Then the researchers will test which seed mixes are most effective at attracting wild bees over longer periods. "Maybe it's not the seed mix that looks fantastic and attracts a lot of bees in the first year," he notes. "Maybe the better seed mix is the one that takes longer to establish but is much more resilient over time."

Minnesota bee keeper, Jim Degiovanni, inspects "BareHoney" hives outside IMS Solar, a pollinator-friendly photovoltaic array site in St. Joseph, Minn. Credit: Dennis Schroeder National Renewable Energy Lab *Flickr* (CC BY-NC-ND 2.0)

BOOST TO FARMS AND BUSINESS

When solar developers consider planting pollinator habitat, they also look at the bottom line, notes Lee Walston, an ecologist at Argonne National Laboratory outside Chicago. Despite a higher upfront cost to purchase and plant seed mixes, Walston contends this can actually offer long-term savings. For example, a field of wildflowers requires less mowing and pesticides than conventional grass does. And gravel absorbs heat whereas plants can help keep panels cool, improving energy efficiency.

Moreover, Walston believes planting wildflowers can help garner support in rural communities that might be resistant to leasing productive farmland to solar developers. New research has found raising pollinator numbers can bring higher yields of crops such as fruits and nuts, offering an obvious boon to farmers.

But one problem with siting insect-friendly solar installations next to pesticide-using farms is the chemicals can drift onto the wildflowers. Pesticides have been shown to impair various pollinating insects' foraging ability, decrease their immune responses, interfere with their absorption of nutrients and shorten their life spans. Mandatory buffer zones could help protect habitat from pesticide drift, Foltz Jordan says. Ultimately, she adds, converting some farmland to solar sites could also reduce overall pesticide use.

Still, experts warn such projects are hardly a panacea. "Establishing pollinator habitat on solar facilities is not the answer to pollinator decline," says Argonne ecologist Ihor Hlohowskyj—but he believes it is still one valuable way to prop up imperiled species. "With the large surface areas that solar facilities occupy," he says, "they offer a pretty unique opportunity to plant and establish pollinator habitat that could help conserve pollinator diversity."

ABOUT THE AUTHOR(S)

We can’t ignore that offshore wind farms are part of marine ecosystems

Offshore wind farms can create their own local climates and may alter currents. How does that affect marine life around them?

BY BECKI ROBINS / UNDARK | PUBLISHED AUG 24, 2023 – POPULAR SCIENCE

Scientists have a lot more work to do before they can know the true effect of thousands of offshore wind turbines, as well as how and where they should be built. DEPOSITPHOTOS

Last year, the Biden administration announced an ambitious goal: enough offshore wind to power 10 million homes by 2030. The move would reduce carbon emissions, create jobs, and strengthen energy security. It would also help the United States—which was responsible for just 0.1 percent of the world’s offshore wind capacity last year—catch up with renewable energy leaders like China and Europe.

The plan is already well underway: Massive turbines are rising off the coast of Massachusetts, and more projects are planned up and down the U.S. coastlines. Advocates say these turbines, and other offshore projects around the world, are a crucial tool in minimizing the effects of climate change: The technology is touted as clean, renewable, and plentiful. And, since offshore wind farms aren’t located in anyone’s backyard, they are, at least in theory, less prone to the political pushback onshore wind power has faced.

It will take a lot of turbines to meet Biden’s 2030 goal, and while wind turbines don’t use fossil fuels or generate carbon emissions, they are enormous structures, with some reaching heights of more than 850 feet above the water’s surface. (The Statue of Liberty, in comparison, stands a little over 300 feet.) As such, they will likely have some effect on the ocean environment.

Scientists already know some of the local impacts of wind farms. For example, they can, somewhat counterintuitively, reduce local wind speed. They also create their own local climates, and cause disturbances in the water in the form of a downwind wake. But what those changes might mean for marine life or for industries that depend on ocean resources is something that scientists are still trying to figure out.

Meanwhile, in the U.S., offshore wind has become the subject of bitter political disagreement and fear, fueling lobbying and lawsuits aimed at halting projects before they even begin. As researchers work to model potential outcomes, they stress that they don't want to derail offshore wind, but rather seek to better understand it so that any negative effects can be minimized, and positive effects maximized.

Scientists have a lot more work to do before they can know the true effect of thousands of offshore wind turbines, as well as how and where they should be built. There may even be questions they haven't thought to ask yet, said Ute Daewel, a scientist who studies marine ecosystems at The Helmholtz-Zentrum Hereon in Germany.

"It's so complex," she said, "that I sometimes think we probably also miss a lot of things that might happen."

Advocates of offshore wind turbines can point to a range of benefits—starting with their proximity to the places most in need of clean energy. Around 40 percent of the world's population lives within 60 miles of the ocean. Energy demand in densely populated coastal regions tends to be high, so offshore wind farms will be located close to where they are most needed.

Evidence suggests offshore wind power could lower energy costs, especially during extreme events like cold snaps when energy demands are high and wholesale prices peak. Meanwhile, the Department of Energy says that, in addition to reducing carbon emissions, the technology would improve human health by cutting air pollution from fossil fuels.

But wind farms have also come under intense criticism from a diverse coalition of stakeholders, including conservation nonprofits worried about the impact on marine ecosystems, fishing industry groups concerned about access to traditional fishing grounds, coastal homeowners keen to maintain their views, and groups that appear to be funded by large oil companies hoping to stifle competition.

Some of those criticisms focus on the impact on animals. Like onshore wind, the turbines can kill birds, though some researchers studying large-bodied waterbirds like sea ducks and geese have found they tend to avoid the turbines, which may mean less bird mortality offshore. Recent criticism from Republican lawmakers also suggests that the noise from offshore wind turbines might kill whales, although the National Oceanic and Atmospheric Administration says there's no evidence to back up this concern.

Meanwhile, some research suggests wind farms might even help fish and other marine life. "A lot of people say, hey, this is going to be a habitat improvement because there's going to be rocks on the bottom, which make artificial reefs," said Daphne Munroe, a shellfish ecologist at Rutgers University. "And that's absolutely true. But it's a shift away from what was there."

Munroe studies pressures on marine ecosystems, including the effects of climate, pollution, and resource exploitation. She's also the lead author of a 2022 Bureau of Ocean Energy Management study on the impacts of offshore wind on surfclams—a type of clam commonly used to make chowders, soups, and stews. (The BOEM study was funded by the federal agency; Munroe has received funding from wind farm developers to conduct other projects.)

The fishing industry fears wind farms will affect their ability to yield a profitable catch — especially since the windy, shallow waters that support a rich diversity of sea life also tend to be ideal locations for turbines. Some scientists say these fears have been overblown—a 2022 study, for example, concluded that the Block Island Wind Farm located off the coast of Rhode Island does not appear to negatively impact bottom-dwelling fish. (Coastal regulators in the state of Rhode Island mandated the study be conducted and paid for by wind farm developers.) Others, like Munroe, say specific fisheries such as Atlantic surfclams will be significantly affected.

Surfclam fishing in wind farm areas, said Munroe, is logistically difficult, if not impossible, since vessels use dredges that drag though the sand to collect the clams. The presence of power cables on the ocean floor, she said, would make it too dangerous to use this kind of equipment around wind farms.

Installed boulders surrounding turbine foundations will also create obstacles, according to Munroe. “Each of the foundations is going to have what’s called scour protection,” she said. “So basically, big boulder fields that are going to be placed around the base of the turbine foundation in order to prevent the sand from scouring away.”

Currently, there are no legal restrictions on fishing in windfarm areas, Munroe said, just physical ones. “They could still get out there, but in order to fish efficiently and be able to get the catch they need and get back to the dock in a reasonable amount of time, it just wouldn’t be feasible,” she said. In her 2022 study, Munroe and her co-authors concluded that the presence of large offshore wind farms could cause fleet revenues to decline by up to 14 percent in some areas.

The industry has also been vocal about other consequences, such as habitat destruction and the possibility that the turbines’ sound might affect fish populations. In Maine, lobstermen worry that heavy mooring lines will drive their catch away. In Massachusetts, groups that represent fishing interests have filed lawsuits against the Bureau of Ocean Energy Management on the grounds that the agency failed to consider the fishing industry when it approved the 62-turbine Vineyard Wind project.

“The Bureau made limited efforts to review commercial fishing impacts,” wrote the plaintiffs in one of the Vineyard Wind lawsuits. “The limited effort that was made focused almost solely on impacts to the State of Massachusetts and on the scallop fishery, despite other fisheries being more active in the lease areas.”

Physical changes to the ecosystem, such as the placement of turbine foundations and scour protection, are some of the more obvious impacts of offshore wind turbines. But wind farms might elicit more subtle changes in local weather, affecting wind patterns and water currents, which models predict could reverberate through the food chain.

A 2023 study led by oceanographer Kaustubha Raghukumar, for example, found that turbine-driven alterations in wind speed could produce changes in ocean upwelling—a natural process where cold water from the deeper parts of the ocean rises to the surface—“outside the bounds of natural variability.” Those cold waters contain nutrients that support phytoplankton, the single-celled plants and other tiny organisms that form the basis of the oceanic food chain. Shifts in upwelling could have an impact on phytoplankton—although those impacts are still in question, particularly as climate change alters the equation.

Raghukumar and his colleagues at Integral, an environmental consulting company, based their predictions off historical data. But such an approach might not create an accurate picture of what will happen in the future as some scientists predict warmer global temperatures will produce stronger winds and increased upwelling, while others foresee localized decreases in upwelling. In their 2023 paper, which was funded by the California Energy Commission and the Ocean Protection Council, the authors noted that wind farms might reinforce—or even counteract—some of these climate change-driven changes in upwelling, but that all remains uncertain.

While Raghukumar's study didn't model how changes in upwelling might affect marine life, other scientists are closely studying possible changes to the ecosystem, though these are also likely to be complex and difficult to predict. A 2022 paper modeled the effect that planned wind farms might have in the North Sea, off the coasts of the U.K. and Norway, and concluded that they could influence phytoplankton, which could alter the food web.

Daewel, the study's lead author, stopped short of drawing conclusions about what these changes might mean for the ecosystem as a whole. "We cannot say if that's really a bad thing or a good thing because the ecosystem is very dynamic, especially in the North Sea," she said.

Changes to ocean processes could impact fish survival, but, again, no one is really sure how. "Young fish need to be in a specific area at a specific time to find the right types of prey," said Daewel. "So this redistribution of ecosystem parameters, that could mean that there might be a mismatch, or a better match also, for fishery life stages. But this is purely hypothetical."

With or without wind farms, climate change is already altering the timing of critical ecosystem processes, said Robert Dorrell, lead author of a 2022 paper that investigated the effects of offshore wind on seasonally stratified shelf seas—coastal regions where water separates during the spring into different layers, with warm water at the top and colder water at the bottom. Shelf seas only represent about 8 percent of the ocean, but the phytoplankton that bloom there generate an estimated 15 to 30 percent of the organic matter that forms the basis of the food web.

In seasonally stratified shelf seas, phytoplankton grow in the upper layers, using up nutrients but also creating a food source for a myriad of marine animals. When the bloom is over, ocean mixing, a natural process driven by wind and waves, helps bring oxygen to the bottom layers and nutrients to the top, ensuring that creatures at every level can thrive. But climate change is expected to increase ocean stratification, which interferes with natural ocean mixing.

"When you have cold water underneath, which is of a higher density, that density difference makes it harder in general to mix water vertically, upwards or downwards," said Dorrell.

Dorrell and his co-authors believe that wind farms could provide a partial solution to this problem by introducing artificial mixing of stratified shelf seas. This process, Dorrell said, is a little like stirring a cup of French coffee. "We have a nice coffee on the bottom and then you have foamy milk on the top. And if you would get a spoon and stir your French coffee you would mix the light milk up with the heavier coffee below."

In much the same way, the downwind wake generated by an offshore turbine could help mix the warm and cold layers of water, which might help offset some of the effects of climate change.

Fortunately, scientists like Dorrell say, there is time to figure out the more subtle nuances of offshore wind and its larger effects on the marine ecosystem. "I think what we have to remember with offshore wind is that although there are plans underway at the moment, they are long-term plans," he said. "In the U.K., for example, there are targets for 2030 certainly, but there are targets all the way through to 2050 and beyond. And there's certainly time there for research to inform and support and maximize the best delivery of offshore wind for the benefit of everybody."

Daewel added that papers like hers, which might suggest potential problems, aren't an argument against wind farms. Instead, they are a call to closely monitor existing wind farms and those that will be built in the future. "I think that's kind of the rule here, to be cautious and make sure that you understand what's happening to your system while you're building," she said.

It's possible that the way wind farms are built and where they are placed might help reduce potential negative impacts on the ocean ecosystem, though that research has yet to be done. "I think it will be a really interesting optimization kind of study, to kind of place the turbines in different locations and different densities," said Raghukumar. The information gleaned from such a study, he said, could be used to balance the benefits of wind energy against any adverse consequences.

As research into the impacts of offshore wind energy continues, scientists say it's important to maintain a sense of perspective, since fossil fuels also affect the ocean by driving changes to the climate.

"It's not our intention to say this is a negative development. It's also not our intention to say wind parks destroy the ecosystem. That's not what our research shows," Daewel said. "I just want to stress the research shows that we need to expect changes, and it's better to learn that as soon as possible."

Becki Robins is a freelance writer who lives with her family in rural Northern California. She writes about science, nature, history, and travel; her favorite stories include a little of all four. Her work has appeared in Science News, Comstock's Magazine, Hakai Magazine, and others.

This article was originally published on Undark.

Farm with the Wind

By Matthew Wilde, Progressive Farmer Crops Editor – Progressive Farmer – March 31, 2021

Corn pours into Kelly Nieuwenhuis' combine grain tank this past fall as 20-plus mph winds keep two MidAmerican Energy wind turbines spinning in his field. The northwest-Iowa row-crop farmer, in effect, is harvesting two revenue streams, but the latter is a stable source.

"For the last four years, the turbines were the most profitable part of my farm," Nieuwenhuis claims as he maneuvers his combine around the base of one of the 262-foot towers. "I wish I had 10 of them."

It's been a struggle to make a profit growing corn and soybeans the past five years, the Primghar farmer contends. The annual lease payment from MidAmerican of about $25,000 -- use of about 2 acres of land for two turbines and infrastructure -- that started in 2017 provides needed revenue to help offset fluctuating commodity markets.

When 40 acres of prime farmland came up for sale three years ago next to his field with the two turbines, Nieuwenhuis says the steady revenue the twin towers offer provided him with the confidence to purchase the property.

"I've been real happy with the wind turbines since they've been built," he continues.

OPPOSITION

Despite Nieuwenhuis' favorable experience, there's plenty of opposition to wind energy. This includes farmers and non-farmers alike.

Opponents have banded together to stop wind farms under development and encourage governing bodies to pass or consider passing zoning ordinances that would effectively prevent future wind development. In some cases, the conflict results in litigation.

Critics generally believe wind turbines are noisy eyesores that reduce property values. They claim audible and inaudible noise (infrasound), and shadow flicker (caused when rotating turbine blades pass between the sun and a home) from turning turbine blades can cause sleep deprivation and other health issues such as headache, fatigue, nausea, dizziness, ear pressure or pain and vertigo.

"It all comes down to quality of life," says Matt Amos, a Reno County, Kansas, resident who opposes the Pretty Prairie Wind Farm project proposed in the county.

Florida-based NextEra Energy Resources signed leases several years ago with 69 Kansas landowners for the 82-turbine wind farm that covers about 45,000 acres. The project was put on hold in 2019 after Reno County Citizens for Quality of Life, of which Amos is a member, submitted a protest petition against the project to county leaders. As a result, the county's three commissioners had to vote unanimously to approve the project's conditional-use permit. One commissioner voted no, so the permit was denied. NextEra is challenging the validity of the petition in court.

"We understand landowners want to make money. Payments can help during lean years with crops," Amos says. "I admire farmers ... but we want our health and [property] rights protected, too."

Nieuwenhuis says commercial wind turbines operate in every direction from his house, with the closest being 1,200 feet away. He reports no ill health effects, such as dizziness or headaches, as a result.

"Some people say [commercial wind turbine] noise is an issue, but I don't even notice it," he adds.

WINDFALL

Nieuwenhuis, like many landowners who have wind turbines on their land, sees opportunity in wind energy. The industry paid $1.6 billion in taxes and land-lease payments in 2020, according to American Clean Power (ACP), formerly the American Wind Energy Association.

Texas is the No. 1 wind energy generator. The state's landowners and taxing bodies annually receive $192 million and $285 million, respectively, in revenue.

"Wind energy provides farmers the chance to enhance revenue given the uncertainty of farming, and it generates taxes to help pay for essential services," says Jeff Danielson, ACP central states director. "That is the reason farm states have embraced it."

Property taxes from wind projects provide revenue for local schools, fire departments, law enforcement and more.

Bruce Dunahoo grows corn and soybeans on 440 acres near Zearing, Iowa. He has one wind turbine on his property, which is part of the 100-turbine Story County 1 Wind Farm, owned by NextEra. Dunahoo has earned more than $20,000 in six years since the lone turbine on his property has been operational.

"The pay is pretty good, but I see it as doing my part to help the environment," he says. "In the future, we will be relying on more green, safe energy."

The wind turbine on Dunahoo's land is located about 1,200 feet from his house. He reports no health issues from the turbine. Occasionally, Dunahoo notices shadow flicker in his house. But, he doesn't consider it a problem that window blinds can't address.

DIVISION

Wind energy has divided some rural communities. It pits supporters against residents who don't want to see turbines or hear the whooshing sound of rotating turbine blades -- some which are about 200 feet long. "It has created animosity, which is bad," Amos admits.

The small business owner and U.S. Marine Corps veteran built a house on 20 acres in southeast Reno County to get away from city noise and lights. Amos lost parts of both legs in a roadside bomb attack in Afghanistan and suffered two traumatic brain injuries.

Amos is concerned the flashing red safety lights on top of the nacelle (the gearbox on top of the tower) of turbines, shadow flicker and turbine noise would be detrimental to his health and property value. The closest turbine, if built, to Amos' house would be about a half-mile away.

Other members of the Reno citizens group, he says, share his concerns.

When the Pretty Prairie project was in the development phase, Amos says the citizens' group asked NextEra to do several things to alleviate concerns. Requests included turbines no closer than 3,000 feet or six times the turbine height from property lines of landowners not participating in the project and high-tech safety lights that only turn on when airplanes are near. NextEra proposed a setback distance of 2,000 feet from homes and wouldn't commit to the more expensive lights, Amos says.

"We live here, and we have something they want. I would think they would want to work with us," he continues.

NextEra spokesperson Conlan Kennedy says the company strives to work with lawmakers and residents in Reno County. He says it sites all of its wind projects to ensure the protection of public health. All local and state guidelines are followed.

He declined to comment about the future of the Pretty Prairie project because of pending litigation.

"I can't speculate on peoples' motives for opposing an industry that has brought great benefits to rural communities across the country," Kennedy says. "Based on our experience in many communities, wind energy still enjoys widespread support in Kansas and throughout the country."

WIND RESTRICTIONS

A fierce battle rages in Madison County, Iowa, about the Arbor Hill Wind Farm, proposed by MidAmerican Energy. If built, it would consist of 52 turbines.

The Madison County Board of Supervisors, in a 2-1 vote, passed in December what some say is the most restrictive commercial wind energy ordinance in the nation. The county is known worldwide for its covered bridges made famous by Robert Waller's best-selling novel "The Bridges of Madison County" and movie of the same name starring Clint Eastwood and Meryl Streep.

Madison County's new ordinance caps the number of turbines in the county at 51 (the current number). It also requires that any new turbine erected must be 1.5 miles from a non-participating landowner's property line.

"To put it bluntly, it's an effective ban on wind energy," says Adam Jablonski, MidAmerican Energy vice president of resource development.

The company filed a lawsuit in January challenging the ordinance. MidAmerican argues it could build the Arbor Hill project because it received previous county approval, which withstood legal challenges from an opposition group.

Jablonski says MidAmerican is "evaluating" the project as the latest court battle continues. County supervisor Diane Fitch says board members can't comment due to ongoing litigation.

Mary and Roy Jobst, of rural Earlham, Iowa, hope the Arbor Hill project remains on the shelf. Even though they signed a development easement with MidAmerican in 2017, which means two turbines could be built on their property, the couple no longer wants to participate. They've asked MidAmerican to terminate the contract to no avail.

The Jobsts, who farm 360 acres, say they agreed to the easement without researching the negative health effects of wind turbines and considering neighbor dissension.

"It's the worst decision we ever made," Mary says. "We should have done our homework and sought legal advice. The money is not worth having [bad] neighbor relations."

She cites a Council of Canadian Academies report that says there's sufficient evidence that exposure to wind turbine noise causes annoyance among some people. The report also says there's limited evidence to establish a causal relationship between exposure to wind turbine noise and sleep disturbance.

However, the report also states the evidence is inadequate to come to any conclusion that exposure to wind turbine noise causes health issues such as fatigue, nausea and cardiovascular disease.

"It's misleading [for proponents] to make assertions that scientific studies have 'proven' that industrial wind turbines don't pose risks to human health," Mary says.

A joint statement from the Environmental Health Sciences Research Center at the University of Iowa College of Public Health, the Common Good Iowa and the Iowa Environmental Council says "there is little evidence that sound from wind turbines represents a risk to human health."

ACP's Danielson continues, "There's no evidence wind turbines cause negative health effects beyond simple annoyance, or they result in a loss of property values."

FUTURE OF WIND ENERGY

Green energy is a priority of President Joe Biden's administration. Goals include a 100% clean-energy economy with zero-net carbon emissions by 2050 and decarbonizing the U.S. power sector by 2035.

To meet these goals, Danielson projects the U.S. will need about 120,000 wind turbines, which is double the current number.

The National Renewable Energy Laboratory says it costs, on average, $991,000 per megawatt (MW) to build a commercial wind turbine. Most commercial units exceed 2 MW.

"The wind is at our back ... the sky's the limit," Danielson asserts. "But, clean energy has to be a partnership between the local, state and federal level."

Local governments passing commercial wind energy ordinances that restrict development concerns the Iowa Conservative Energy Forum (ICEF). The group believes landowners have the right to utilize their property and profit from it as they see fit.

"We want folks to be able to look at the pluses and minuses of wind energy, and make decisions that best work for them," says Ray Gaesser, a farmer and ICEF chairman.

Judy and Steve Neal, of Madison County, filled out MidAmerican Energy's landowner interest form years ago with hopes of financially benefiting from wind turbines on family land. The extra income would come in handy, the retirees say. It would allow them to visit family in California more and help pay for grandkids' college educations.

The Neals fear both county leaders and the fierce opposition have dashed their hopes of a more financially secure future.

"Apparently, we only have the right to pay property taxes," Steve quips.

Judy adds, "I feel [county leaders] are dictating what we can and cannot do on our farm."

Wind Energy Contracts 101:

Experts familiar with commercial wind energy contracts recommend landowners consult with an attorney before they sign on the dotted line to allow wind turbines on their property. Wind energy companies may foot all or part of the legal fees, explains Mary Ludwig, an agricultural attorney and partner at Johnson and Taylor, in Pontiac, Illinois.

Ludwig has reviewed about 80 wind energy contracts for clients. Some agreements can be lengthy, up to 60 pages, and provide companies access to land for decades, she says. It's in the landowner's best interest to understand all provisions within a contract to protect their rights and property.

"Wind companies write contacts in their favor to protect their multimillion-dollar projects. That's why a landowner needs to have their own attorney review it," Ludwig explains. "A farmer may get paid for the use of their land, but they need to know how wind turbines could affect farm operations."

Here are eight points landowners should consider before signing a wind energy contract:

- It's important to understand the basic concepts of all lease and easement provisions and associated time periods. A contract typically includes an option agreement, operating option and option to extend. Lease agreements typically last 20 to 30 years but could be extended for decades more. If the land is sold, the new owner assumes the contract. Wind farm decommissioning provisions are also usually part of the contract, spelling out how the wind provider will remove turbines and infrastructure.
- Payment terms. Contracts could include options such as fixed payments, royalty or revenue-based payments, or a combination of both.
- Wind turbine and infrastructure placement. It's unlikely a company can pinpoint where construction will take place, if at all, when a landowner agrees to participate since siting studies and landowner participation are usually not complete, Ludwig says. However, she recommends farmers keep in contact with the land agent to get a "good feel" of the location, because it can affect farm operations.
- Detail how agricultural drainage tile and fencing will be repaired or replaced if damaged during construction. A landowner may want their own contractor to make repairs or

supervise the wind company's contractor. Farmers may want GPS coordinates of tile repairs.

- Crop and soil-compaction damage. Both could occur during construction, and the latter could cause yield losses for years to come. Farmers may want to include provisions on how yield loss is calculated, time frames and what price is used to determine loss payments.
- Farming obstacles. Farmers can request electric transmission lines be buried and other structures associated with the wind farm be removed or placed in areas that don't impede farming activities.
- Existing infrastructure. Landowners can request the wind energy company keep existing roads, fences, culverts driveways, vegetation, etc., in good condition.
- Property taxes. A wind energy company often will pay the increase in property taxes for wind turbines, but landowners will want to make sure they are not stuck with the bill.

"Generally, I would say most of my clients are happy after entering into agreements with wind energy companies, but a few declined because they heard about bad experiences or could foresee possible issues with neighbors or other things," Ludwig says.

Hydropower Explained: Hydropower and the Environment

US Energy Information Administration, 2022

Hydropower generators produce clean electricity, but hydropower does affect the environment

Most dams in the United States were built mainly for flood control, municipal water supply, and irrigation water. Although many of these dams have hydroelectric generators, only a small number of dams were built specifically for hydropower generation. Hydropower generators do not directly emit air pollutants. However, dams, reservoirs, and the operation of hydroelectric generators can affect the environment.

A dam that creates a reservoir (or a dam that diverts water to a run-of-river hydropower plant) may obstruct fish migration. A dam and reservoir can also change natural water temperatures, water chemistry, river flow characteristics, and silt loads. All of these changes can affect the ecology and the physical characteristics of the river. These changes may have negative effects on native plants and on animals in and around the river. Reservoirs may cover important natural areas, agricultural land, or archeological sites. A reservoir and the operation of the dam may also result in the relocation of people. The physical impacts of a dam and reservoir, the operation of the dam, and the use of the water can change the environment over a much larger area than the area a reservoir covers.

Manufacturing the concrete and steel in hydropower dams requires equipment that may produce emissions. If fossil fuels are the energy sources for making these materials, then the emissions from the equipment could be associated with the electricity that hydropower facilities generate. However, given the long operating lifetime of a hydropower plant (50 years to 100 years) these emissions are offset by the emissions-free hydroelectricity.

Greenhouse gases (GHG) such as carbon dioxide and methane form in natural aquatic systems and in human-made water storage reservoirs as a result of the aerobic and anaerobic decomposition of biomass in the water. The exact amounts of GHG that form in and are emitted from hydropower reservoirs is uncertain and depend on many site specific and regional factors.

Fish ladders help salmon reach their spawning grounds

Hydropower turbines kill and injure some of the fish that pass through the turbine. The U.S. Department of Energy has sponsored the research and development of turbines that could reduce fish deaths to lower than 2%, in comparison with fish kills of 5% to 10% for the best existing turbines.

Many species of fish, such as salmon and shad, swim up rivers and streams from the sea to reproduce in their spawning grounds in the beds of rivers and streams. Dams can block their way. Different approaches to fixing this problem include the construction of fish ladders and elevators that help fish move around or over dams to the spawning grounds upstream.

The Safe Harbor Dam on the Susquehanna River in Pennsylvania has elevators that lift migrating shad from the base of the dam to the top of the reservoir.

Hydropower dams threaten fish habitats worldwide

New research maps impacts of hydropower dams on species critical to human livelihoods.

BY SARAH CAFASSO, STANFORD NATURAL CAPITAL PROJECT – February 3, 2020

Rivers and other ecosystems that provide essential habitats to freshwater fish are under increasing pressure from global hydropower development. While dams can provide flood protection, energy supply, and water security, they also pose a significant threat to freshwater species. Dams block fish from moving along their natural pathways between feeding and spawning grounds, causing interruptions in their life cycles that limit their abilities to reproduce. As hydropower development continues along river basins around the world, scientists are concerned about the unknown impacts to the diverse species found in freshwater habitats – many of which are critical sources of food and livelihood for humans.

"Because fisheries based on migratory species support tens of millions of people, understanding where hydropower development could negatively impact river basin connectivity – and therefore fish – is an important step in identifying solutions that deliver needed electricity while minimizing the loss of essential natural resources," said Jeff Opperman, Global Lead Freshwater Scientist for World Wildlife Fund.

Without detailed information about where exactly freshwater species feed and spawn, it has been difficult for planners to make more sustainable decisions around hydropower and river basin development. Now, researchers from the Stanford Natural Capital Project and Radboud University have mapped the impacts of past and future hydropower development on fish habitats worldwide. Their results were published Feb. 3 in Proceedings of the National Academy of Sciences.

"We've known that future development will impact fish species, but we didn't have the detailed information about some of the places with the highest development pressures – like the Amazon, the Mekong, and the Congo – until now." – RAFAEL SCHMITT, Postdoctoral Research Fellow, Natural Capital Project

Data-driven decision making

"We've known that future development will impact fish species, but we didn't have the detailed information about some of the places with the highest development pressures – like the Amazon, the Mekong, and the Congo – until now," said Rafael Schmitt, researcher at the Natural Capital Project and second author on the study. "This dataset will help decision-makers better understand impacts of land and infrastructure development on aquatic biodiversity, so they can make choices that protect it."

The researchers used detailed spatial data for 10,000 fish species to measure impacts of dams on their habitats. They evaluated around 40,000 existing and 3,700 planned hydropower dams to create high resolution global maps. "These dams pose a real danger to the survival of species and associated human livelihoods," said Schmitt. "Salmonids in North America were mostly wiped out by dams, and with them the livelihoods of people depending on their annual migration. Now, similar impacts become evident in other geographies. Recently, we've seen how dams on the Yangtze contributed to the extinction of the Chinese paddlefish, a source of food and cultural reverence for communities along the river. If we aren't more strategic about where and how we develop future hydropower, we can expect to see more and more examples like this one."

Opportunity for strategic hydropower planning

The study shows the highest numbers of fragmented habitats from current hydropower are found in the United States, Europe, South Africa, India and China. In developing countries, though, the impacts of planned hydropower development are disproportionally high. "For example, we see that the completion of only one dam close to the outlet of Purari River in Papua New Guinea will decrease habitat connectivity by about 80 percent on average for freshwater fish in the region," said Valerio Barbarossa, environmental researcher at Radboud University and lead author on the study.

"With these maps, we have a global picture of where fish species are already impacted by dams and where local conservation efforts should be fostered," said Barbarossa.

The researchers hope that their results will help guide strategic decision-making around hydropower planning. "Evaluating impacts of dams is only the first step," said Schmitt. "These data can be used to highlight the additional benefits of thoughtful, strategic river basin development to drive conservation and restoration efforts in local areas and at global scales."

Rafael Schmitt is a postdoctoral fellow at the Natural Capital Project and the Stanford Woods Institute for the Environment.

NCF-Envirothon 2024 New York

Current Issue Part A Study Resources

Key Topic #4: Global Perspectives on Renewable Energy

15. Describe the landscape of renewable energy across various regions of the world, including strengths and challenges.
16. Explain the barriers to transitioning to renewable energy and identify solutions to these barriers.
17. Evaluate the effectiveness of different approaches to renewable energy given varying environmental, social, and economic conditions.
18. Explain the roles of economic and political policy, public perception, community advocacy, and scientific advancements in a successful transition to renewable energy.

Study Resources

Study Resources begin on the next page! ➡

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.”

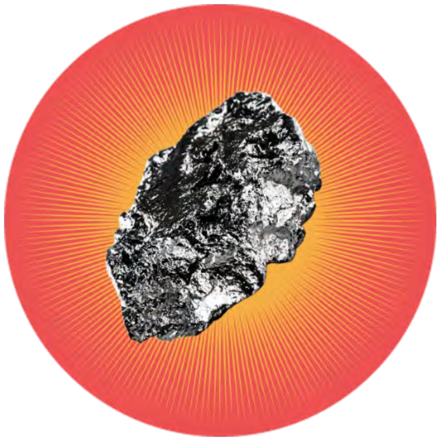
Make renewable energy technology a global public good

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."

1. Introduction

The world's population is growing at an unprecedented rate and that has necessitated a dramatic increase in energy demand globally. Matching supply with this surging demand is a principal and critical challenge for countries around the world. Currently, this demand is being met through the increased use of fossil fuels. The majority of the world's power is generated from the use of coal, oil and gas. These so-called fossil fuels, when burned, release heat energy which is then converted into electricity releasing into the atmosphere a lot of carbon dioxide (CO2), a greenhouse gas that contributes to the issue of global warming. A renewable energy supply offers a solution to both challenges. For economic growth and human advancement, energy has always been universally considered one of the most crucial measures (Rawat and Sauni, 2015). There is a three-dimensional relationship alongside a bi-directional causal relationship between economy, the environment and energy (Azad et al., 2014).

Globally, the population is growing at fast rate; however, the world's energy demand is likely to grow even more rapidly than the increase in the population. According to International Energy Outlook (2013), global energy demand will be increased by 56 per cent between 2010 and 2040 (Azad et al., 2014). Currently, the majority of the world's energy consumption is satisfied by consuming energy created using fossil fuels. To satisfy the ever-increasing energy demand and to protect the climate, breakthrough advancements have been made in the past to design technologies that can control and harness power from alternative energy sources. As controlling carbon emissions is critical in dealing with climate change, renewable energy is an appropriate way to satisfy energy demand without degrading the ecosystem (Jing, 2016). Apart from bringing environmental sustainability, renewable energy offers another advantage—the ability to provide power to even the most underprivileged people living in the remotest areas where traditional power is not yet available (Rawat and Sauni, 2015).

Awareness of the need to encourage deployment of renewable energy has increased drastically in recent years. More countries, whether developed or developing, are promoting and changing policies to promote the deployment of renewable energy. In 2005, only 55 countries had taken steps to make renewable targets and create policies supporting renewable energy. This number had increased to 144 countries by 2013, with almost all the world understanding the need to reduce carbon emissions.

2. Background

Despite remarkable promotion and commitment from various nations, only a small percentage of energy is generated from renewable energy, especially in developing countries. This scenario is because of the numerous barriers that control the diffusion

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of renewable energy. These barriers prevent renewable energy from effectively competing with traditional energy and hamper achievement of the necessary large-scale deployment (Nasirov et al., 2015). Penetration and scale-up of renewable require a strong political and regulatory framework which supports and promotes a continued focus on fossil fuels (Karatayev et al., 2016).

A review of the literature shows that many studies have been conducted to identify barriers to the use of renewable energy. However, very few studies have grouped these barriers and discussed the impact of these barriers in the deployment of renewable energy. The variables which were identified from the literature review for use in future research were *social barriers*, *economic barriers, technological barriers and* regulatory barriers.

The objective of this research is to discover the impacts of breaking barriers in the deployment of renewable energy. This research tries to resolve the following questions to reach a solution which is in line with the objective of this research:

a. What are the factors affecting the deployment of renewable energy and are they significant or not?
b. What impact will breaking barriers have on the deployment of renewable energy?
c. In the wake of breaking barriers, is Rogers' (2003) theory of diffusion (political and social) valid for renewable energy?

3. Theory

Theory of diffusion (technical, political & social) in the wake of breaking barriers.

Diffusion of innovation theory is one of the most important concepts in theorizing the changing format of energy provision, being concerned with the process of adoption of innovations by society (Lacerda et al., 2014). Rogers (1983: 11) defined diffusion as 'the process by which innovation is communicated through certain channels over time among members of a social system' and innovation as 'an idea, practice or object that is perceived as new by an individual or other unit of adoption' (Sahin, 2006). Other types of diffusion include social diffusion and theories of change, going back to Lewin's description of the need to alter group standards to promote lasting individual change (Lewin, 1951). The focus has since shifted towards external conditions that are likely to be more influential than group decisions (Darnton, 2008). Political diffusion deals with the spread of policies and governance approaches across jurisdictional boundaries which come about because of external pressures and/or internal pressures relating to quests for legitimacy (Weyland, 2005). More fundamentally, diffusion defines the often random movement of a

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characteristic. The theory of diffusion is used to understand the attitude and perception of people with regard to government policies.

4. Hypotheses

This literature review looks at the outcomes of penetration and deployment of renewable energy, which are affected by four major factors: social barriers, economic barriers, technological barriers and regulatory barriers.

4.1. Social barriers

The transition from conventional resources to renewable energy has encountered public resistance and opposition. This is due to a lack of awareness of the benefits of renewable energy, disruption of seascape, and acquisition of land which could have been used for agriculture, tourism, etc. (Goldsmiths, 2015).

Public awareness and information barriers: Sustainable development stems from the satisfaction of human desires, through socially recognized technological systems and suitable policies and regulatory tools (Paravantis et al., 2014). The main concerns with respect to public understanding are: 1) insufficient information regarding ecological and financial benefits; 2) inadequate awareness of renewable energy technologies (RET); and 3) uncertainties about the financial feasibility of RE installation projects (Nasirov et al., 2015).

Not in my backyard' (NIMBY) syndrome: According to NIMBY syndrome, people do support renewable energy generally, but not in their own neighbourhood. Renewable power project proposals often face opposition from individual citizens, political leaders, grassroots organizations, national interest groups and, in some cases, even environmental groups (Jianjun and Chen, 2014). Public opposition occurs for a number of reasons, including landscape impact, environmental degradation and lack of consultation concerns among local communities (Nasirov et al., 2015).

Loss of other/alternative income: A major issue with renewable plants (especially solar and wind farms) is the vast area of land required to produce an amount of energy equivalent to that which can be produced from a small coal fire power plant (Chauhan and Saini, 2015).

To make a significant contribution to global energy consumption, there is a need to develop large scale renewable energy plants, but this requires vast areas of countryside. Enormous parts of the countryside, which includes farmland, need to be converted into buildings or roads or any other infrastructure to support a renewable energy power plant. In achieving this, often agriculture, tourism, fishing, etc. can be affected (Nesamalar et al., 2017).

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Lack of experienced professionals: Universal transition from fossil fuels to renewable energy sources requires the solid foundation of a skilled labour force. There is huge demand for skilled professionals to design, build, operate and maintain a renewable energy plant.

Incompetent technical professionals and lack of training institutes prevent renewable energy technologies from scaling new heights (Ansari et al., 2016). There is a need to teach renewable energy courses and for proper training to be conducted to develop the skills required to install and operate renewable energy projects. The shortage of trained workforce to design, finance, build, operate and maintain renewable energy projects is considered a major obstacle to the wide penetration of renewable energy (Karakaya and Sriwannawit, 2015).

H1: Social barriers have a significant influence on the deployment of renewable energy.

H2: Social barriers have a significant influence on economic barriers.

4.2. Economic barriers

Factors influencing economic and financial barriers are high initial capital, lack of financial institutes, lack of investors, competition from fossil fuels, and fewer subsidies compared to traditional fuel (Raza et al., 2015). These factors have prevented renewable energy from becoming widespread.

Tough competition from fossil fuel: Fossil fuels will remain a dominant player in supplying energy in the future. A report by EIA's International Energy Outlook (2016) suggests that fossil fuels (oil, natural gas and coal) are expected to supply 78 per cent of the global energy used in 2040. Investment in fossil fuels (including supply and power generation) still accounts for 55 per cent of 2016 global energy investment, compared with 16 per cent for renewable energy. Coal is still a dominant fuel source in most counties because of its abundance, which makes it cheap and accessible (Dulal et al., 2013). There have been huge changes in energy since summer 2014. Oil, as measured by the Brent crude contract, which was priced at $115.71/barrel in June 2014, fell to $27.10 on 20 January 2016, a huge drop of 76 per cent. Similarly, the ARA coal contract dropped from $84/tonne in April 2014 to $36.30 in February 2016. There was a huge decline in the price of natural gas, which slid from around $4.50/MMBtu in June 2014 to $1.91 in mid-February 2016. Due to falling prices and fossil fuel still emerging as a cheaper alternative to renewable energy, it is able to offer tough competition to renewable energy projects.

Government grants and subsidies: The amount of government subsidies provided to conventional energy is much higher than the subsidies awarded to renewable energy.

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This keeps renewable energy at a disadvantage. The subsidies provided by governments to generate electricity from fossil fuel sources is overshadowing the wide use of low emission technologies. For example, coal companies in Australia and Indonesia still receive government subsidies for mining and exploration (Dulal et al., 2013).

Fewer financing institutions: Renewable energy developers and producers face severe difficulties in securing financing for projects at rates which are as low as are made available for fossil fuel energy projects (Ansari et al., 2016). There are limited financial instruments and organizations for renewable project financing. This reflects that the investments are considered somewhat risky, thus demotivating investors (Ohunakin et al., 2014).

High initial capital cost: Renewable energy projects require high initial capital cost and, because of the lower efficiency of renewable technology, the net pay back period is high, which in turn pushes investors on to the back foot (Ansari et al., 2016). Both the users and the manufacturers may have very low capital and to install a plant they require capital financing. This problem is further highlighted by the strict lending measures that restrict access to financing even when funding is available for traditional energy projects (Suzuki, 2013). High cost of capital, often lack of capital and most important with high payback period projects often becomes un-viable (Painuly. J, 2001).

Intangible costs: Currently, in almost all countries, the total cost of fuel includes the cost of exploration, production, distribution and usage, but it does not include the cost of the damage it does to the environment and society. Despite severe effects on health and on the atmosphere, the unseen costs (externalities) which are connected with traditional fuels are not included in their price (Arnold, 2015). Understanding these impacts is essential for evaluating the actual cost of utilizing fossil fuels for energy generation.

H3: Economic barriers have a significant influence on the deployment of renewable energy.

4.3. Technological barriers

There are a number of legitimate technological barriers to the widespread deployment of renewable energy, including limited availability of infrastructure, inefficient knowledge of operations and maintenance, insufficient research and development initiatives, and technical complexities like energy storage and unavailability of standards (Zhao et al., 2016).

Limited availability of infrastructure and facilities: There is limited availability of advanced technologies required for renewable energy, especially in developing

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countries, which acts as a factor preventing penetration of renewable energy. Even if this technology is available, the cost of procuring it is very high (Dulal et al., 2013). Since renewable energy power plants are mostly placed in remote locations, they require additional transmission lines to connect to the main grid. Since most of the existing grids are not designed to integrate with renewable energy, these existing grids need to be upgraded or modified (Izadbakhsh et al., 2015). Grid integration is amongst the biggest problems affecting the development of renewable energy projects.

Lack of operation and maintenance culture: Since renewable energy technology is comparatively new and not optimally developed, there is a lack of knowledge about operation and maintenance. Efficiency cannot be achieved if a plant is not optimally operated and if maintenance is not carried out regularly (Sen and Bhattacharyya, 2014). Lack of availability of equipment, components and spare parts will require a substantial increase in the production costs, as these items need to be imported from other countries, therefore being procured at high prices and so increasing the overall cost (Bhandari et al., 2015).

Lack of research and development (R&D) capabilities: Investment in research and development (R&D) is insufficient to make renewable energies commercially competitive with fossil fuel. Both governments and energy firms shy away from spending on R&D as renewable energy is in its development stage and risks related to this technology are high (Cho et al., 2013).

Technology complexities: There are not enough standards, procedures and guidelines in renewable energy technologies in terms of durability, reliability, performance, etc. This prevents renewable energy from achieving large scale commercialization (Nasirov et al., 2015). A major technical issue which renewable energy is facing today is the storage of energy. The supply of sun or wind is not continuous despite their infinite abundance and electricity grids cannot operate unless they are able to balance supply and demand. To resolve these issue, large batteries need to be developed which can compensate for the times when a renewable resource is not available (Weitemeyer et al., 2014).

H4: Technological barriers have a significant influence on the deployment of renewable energy.

H5: Technological barriers have a significant influence on economic barriers.

4.4. Regulatory barriers

Factors like lack of national policies, bureaucratic and administrative hurdles, inadequate incentives, impractical government targets, and lack of standards and

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certifications have prevented renewable energy from expanding dramatically (Stokes, 2013).

Ineffective policies by government: Strong regulatory policies within the energy industry are not only required for a nation's sustainable development, but also resolve the inconsistency between renewable and non-renewable energy. Lack of effective policies creates confusion among various departments over the implementation of the subsidies. Major issues such as unstable energy policy, insufficient confidence in RET, absence of policies to integrate RET with the global market and inadequately equipped governmental agencies act as barriers to the deployment of renewable energy projects (Zhang et al., 2014).

Inadequate fiscal incentives: There have not been enough measures by governments to remove tax on imports of the equipment and parts required for renewable energy plants. Feed-in tariffs are the measures by which governments aim to subsidize renewable energy sources to make them cost-competitive with fossil fuel-based technologies, but the absence of these adequate financial incentives results in high costs that hinder the industry's development, operation and maintenance, and stagnate the future (Sun and Nie, 2015).

Administrative and bureaucratic complexities: Obstacles arising in the deployment of renewable energy projects are manifold, including (and not limited to) administrative hurdles such as planning delays and restrictions. Lack of coordination between different authorities and long lead times in obtaining authorization unnecessarily increase the timeline for the development phase of the project. Higher costs are also associated with obtaining permission due to lobbying. All these factors prolong the project start-up period and reduce the motivation required to invest in renewable energy (Ahlborg & Hammar, 2014).

Impractical government commitments: There is a gap between the policy targets set by governments and the actual results executed by implementation (Goldsmiths, 2015). There is a lack of understanding of a realistic target and loopholes in the implementation process itself. The responsibility for overcoming these commitment issues lies with governments. Policies should be devised that can offer clear insight into important legislation and regulatory issues so that the industry can be promoted as stable and offering growth. Governments can fix this mismatch by becoming more responsive and reactive.

Lack of standards and certifications: Standards and certificates are required to ensure that the equipment and parts manufactured or procured from overseas are in alignment with the standards of the importing company. These certifications make sure that companies are operating the plant in compliance with local law. Absence of such standards creates confusion and energy producers have to face unnecessary difficulties (Emodi et al., 2014).

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H6: Regulatory barriers have a significant influence on the deployment of renewable energy.

H7: Regulatory barriers have a significant influence on economic barriers.

4.5. Breaking barriers in deployment of renewable energy

Deployment of renewable energy is crucial not only to meet energy demands but also to address concerns about climate change (Byrnes et al., 2013). However, the barriers (social, economic, technological and regulatory) existing in this sector prevents the development and penetration of renewable energy globally.

User-friendly procedures: Bureaucratic procedures in the deployment of renewable energy are considered the biggest hindrance, and this demotivates investors and entrepreneurs from entering and investing in renewable energy. Government policies are not aligned at national and state level, thus failing to attract energy sector investment (Nesamalar et al., 2017). Countries with excessively complicated administrative procedures have less penetration of renewable energy compared to countries with simple and straightforward procedures (Huang et al., 2013).

Higher stakeholder satisfaction: Energy is the backbone of the socioeconomic development of any country (Raza et al., 2015). By utilizing more renewable energy resources, nations can help fulfil energy deficiencies without damaging nature. The repercussions of this change would be the creation of more jobs in the designing, building, operation and maintenance of renewable energy project infrastructures. Higher levels of diffusion will help to achieve economies of scale, and that will bring down the costs and thus the price for the end user. This will improve investors' confidence and will trigger increased investments in renewable energy projects. Higher benefits can be reaped from the availability of green energy as there will not be severe environmental implications, and that can help in maintaining the earth's ecosystem.

Successful research and development (R&D) ventures: In a study conducted by Halabi et al. (2015), it was pointed out that technological advancement to effectively generate, store and distribute renewable energy at lower costs is crucial. However, compared to conventional energy, insufficient R&D initiatives are undertaken. This is due to fact that organizations are unable to earn beneficial returns from R&D, and that makes the future of these initiatives look dull.

Cost savings: The biggest challenge that renewable energy faces is the competition from low cost fossil fuels (El-katiri, 2014). Renewable energy projects require huge land areas to produce the amount of energy which a conventional plant can produce in a small area. Prohibitive costs are involved in establishing and running renewable energy projects, mainly due to the huge financial capital required to acquire a

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A Just Transition to Renewable Energy in Africa

South Africa's plan could be a roadmap for countries transitioning from high-polluting energy sources to renewables

From Africa Renewal – United Nations: November 2022

By: Kingsley Ighobor

Wind turbines in the Sinai Desert, Hurghada, Egypt

The President of the African Development Bank (AfDB) Akinwumi Adesina has a nuanced view of what a just transition to renewable energy means for Africa. He believes it should be pragmatic and sensitive to Africa's development reality but not antithetical to the commitments of net zero greenhouse gas emissions.

In an interview with Africa Renewal ahead of COP27, which is scheduled for 6-18 November in Sharm El-Sheikh, Egypt, Mr. Adesina says that Africa, in the short term, needs to tap a range of energy sources — wind, solar, geothermal and gas.

His rationale? About 600 million Africans, about half the continent's population, lack access to electricity; some 900 million have no access to clean cooking fuels and technologies.

"African countries need space to industrialize, and the energy mix that will allow them to do that is fundamental," he insists, preferring an incremental, rather than a leapfrog approach toward renewables.

“We shouldn’t get ourselves confused,” he cautions. “Moving from coal to gas will reduce emissions in Africa by 40 per cent and pivoting from fuelwood to gas for cooking will reduce emissions significantly.”

In addition, he emphasizes that geopolitical factors, such as the war in Ukraine and its impact on global oil prices put “Europe in a serious situation with energy security…I think Africa should become a major supplier of gas to help energy security in Europe.”

At the same time, Mr. Adesina, who is considered a top African development expert, underscores the AfDB’s renewable energy bona fides.

“Don't get me wrong,” he maintains. “We're doing flat-out everything to get to renewables, but we must be realistic. Wind and solar are highly variable [in Africa]. Africa does not have nuclear power. Even hydro is no longer reliable because of droughts and low water levels.

“And by the way, when people talk about emissions, if Africa were to triple the use of natural gas for energy generation, it will contribute 0.67 per cent to global emissions.”

African Common Position

Mr. Adesina unsurprisingly echoes the African Common Position on Energy Access and Just Energy Transition adopted on 22 July 2022 by the African Union (AU) Executive Council.

The common position states that “Africa will continue to deploy all forms of its abundant energy resources, including renewable and non-renewable energy to address energy demand.”

It dichotomizes energy needs, with gas, green and low-carbon hydrogen and nuclear energy preferred for the short-to-medium term and mostly renewables for the long-term.

Amani Abou-Zeid, AU Commissioner for Infrastructure and Energy, contends that Africa has a right to a “differentiated path towards the goal of universal access to energy, ensuring energy security for our continent and strengthening its resilience, while at the same time acting responsibly towards our planet by improving the energy mix.”

However, environmentalists continue to clamour for a total abandonment of oil and gas in favour of renewable energy based on the Paris Agreement on climate, which aims for a 50 per cent cut in emissions by 2030 and net zero by 2050.

UN Secretary-General António Guterres has also consistently advocated urgent significant investments in renewables.

“Had we invested massively in renewable energy in the past, we would not be in the middle of a climate emergency now,” Mr. Guterres said in September, referring to frequent climate disasters and rising fuel prices in his address to the UN Global Compact board meeting.

The world must end its “addiction to fossil fuels,” he declared. “Leaders in business, as well as government, must stop thinking about renewables as a distant project of the future. Without renewables, there can be no future.”

The world must end its “addiction to fossil fuels,” he declared. “Leaders in business, as well as government, must stop thinking about renewables as a distant project of the future. Without renewables, there can be no future.

UN Secretary-General’s Five-Point Plan

The UN chief outlined a five-point plan for transitioning to renewables.

First is the need to achieve a fair and accelerated energy transition, which requires “patents that can be made freely available — especially those relating to battery and storage capacity,” he stressed.

Second is increasing and diversifying renewable energy technology supply chains, which are currently “concentrated in a handful of countries.” He said pertinent technologies should be considered “global public goods” and readily available to all.

His third point is putting “policies and frameworks in place to incentivize investments and eliminate bottlenecks caused by red tape, permits and grid connections.”

Fourth is shifting fossil fuels subsidies to renewables. The $500 billion spent annually to lower the price of fossil fuels “more than triple what renewables receive…if we channel these resources and subsidies to renewables, we not only cut emissions, we also create more decent and green jobs,” he argues.

Fifth is investing up to $4 trillion in renewable energy projects. He expressed concern that Africa, with substantial renewable energy potentials, currently receives just 2 per cent of clean energy investments.

“The cost of capital for renewable energy projects in the developing world can be seven times higher than in the developed world,” he laments. “Upfront costs for solar and wind power account for 80 per cent of lifetime costs, meaning big investments today will reap even bigger rewards tomorrow.”

The UN Secretary-General's emphatic call for significant investments in renewable projects, particularly in developing countries, converges with the AU’s position, which is linked to adequate financing and investments that address energy poverty in Africa.

In other words, huge investments in Africa’s mostly untapped renewable sources could speedily wean the continent off fossil fuels.

South Africa’s Plan

It is exactly what South Africa, the world’s 12th biggest carbon emitter, wants to achieve with an investment plan to fast track its transition to renewable energy. Coal accounts for 80 per cent of South Africa’s power generation, with substantial economic, environmental and social ramifications.

Approved by the country’s cabinet earlier this month, the plan consists of the $8.5 billion investments pledged at COP26 in Glasgow by Britain, France, Germany, the US and the European Union in concessional and commercial loans, as well as investment guarantees. The details of this Just Energy Transition Partnership investment deal will likely be wrapped up ahead of COP27.

The cabinet says it hopes to “achieve the decarbonization commitments made by the government of South Africa, while promoting sustainable development, and ensuring a just transition for affected workers and communities.”

Under the transition plan, turbines and solar panels will replace high-polluting coal power stations. If successful, it could be a model for other developing countries.

Regarding a just transition to a renewable energy future, Mr. Guterres said in September: “Lip service won’t do. We need credible actions and accountability.” South Africa’s plan, which might be replicated in other African countries, seems like such a credible action.

China on Course to Hit Wind and Solar Power Target Five Years Ahead of Time

Beijing bolstering position as global renewables leader with solar capacity more than rest of world combined

By Amy Hawkins and Rachel Cheung

June 28, 2023 – The Guardian

China is shoring up its position as the world leader in renewable power and potentially outpacing its own ambitious energy targets, a report has found.

China is set to double its capacity and produce 1,200 gigawatts of energy through wind and solar power by 2025, reaching its 2030 goal five years ahead of time, according to the report by Global Energy Monitor, a San Francisco-based NGO that tracks operating utility-scale wind and solar farms as well as future projects in the country.

It says that as of the first quarter of the year, China's utility-scale solar capacity has reached 228GW, more than that of the rest of the world combined. The installations are concentrated in the country's north and north-west provinces, such as Shanxi, Xinjiang and Hebei.

In addition, the group identified solar farms under construction that could add another 379GW in prospective capacity, triple that of the US and nearly double that of Europe.

China has also made huge strides in wind capacity: its combined onshore and offshore capacity now surpasses 310GW, double its 2017 level and roughly equivalent to the next top seven countries combined. With new projects in Inner Mongolia, Xinjiang, Gansu and along coastal areas, China is on course to add another 371GW before 2025, increasing the global wind fleet by nearly half.

"This new data provides unrivalled granularity about China's jaw-dropping surge in solar and wind capacity," said Dorothy Mei, a project manager at Global Energy Monitor. "As we closely monitor the implementation of prospective projects, this detailed information becomes indispensable in navigating the country's energy landscape."

The findings are in line with previous reports and government data released this year, which predicted that China could easily surpass its target of supplying a third of its power consumption through renewable sources by 2030.

China's green energy drive is part of its effort to meet dual carbon goals set out in 2020. As the world's second largest economy, it is the biggest emitter of greenhouse gases and accounts for half of the world's coal consumption. The Chinese president, Xi Jinping, pledged in 2020 to achieve peak CO_2 emissions before 2030 and carbon neutrality by 2060.

A coal-fired power plant in Shanghai. China approved more coal power in the first three months of 2023 than in the whole of 2021. Photograph: Aly Song/Reuters

The report attributed China's remarkable progress in expanding its non-fossil energy sources to the range of policies its government has implemented, including generous subsidies to incentivise developers as well as regulations to put pressure on provincial governments and generating companies.

China began operating the world's largest hybrid solar-hydro power plant in the Tibetan plateau on Sunday. Named Kela, the plant can produce 2bn kW hours of electricity annually, equal to the energy consumption of more than 700,000 households.

It is only the first phase of a massive clean energy project in the Yalong River basin. The installation has a 20GW capacity now and is expected to reach about 50GW by 2030.

Despite China's careful planning, its energy transition is not without its challenges. In recent years, record heatwaves and drought crippled hydropower stations, resulting in power crunches that brought factories to a halt. An outdated electricity grid and inflexibility in transferring energy between regions add to the uncertainty.

The Kela plant is located in the sparsely populated west of the country, where more than three-quarters of coal, wind and solar power is generated. But the vast majority of energy consumption happens in the east. Transporting energy thousands of miles across the country results in inefficiencies.

The way China's grid is organised can incentivise building coal plants around renewable generators. Much of the new renewable capacity is not connected to the local energy supply and often bundled with coal power to be transmitted to areas of higher demand.

More coal power was approved in the first three months of 2023 than in the whole of 2021.

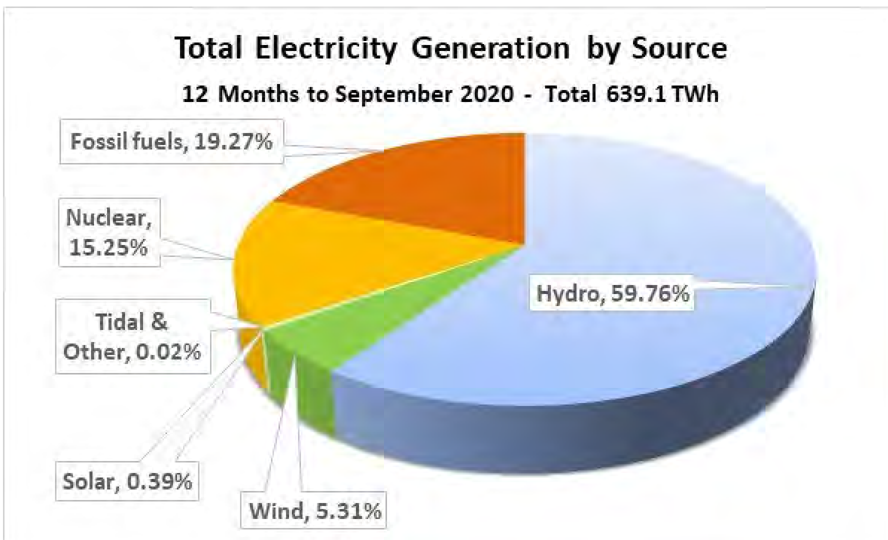
"China is making strides," said Martin Weil, a researcher at Global Energy Monitor and an author of the report. "But with coal still holding sway as the dominant power source, the country needs bolder advancements in energy storage and green technologies for a secure energy future."

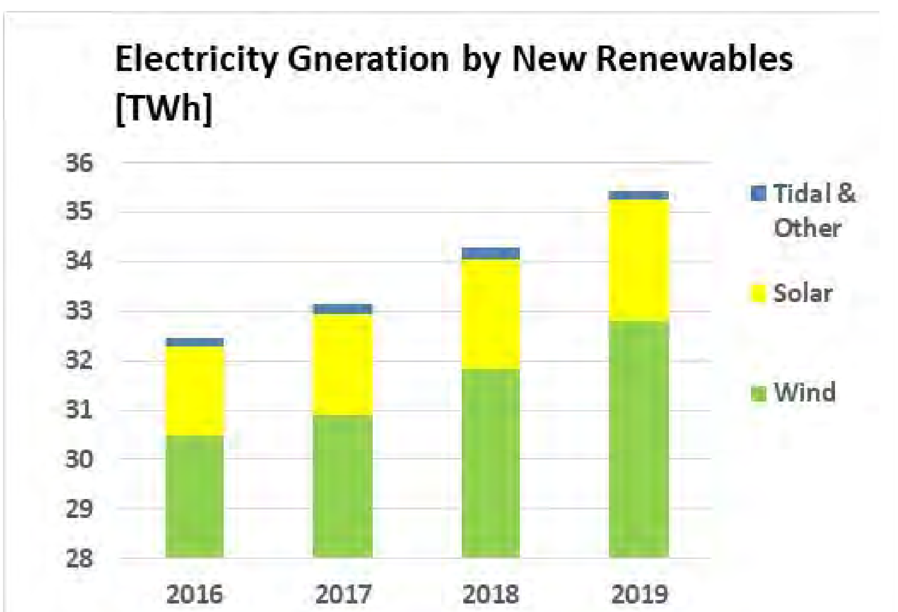
Renewable Energy – Canada

International Trade Administration, 2021

Executive Summary

Canada is one of the world's leading countries in using clean, renewable energy. Approximately 65% of the total electricity generation in 2019 was sourced from hydro, wind, solar, and other sources such as biomass, geothermal and marine/tidal wave energy. Hydro power is historically Canada's main source of energy, providing around 60% of the electricity. New renewable sources - wind, solar, tidal waves and others – have the highest growth rate and are projected to reach 12% of total power generation by 2035, according to the Canada Energy Regulator (CER).





(Source: Statistics Canada)

Total electricity generation has been relatively stable in recent years, around 640 TWh annually, as steady, slow increases in industrial, commercial, and residential electricity needs have been offset by improved efficiency solutions. A slight annual increase is expected for the coming years. Canada's total installed electricity generation capacity from all sources was approximately 135 GW in 2017 and is projected to reach 170 GW by 2035.

Canadian provinces and territories have the authority over their own electrical power systems, and all are pursuing renewable power generation sources. Quebec has 98% of electricity generation from hydro power, while British Columbia, Manitoba, Newfoundland and Labrador, Prince Edward Island and Yukon systems rely on between 89% to 95% hydro.

The renewable energy sector needs, for the maintenance and upgrade of the existing capacities and for further new capacities, are estimated to drive one third of Canada's $20 billion USD total annual imports for the electrical power sector. Around 45% of all Canadian imports for the electrical power sector are from U.S. providing significant opportunities for U.S. exporters.

Current Market Needs

The main market drivers at the macro level are primarily the need for ongoing maintenance and the upgrade of the existing power generation capacities. In addition, slow increase of the total capacity combined with policies and planning for further shifting the generation towards renewable sources supported by all government levels from federal to provincial and local level are also driving the market.

Hydro

Canada has a total installed capacity of over 80,846 MW in over 450 hydroelectric power stations and 200 small hydro plants (less than 10 MW), almost entirely in water accumulation and down the river generation plants. The remaining technical potential that Canada has in building hydro power generation is more than the current installed capacity. New projects of large capacity are already in development or in planning capacities from 500 MW to over 2,000 MW, including:

- Lower Churchill Project on Muskrat Falls and Gull Island in Labrador,
- Site C dam on the Peace River in British Columbia,
- Keeyask on the Nelson River, Manitoba.

Many small hydro plants are also in development. The segment will require hydraulic turbines and electrical generators across the entire range of electrical ancillary equipment and materials used in hydro power stations.

Wind

Wind is Canada's second largest source of renewable energy. Installed wind energy capacity in Canada was 114 MW in 2009. Strong provincial policies and support like the "Fed-in-Tarif" program introduced by Ontario in 2009, led to a steady dynamic growth on an average annual rate of 16% for the last 10 years. Total installed capacity reached 13,413 MW at the end of 2019. There were over 300 operational wind farms in Canada with a total of over 6,770 wind turbines. 37 wind farms have at least 100 MW capacity, including three with over 300 MW capacity each. Almost all are on shore and grid connected wind farms. The leading provinces for wind power generation are Ontario (5,436 MW), Québec (3,882 MW), and Alberta (1,685 MW).

The market is expected to continue to grow in 2020 – 2025 by an average annual rate of 5% (Source: CanWEA – Canadian Wind Energy Association). For the forecasted annual growth, the market will need all types of equipment and components from wind turbines and wind driven electrical generators, to all ancillary components and materials.

Solar

The total solar photovoltaic (PV) power installed capacity for electricity generation was approximately 3,700 MW in over 44,000 installations by the end of 2019. Note that all installed power capacities are in direct current (DC). That is combined from 2,600 MW in centralized installations (feeding only directly to the grid) and 1,100 MW of distribution installations which also consume for individual needs. The majority are connected to the low voltage grids and only about 15% to high voltage grids. For off grid installations, there is no available data. PV generation is located mainly in Ontario with about 3,000 MW, and the rest in all other provinces, each having under 25 MW, except British Columbia and Alberta.

According to the former National Energy Board, recently renamed Canada Energy Regulator, Canada's future renewable energy capacity is expected to grow with wind capacity doubling and solar capacity more than tripling by 2040 (Source: CanSIA – Canadian Solar Industries Association). For the forecast increased capacity, the market will need all types of components from PV cells/ panels and inverters to all ancillary operational components and materials for grid or local distribution connection. Similar needs are also for the maintenance of the existing installations.

Energy Storage and Combined Projects

Energy storage projects were initiated in Canada for the past several years and there are already local significant players in this segment, developing various technologies from battery storage to dynamic (flywheel) solutions. An important trend in discussion is between the wind, solar and storage industries in developing combined projects.

Other Energy Sources

This market segment needs a variety of specialized equipment and ancillary component and materials.

- Tidal Wave Energy: A longtime initiative. Canada has a research project for electricity generation from tidal waves in the Bay of Fundy, Nova Scotia. At present, the project is developed by a not-for-profit consortium led by the provincial government, Fundy Ocean

Research Center for Energy (FORCE), which determined that approximately 2,500 MW may be extracted from the 8,000MW of kinetic resource of the Bay of Fundy. The project is budgeted at about $40 million. The federal government provided a grant covering roughly half of the budget.

- Geothermal Energy: Only in initial phase. In Canada there are 18 projects in development, mainly at the research stage. A detailed listing is available from the industry association.
- Biogas and Renewable Natural Gas (RNG): Operational and initiate projects in Canada have a total capacity of 196 MW, of which approximately 50% are used for electricity generation and the rest mainly for combined electricity and heat (co-generation) and heat only.
- Biomass: Produced in 47 facilities located in Canada in all provinces coast to coast. 2 new plants are in construction and 6 others are in planning.

‘Global China’ is a Big Part of Latin America’s Renewable Energy Boom, but Homegrown Industries and ‘Frugal Innovation’ are Key

By Zdenka Myslikova, Nathaniel Dolton-Thornton, and The Conversation

Published July 8, 2023 in Fortune

The story of renewable energy’s rapid rise in Latin America often focuses on Chinese influence, and for good reason. China’s government, banks and companies have propelled the continent’s energy transition, with about 90% of all wind and solar technologies installed there produced by Chinese companies. China’s State Grid now controls over half of Chile’s regulated energy distribution, enough to raise concerns in the Chilean government.

China has also become a major investor in Latin America’s critical minerals sector, a treasure trove of lithium, nickel, cobalt and rare earth elements that are crucial for developing electric vehicles, wind turbines and defense technologies.

In 2018, the Chinese company Tianqi Lithium purchased a 23% share in one of Chile’s largest lithium producers, Sociedad Química y Minera. More recently, in 2022, Ganfeng Lithium bought a major evaporative lithium project in Argentina for US$962 million. In April 2023, Brazilian President Luiz Inacio Lula da Silva and Chinese President Xi Jinping signed around 20 agreements to strengthen their countries’ already close relationship, including in the areas of trade, climate change and the energy transition.

China’s growing influence over global clean energy supply chains and its leverage over countries’ energy systems have raised international concerns. But the relationship between China and Latin America is also increasingly complicated as Latin American countries try to secure their resources and their own clean energy futures.

Alongside international investments, Latin American countries are fostering energy innovation cultures that are homegrown, dynamic, creative, often grassroots and frequently overlooked. These range from sophisticated innovations with high-tech materials to a phenomenon known as “frugal innovation.”

Chile Looks to the Future

Chile is an example of how Latin America is embracing renewable energy while trying to plan a more self-reliant future.

New geothermal, solar and wind power projects – some built with Chinese backing, but not all – have pushed Chile far past its 2025 renewable energy goal. About one-third of the country is now powered by clean energy.

But the big prize, and a large part of China’s interest, lies buried in Chile’s Atacama Desert, home to the world’s largest lithium reserves. Lithium, a silvery-white metal, is essential for producing lithium ion batteries that power most electric vehicles and utility-scale energy storage. Countries around the world have been scrambling to secure lithium sources, and the Chilean government is determined to keep control over its reserves, currently about one-half of the planet's known supply.

In April 2023, Chile's president announced a national lithium strategy to ensure that the state holds partial ownership of some future lithium developments. The move, which has yet to be approved, has drawn complaints that it could slow production.

However, the government aims to increase profits from lithium production while strengthening environmental safeguards and sharing more wealth with the country's citizens, including local communities impacted by lithium projects. Latin America has seen its resources sold out from under it before, and Chile doesn't intend to lose out on its natural value this time.

Learning from Foreign Investors

Developing its own renewable energy industry has been a priority in Chile for well over a decade, but it's been a rough road at times.

In 2009, the government began establishing national and international centers of excellence – Centros de Excelencia Internacional – for research in strategic fields such as solar energy, geothermal energy and climate resilience. It invited and co-financed foreign research institutes, such as Europe's influential Fraunhofer institute and France's ENGIELab, to establish branches in Chile and conduct applied research. The latest is a center for the production of lithium using solar energy.

The government expected that the centers would work with local businesses and research centers, transferring knowledge to feed a local innovation ecosystem. However, reality hasn't yet matched the expectations. The foreign institutions brought their own trained personnel. And except for the recently established institute for lithium, officials tell us that low financing has been a major problem.

Chile's Startup Incubator and Frugal Innovation

While big projects get the headlines, more is going on under the radar.

Chile is home to one of the largest public incubators and seed accelerators in Latin America, StartUp Chile. It has helped several local startups that offer important innovations in food, energy, social media, biotech and other sectors.

Often in South America, this kind of innovation is born and developed in a resource-scarce context and under technological, financial and material constraints. This "frugal innovation" emphasizes sustainability with substantially lower costs.

For example, the independent Chilean startup Reborn Electric Motors has developed a business converting old diesel bus fleets into fully electric buses. Reborn was founded in 2016 when the national electromobility market in Chile was in its early stages, before China's BYD ramped up electric bus use in local cities.

Reborn’s retrofitted buses are both technologically advanced and significantly cheaper than their Chinese counterparts. While BYD’s new electric bus costs roughly US$320,000, a retrofitted equivalent from Reborn costs roughly half, around $170,000. The company has also secured funding to develop a prototype for running mining vehicles on green hydrogen.

Bolivia’s “tiny supercheap EV” developed by homegrown startup Industrias Quantum Motors is another example of frugal innovation in the electric vehicles space. The startup aspires to bring electric mobility widely to the Latin American population. It offers the tiniest EV car possible, one that can be plugged into a standard wall socket. The car costs around $6,000 and has a range of approximately 34 miles (55 kilometers) per charge.

Phineal is another promising Chilean company that offers clean energy solutions, focusing on solar energy projects. Its projects include solar systems installation, electromobility technology and technology using blockchain to improve renewable energy management in Latin America. Many of these are highly sophisticated and technologically advanced projects that have found markets overseas, including in Germany.

Looking Ahead to Green Hydrogen

Chile is also diving into another cutting-edge area of clean energy. Using its abundant solar and wind power to produce green hydrogen for export as a fossil fuel replacement has become a government priority.

The government is developing a public-private partnership of an unprecedented scale in Chile for hydrogen production and has committed to cover 30% of an expected $193 million public and private investment, funded in part by its lithium and copper production. Some questions surround the partnership, including Chile’s lack of experience administering such a large project and concerns about the environmental impact. The government claims Chile’s green energy production could eventually rival its mining industry.

With plentiful hydropower and sunshine, Latin America already meets a quarter of its energy demand with renewables – nearly twice the global average. Chile and its neighbors envision those numbers only rising.

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Renewable Energy in Singapore: Resources, Plan, and Strategy

20 June 2022 – by Eric Koons; Last updated on 31 July 2023

Over 95% of the energy currently consumed in Singapore is from LNG and oil. However, the country has robust renewable energy targets for the next several decades, largely driven by local solar energy production and importing clean energy from neighbouring countries.

Renewable energy in Singapore is produced in a liberalised energy market, meaning that most, if not all, of its energy investments are commercial. However, as Singapore resumes its production in the post-COVID era, energy demand in the Singapore is rising, along with climate change concerns, and production needs to increase. This is fueled, in part, by the electrification of the transportation segment. Additionally, the high initial investment for developing renewable energy systems keeps solar PV systems investments relatively low.

We are hopeful that the country's changing renewable energy policies will create a shift in its energy investment profile. The rise in its carbon tax from S$5 to S$10-15 per tCO2e by 2023 will drive this change. As a result, the carbon tax should reshape commercial investment in the energy market to favour renewable energy sources.

Singapore's Current Energy Mix in 2023 – Natural Gas and Solar Energy Systems

For most of its energy security and production, Singapore relies on liquefied natural gas (LNG) and oil. On the other hand, Singapore's renewable energy initiative is led by solar power. Singapore has reached its target of 350 MWp solar production (its 2020 green energy agenda goal) and is targeting 2 GW by 2030.

Energy Source Classification	Energy Source	Total Production Capacity in 2021	Percent Change 1965-2021
non-renewable	coal	0.00 TWh	not available*
non-renewable	oil	1.58 TWh	-89%
non-renewable	LNG	50.30 TWh	+250%
green, non-renewable	nuclear	0.00 TWh	not available*
renewable	solar	0.72 TWh	not available*
renewable	wind	0.00 TWh	not available*
renewable	hydropower	0.00 TWh	not available*
renewable	other renewables	0.41 TWh	not available*

Source: Our World In Data ** – the resource was not or is not being utilized*

Singapore's Energy Mix Over Time

Singapore is undertaking bold steps to reduce its carbon footprint and increase renewable energy capacity. Firstly, Singapore altered its energy capacity by switching from oil to natural gas. This effectively brought down the carbon emissions by 30%.

Secondly, solar power is being brought into Singapore's energy mix. With a total expected solar capacity of around 2 GW by 2030, Singapore is seriously rethinking its electricity generation and is moving towards renewable energy options.

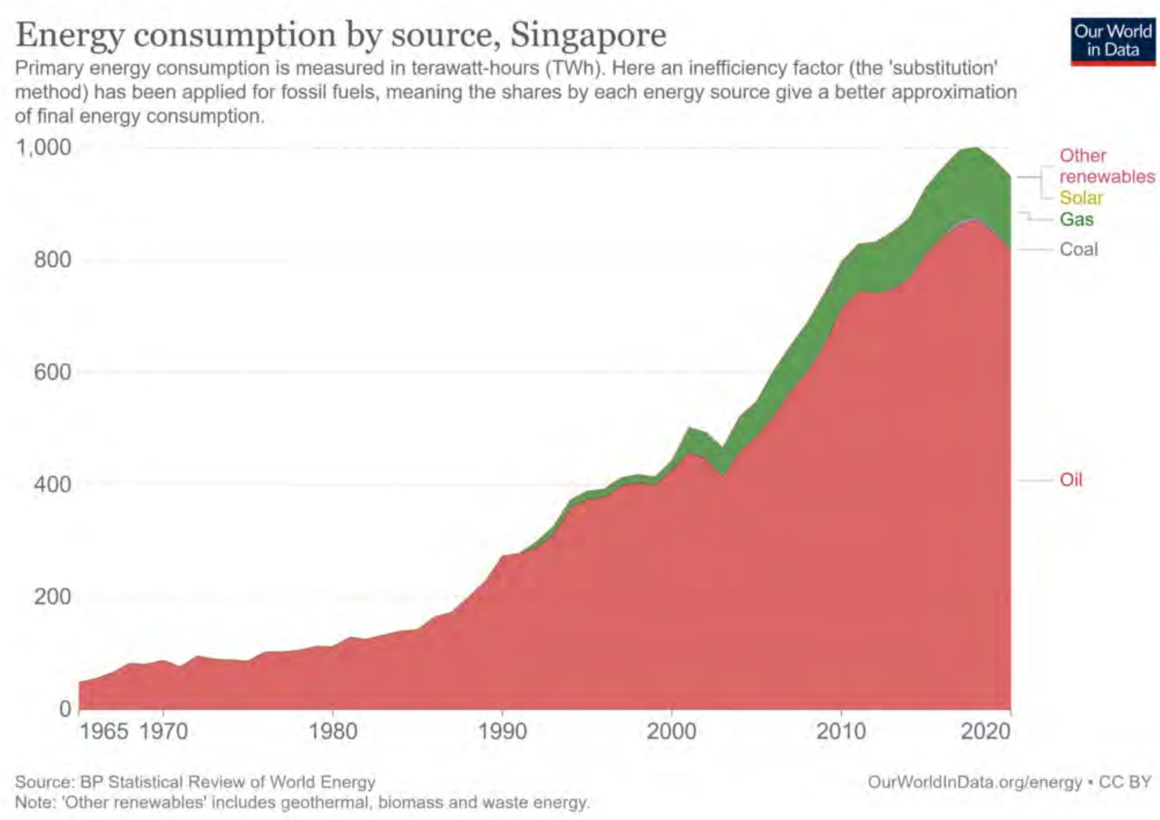
Thirdly, Singapore aims to connect with regional power grids to access cost-effective clean energy. This is already underway with the Singapore-Australia Sun Cable, which will supply 15% of Singapore's energy needs (or 30GW).

Finally, hard-to-decarbonise industries will harness carbon capture and storage/utilisation (CCSU) technologies to meet greenhouse gas emissions targets.

Singapore Renewable Energy Percentage

Due to various reasons, there has been minimal investment in renewable energy in Singapore in recent decades. As of 2020, solar energy only accounted for 0.08% of the country's total energy consumption, while fossil fuels like oil and natural gas accounted for around 98%.

Furthermore, the Singapore-Australia Sun Cable will likely change this ratio in favour of solar, but construction will not start until 2024.

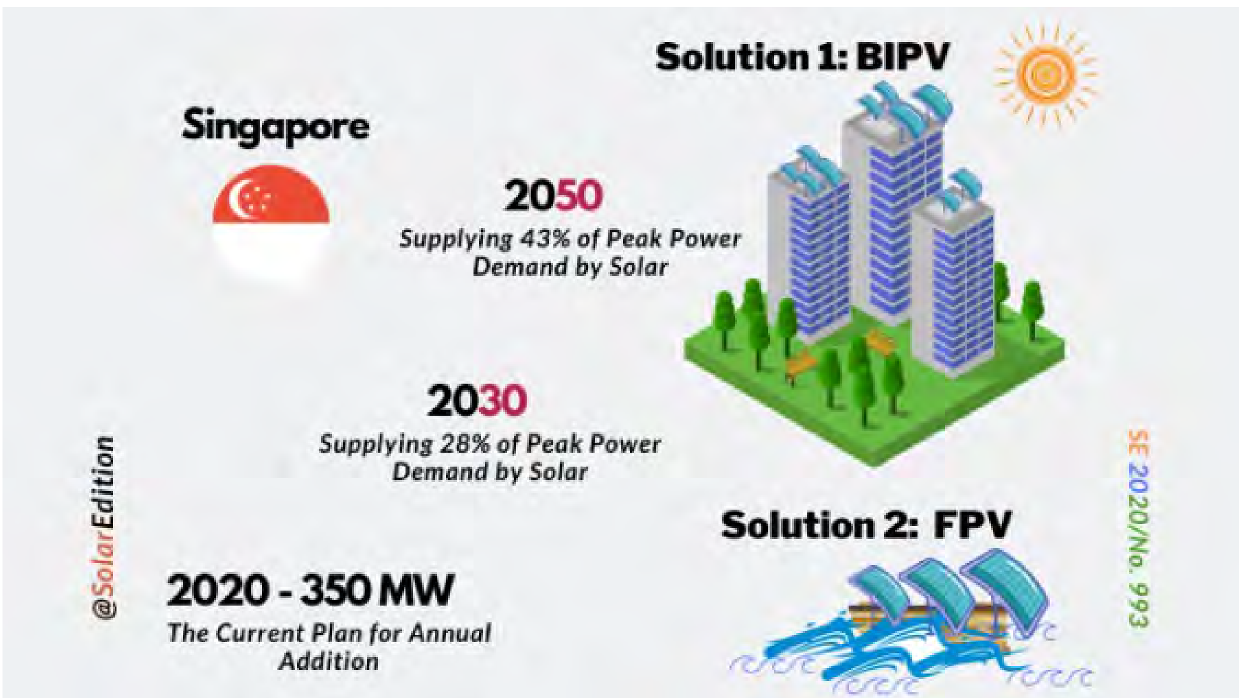


Solar Energy in Singapore Is Leading The Way

Only a few types of renewable energy are viable in Singapore. The country has a very small amount of land, with low wind speeds and large ports limiting tidal energy potential. Therefore, solar is leading the way in Singapore, although there is a small amount of land available for deploying solar panels. Moreover, further investments in solar energy production, international energy generation and regional grids for clean electricity importation are critical to sustainable renewable energy growth.

What is Singapore’s Renewable Energy Plan?

In addition to bringing online 2 GW of domestic solar production by 2030, Singapore plans on supplying 30% of its energy needs with low-carbon imports by 2035. In addition to solar, many other renewable energy options are being thrown around. For example, Sembcorp Industries is introducing a green hydrogen (decarbonised) production facility in the country.



Renewable Energy Singapore: A Changing Policy Landscape Will Spur Growth

The pro-renewable energy agenda ensures that investments in Singapore’s renewable energy sector are fully utilised. It also ensures future renewable investment for both the residential and non-residential sectors. So, with the current energy mix largely dependent on oil and LNG, many changes will be in the coming decades.

The Role of Citizens in Producing and Consuming Their Own Renewable Energy

Susanne Hirschmann – Som Energia, European Institute of the Mediterranean – 2023

Climate change has reached the Mediterranean region, which now has to face enormous problems. Since 1950, the air temperature in Catalonia has increased by more than 1.6ºC, rivers have run dry and hitherto unknown insects such as the tiger mosquito are appearing (Generalitat de Catalunya, 2016). To stop this, carbon dioxide emissions must be radically lowered. By using clean energy sources like wind, water, biomass and the sun and reducing our energy demand with energy efficiency measures, carbon dioxide emissions can be avoided and climate change can be decelerated. Therefore, the transition from fossil fuels to renewable energies is unquestionably the solution that must be put into practice as soon as possible. But the remaining question is: who will be the main player in this new power game that will change the energy system, big companies or the people?

Power to, by and from the People

A real change in the energy system means power to the people. A decentralised energy production with, on the one hand, wind parks, solar fields owned by a group of people and efficient use of urban spaces to cover the energy demand in crowded areas and, on the other, smaller installations owned by individuals to cover the demand in the rural sector. This means citizens generating their own energy because who, if not consumers themselves, better understands their energy needs? There are several powerful reasons why people must be involved in taking important decisions about the future of our energy. First, by producing our own energy we will get a feeling for energy. With the decoupling of energy production and energy consumption that took place in the early industrialisation period, we lost the ability to determine the amount of energy needed to sustain our standard of living. How much energy do we need to cover our energy demand, is our energy consumption sustainable or should we lower the amount of energy we are consuming every day? When energy comes only from power plants it is nearly impossible to see the impact of these plants on nature, such as big coal mines destroying thousands of hectares of fertile land. By producing electricity on our own roof our vision of energy surely will change and we can understand what the kilowatt-hours on our electricity bill really mean. Second, lack of acceptance is one of the big problems renewables are facing: renewables, yes, but not in my own backyard. Most people do not want to live next to huge wind parks or giant solar fields but this opinion often goes hand in hand with big installations that are planned without asking or informing anyone living in the affected area. People who have decided that the energy they are consuming should come from renewable power plants as near as possible will have another perspective on renewables. They will see the need for this investment and will also benefit from the power plants as they will be the owners of the installations. Jobs and money will stay local.

People who have decided that the energy they are consuming should come from renewable power plants as near as possible will have another perspective on renewables

But there is more to it than that. The discussion is not only about people's own backyards, it is about a new society that will blossom into a paradise of participation and a firmly imbedded feeling for democracy. For instance, to provide a platform to work together and achieve more participation, cooperatives can be created. In 2006, Som Energia was the first renewable energy source cooperative (REScoop) to sell renewable energy to its members in Spain. REScoop refers to a business model where citizens jointly own and participate in renewable energy or energy efficiency projects. Now there are already more than ten cooperatives in the Iberian Peninsula pursuing the same goals. The most important aspect of cooperatives is the concept: it is not about money, it is about people. These people take decisions together democratically, invest in renewable energy projects, generate their own energy and thereby ensure that the money stays local. Now there are many more cooperatives pulling in the same direction, decentralising and changing energy systems towards renewables and giving power back to those the energy belongs to: the people.

Güssing: How Participation and Political Willingness Changed the Austrian Region for the Better

The example of Güssing, a town in Austria with approximately 27,000 inhabitants, is a success story about how locally-generated energy can benefit the whole region and its community and why a favourable legal framework is important to promote renewables.

In 1988, the region of Güssing was one of the poorest regions in Austria. With high unemployment rates, rural depopulation, young people leaving the town to find work in Vienna and the high cost of covering energy needs for electricity, heating and mobility, the region had to face problems similar to those of the region of Castile and León in Spain, with one of the highest exodus rates in the country. To make the situation worse, there was a lack of infrastructure as no train or highway passed nearby so it was not attractive for business to settle in this region. To solve these problems, Güssing decided to work out the details of a new energy concept, based mainly on biomass with 100% renewables, to become self-sufficient. With this positive change in political opinion a favourable legal framework was developed to clear the way for energy produced regionally for and by the people. Without a stable framework and the political willingness to let participation and innovative projects happen, Güssing would not have had the chance to develop as it has done so far. The first step was the implementation of an energy efficiency programme including new insulation of buildings and optimising heating systems. Due to these measures, the energy needs of the town hall decreased by more than 50%. Later, the town started to invest in a biomass gasification plant, which led to energy self-sufficiency. This plant is powered by wood that surrounds the city and is available in abundance. At present, Güssing produces more energy from renewable sources than is consumed in the town annually. The region can benefit from the electricity sold, the district heating system and the biodiesel, which brings an added value of 13 million euros per year. As the infrastructure was improved, more businesses started to be interested in this region and there are now 50 new enterprises with more than 1,000 direct or indirect jobs in the renewable energy sector (bmvit, 2007). People are involved and money stays local and can be reinvested in local projects (Vansintjan, 2015).

Güssing is a good example of a town achieving self-sufficiency, but relying on biomass is not the only way people can produce and consume their own renewable energy.

The Spanish Sun and the Spanish Problem with Self-Consumption

In Spain it is interesting to widen the horizon to how solar energy can be used for self-consumption in the future. The latest publication about self-consumption from the European Commission clearly points out that self-consumption of PV (photovoltaic) energy is going to be one of the new cores of EU energy policy and therefore this should include Spain. To achieve the goal of greater self-consumption by European citizens the legal situation in some countries must be changed because some governments are building barriers to avoid this development towards a democratic energy system (European Commission, 2015). “Self-consumption of PV energy” is defined by the European Photovoltaic Industry as “the possibility for any kind of electricity consumer to connect a photovoltaic system, with a capacity corresponding to his consumption, to his own system or to the grid, for his own or for on-site consumption” (Roesch, 2013). Self-consumption seems to be easy to achieve and, together with other additional drivers for change in current energy systems, something which should be supported. Some countries, such as Denmark or Germany, are already in the fast lane to achieving the glorious objective of “power to the people”, but is this also a reality in Spain or just a utopia? Crossing Germany by car means passing through lovely villages, in which even church rooftops are covered by solar panels, and driving by huge solar fields and wind parks along the road. In Spain it seems that only tourists getting burnt on the beach are benefiting from the high solar irradiation, but it is rare to see solar panels in public. It is a big opportunity that Spain is missing. Nearly one and a half times the size of Germany, with just half of its population and global irradiation rates much higher than in northern European countries, Spain could easily be one of the role models for the energy transition but it is squandering this golden opportunity. Even though solar energy is very attractive because of the economic benefit of the installation, it is not very popular in Spain. The cost of solar power is decreasing and becoming more affordable. In 2010 the price was €2/Wp (Fraunhofer ISE, 2015) and today the average price of Multi-Si Modules has dropped down to €0.36/Wp. At the same time, energy bills are rising in many countries and the future price development seems to be following this trend. Between 2005 and 2015 the price of electricity in Europe rose by about 10 cents and in Spain and Germany prices even doubled, which should make renewables even more attractive. But it seems that the Spanish government does not share the same ideology and prefers to block this movement. In the last few years, instead of moving forward, the legal situation for cooperatives, small-scale consumers and producers of renewable energy has become increasingly precarious. The fixed charges on electricity bills rose, meaning saving energy no longer reduces the bill and small consumers pay higher prices than big consumers who do have variable charges. But energy efficiency is still the best way to save energy because the best kWh is the one that is not consumed. Installing solar panels on a roof legally involves so much paperwork and time that people get frustrated and do not even try to become prosumers. Last but not least, laws such as Royal Decree 900/2015, which is the basis of the so-called “sun tax”, reinforces stigmas and fears that self-consumption is illegal and it is better to avoid this technology. The Spanish government should change direction as there are so many good self-consumption projects just waiting for their opportunity to develop and spread across the country. Some will be explained here. There are two main ways to achieve self-consumption: as an individual or a group.

A Glimpse into the Future: Prosumers Connected Through Virtual Power Plants Will Rule the Energy Market

For a glimpse into the future of a decentralised energy system, consisting of solar panels and intelligent connected batteries, we need only look at the intelligent battery provider Sonnenbatterie and the sonnenCommunity. Members of this community can generate their own power, store it with an intelligent storage system and share surpluses online with friends or other members. This community is able to partly replace the traditional power companies as it consists of decentralised energy production and not merely providing energy from central power stations. The benefits are obvious. Members are independent of established electricity providers, have significantly lower energy costs and receive the surplus energy from other members for free. Even the problem of costly grid expansion is partly solved by direct marketing in the region and even between neighbours or small residential systems. Three technologies are combined in this visionary idea: decentralised power generation, advanced battery storage technology and digital networking. Therefore, a virtual energy cloud can be created and controlled by self-learning software that connects the members with the community. This software can make predictions about how much energy will be produced and how this energy has to be distributed to cover the whole demand of the sonnenCommunity (Sonnenbatterie GmbH 11/25/2015). Systems like these are part of so-called virtual power plants. Virtual power plants are relatively new energy management systems. They distribute and coordinate in real time the energy production of different energy sources and the actual energy demand. So wind turbines, hydroelectricity, small scale PV and batteries provide a stable energy supply. For instance, when one consumer who is producing PV electricity has run out of energy he will get access to other sources of energy, such as electricity produced by his neighbour's wind turbine. The energy can be provided at lower costs, it is more flexible and there is less energy loss because of the shorter transportation. The idea of an energy community is not unique but the example of sonnenCommunity clearly shows what the future will bring and how important the role of citizens in the new energy system will be. There is still a long way to go to turn this idea into reality in Spain. Because of the high bureaucracy barriers imposed by the government, few people even think about installing their own solar system. Furthermore, shared energy consumption is still a difficult topic in Spanish legislation.

Generation kWh: The Solution for Collective Self-Consumption

But what about all the others who do not own a house, a roof or land for solar installations? Is there a way for renters to take control of their destiny and produce and own their own energy? Helen Keller once said "alone we can do so little, together we can do so much" and she is absolutely right. One example of how we can do so much together is provided by Som Energia. The project "Generation kWh" plays on the two meanings of the word generation: a new generation of people standing up for their rights to own their own energy plants and the idea of producing green electricity. Feed-in-tariffs fulfilled the function of making renewables more attractive and ensuring their profitability in the long term and creating a stable environment to invest in them. As the rapidly changing legal situation in Spain made investments in renewables very risky, this stable environment could not be created and there was stagnation in the renewable energy sector. Therefore, Som Energia started the project Generation kWh, which asserts that self-consumption is still possible even without government funding. Every member 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 been illegal according to Royal Decree 900/2015 (Tribunal Constitucional de España, 2 June 2017).

Azimut: Tenants of a Whole Building are Joining Forces to Produce their Own Energy

The PV installation does not necessarily have to be owned by the supplier. The tenants themselves (with the permission of the owner) can pay for the installation and be consumer and producer of their own energy at the same time. In spring 2017 the Azimut 360 cooperative located in Barcelona presented its pilot project Agrupación de Consumos (joint consumption). Their main objective in this project is to carry out a PV installation on a rooftop of a multi-family building and link all the electricity meters to one single meter. The electricity will be distributed to the different parties living in the building and with an internal electricity meter they can manage billing themselves. This change will lower the building’s peak load and provide savings on the energy bill. Moreover, the electricity generated by the solar panels can cover a significant amount of the daily energy demand. As there are more households with different habits the energy demand will be more balanced. The tenants must work together, cooperate and make decisions about how to carry out the installations and how energy should be distributed. Projects like these help to build community and make people feel responsible for their habits according to their electricity consumption because it is not your own electricity but belongs to the whole community (azimut360, 2017).

Citizens Will Bring About Renewables: Self-Consumption is Necessary

With these inspiring examples and role models with so many people involved one thing is clear: self-consumption of renewables should not be illegal, it is necessary and must be driven by the people. But how can we bring this about? With less bureaucracy, lower prices and more publicity in favour of renewables and energy efficiency we could move towards a better future. What is needed is a change in the Spanish energy policy because it does not represent the will of the people, which should be the basis of the government’s authority. And the will of the people is democracy, including in the energy sector.

United States
Primary Consumption of Energy
by Fuel Type and Sector, 2020

Figure 2-1a. United States Primary Consumption of Energy

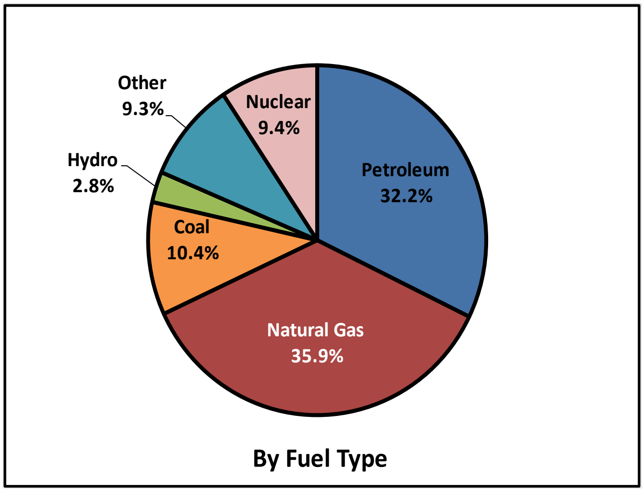


Figure 2-1b. United States Primary Consumption of Energy

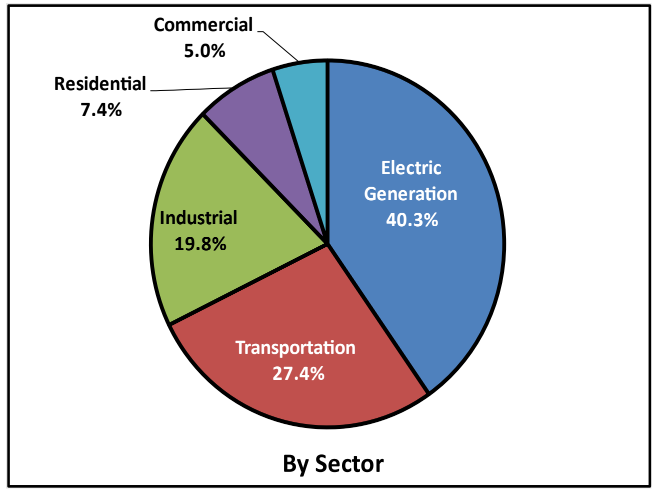


Table 2-1. (In Trillion Btu)

	Residential TBtu	Commercial TBtu	Industrial TBtu	Transportation[1] TBtu	Net Consumption TBtu	Electric Generation[2] TBtu	Primary Consumption[3] TBtu
Coal	0	14	939	0	954	8,229	9,183
Natural Gas	4,876	3,304	10,304	1,096	19,579	12,011	31,590
Petroleum Products:	913	852	4,625	21,787	28,177	184	28,362
Distillate	407	276	1,065	6,183	7,931	44	7,975
Residual	0	2	32	391	426	53	478
Kerosene	11	2	3	0	16	0	16
LPG	495	201	3,256	5	3,956	0	3,956
Gasoline	0	371	269	14,243	14,883	0	14,883
Jet Fuel	0	0	0	2,254	2,254	0	2,254
Other[4]	767	266	1,565	1,289	3,886	1,340	5,226
Electric Sales	4,997	4,393	3,272	22	12,685		
Net Consumption	11,553	8,829	20,706	24,194	65,281		
					Hydro Electricity	2,492	2,492
					Nuclear Electricity	8,248	8,248
					Wind Electricity	2,958	2,958
					Primary Consumption	35,462	88,058

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1 Components of petroleum may not sum to petroleum total because ethanol values ("Other" category in transportation sector) are embedded in motor gasoline.

2 Hydro and wind are excluded from the "Other" category and listed separately.

3 Excludes petroleum products not used as a form of energy.

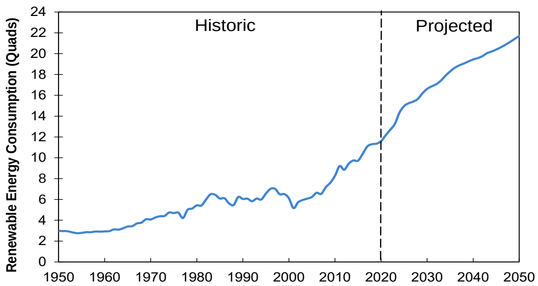
4 "Other" includes wood, waste, ethanol, landfill gas, solar, geothermal, and biodiesel.

U.S. Renewable Energy

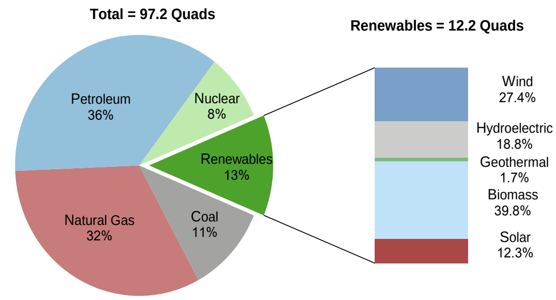
Patterns of Use

While energy is essential to modern society, most primary sources are unsustainable. The current fuel mix is associated with a multitude of environmental impacts, including global climate change, acid rain, freshwater consumption, hazardous air pollution, and radioactive waste. Renewable energy has the potential to meet demand with a much smaller environmental footprint and can help to alleviate other pressing problems, such as energy security, by contributing to a distributed and diversified energy infrastructure. About 79% of the nation's energy comes from fossil fuels, 8.4% from nuclear, and 12.5% from renewable sources. In 2019, renewables surpassed coal in the amount of energy provided to the U.S. and continued this trend in 2021. Wind and solar are the fastest growing renewable sources, but contribute just 5% of total energy used in the U.S.[1]

U.S. Renewable Energy Consumption: Historic and Projected[1,2]



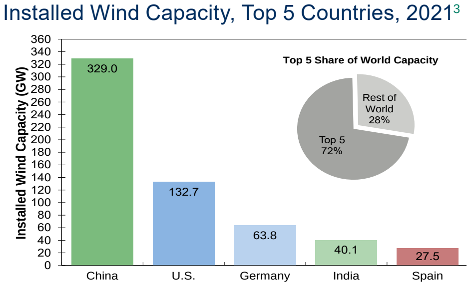
U.S. Total and Renewable Energy Consumption by Source, 2021[1]



Major Renewable Sources

Wind

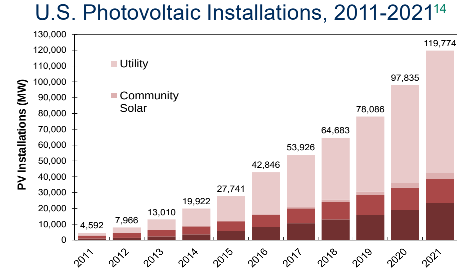
Installed Wind Capacity, Top 5 Countries, 2021[3]



- U.S. onshore wind resources have a potential capacity of almost 11,000 GW and current installed capacity of 132.7 GW.[3,4] Offshore wind resources are potentially 4,200 GW, current capacity is 42 MW, and the development pipeline contained over 28 GW of projects in 2019.[4,5,6]
- Over 16 GW of wind capacity was installed in the U.S. in 2020, a 85% increase from 2019.[7,8]
- The federal production tax credit (PTC) significantly influences wind development, but cycles of enactment and expiration lead to year-to-year changes in investment.[9] In 2020, the PTC was extended to allow wind projects beginning construction in 2020 or 2021 a PTC at 1.5¢/kWh for 10 years of electricity output.[10]
- Based on the average U.S. electricity fuel mix, a 1.82 MW wind turbine (U.S. average in 2019) can displace 3,679 metric tons of CO_2 emissions per year.[11] By 2050, 404 GW of wind capacity would meet an estimated 35% of U.S. electricity demand and result in 12.3 gigatonnes of avoided CO_2 emissions, a 14% reduction when compared to 2013.[12]
- Wind turbines generate no emissions and use no water when producing electricity, but concerns include bat and bird mortality, land use, noise, and aesthetics.[13]

Solar

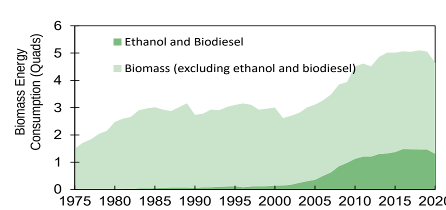
U.S. Photovoltaic Installations, 2011-2021[14]



- Assuming intermediate efficiency, solar photovoltaic (PV) modules covering 0.6% of U.S. land area could meet national electricity demand.[15]
- PV module prices have declined to $0.27/Watt in residential systems.[16] The U.S. manufactured 1% of PV cells and 3% of PV modules globally in 2020.[17]
- In 2021, a new record high of over 23.6 GW of solar photovoltaic capacity was added in the U.S., raising total installed capacity to over 121 GW.[14] Solar accounted for 46% of new generating capacity in 2021.[14]
- The U.S. Department of Energy's SunShot Initiative aims to reduce the price of solar energy 50% by 2030, which is projected to lead to 33% of U.S. electricity demand met by solar and a 18% decrease in electricity sector greenhouse gas emissions by 2050.[18]
- While solar PV modules produce no emissions during operation, toxic substances (e.g., cadmium and selenium) are used in some technologies.[15]

Biomass

U.S. Biomass Consumption, 1975-2021[1]



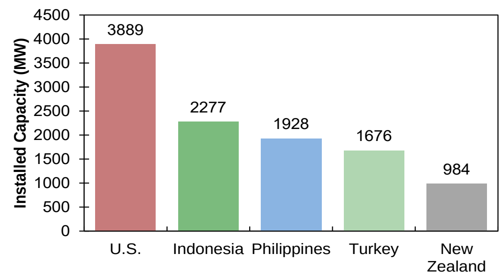
- Wood—mostly as pulp, paper, and paperboard industry waste products—accounts for 43% of total biomass energy consumption. Waste—municipal solid waste, landfill gas, sludge, tires, and agricultural by-products—accounts for an additional 9%.[1]
- Biomass has low net CO_2 emissions compared to fossil fuels. At combustion, it releases CO_2

previously removed from the atmosphere. Further emissions are associated with processing and growth of biomass, which can require large areas of land. Willow biomass requires 121 acres of land to generate one GWh of electricity per year, more land than other renewable sources.[19]

- U.S. ethanol production is projected to reach 54 million gallons per day in 2050.[2]

Geothermal

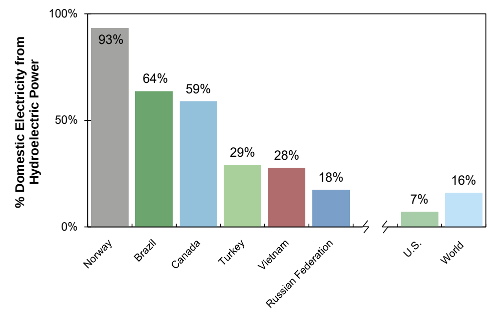
Geothermal Installed Capacity, Top 5 Countries, 2021[20]



- Hydrothermal resources, i.e., steam and hot water, are available primarily in the western U.S., Alaska, and Hawaii, yet geothermal heat pumps can be used almost anywhere to extract heat from shallow ground, which stays at relatively constant temperatures year-round.[21]
- Each year, electricity from hydrothermal sources offsets the emission of 4.1 million tons of CO_2, 80 thousand tons of nitrogen oxides, and 110 thousand tons of particulate matter from coal-powered plants.[22] Some geothermal facilities produce solid waste such as salts and minerals that must be disposed of in approved sites, but some by-products can be recovered and recycled.[21]
- Electricity generated from geothermal power plants is projected to increase from 15.9 billion kWh in 2021 to 47.4 billion kWh in 2050. Geothermal electricity generation has the potential to exceed 500 GW, which is half of the current U.S. capacity.[2,23]

Hydroelectric

Hydropower Electricity Generation, 2019[24]



- In the U.S., net electricity generation from conventional hydropower peaked in 1997 at 356 TWh/yr. Currently, the U.S. gets about 260 TWh/yr of electricity from hydropower.[1]
- While electricity generated from hydropower is virtually emission free, significant levels of methane and CO_2 may be emitted through the decomposition of vegetation in the reservoir.[25] Other environmental concerns include fish injury and mortality, habitat degradation, and water quality impairment. "Fish-friendly" turbines and smaller dams help mitigate some of these problems.[26]

Advancing Renewable Energy

Encourage Supportive Public Policy

- Lawrence Berkeley National Laboratory estimates that 45% of renewable energy growth in the U.S. can be attributed to state Renewable Portfolio Standards (RPS) that require a percentage of electricity be derived from renewable sources.[27] Clean Energy Standards (CES) that mandate certain levels of carbon-free generation can include some non-renewables such as nuclear fuels.[28] Thirty-three states, the District of Columbia, and three U.S. territories had renewable portfolio standards or goals in place as of August 2021.[29] State standards are projected to support an additional 90 GW of renewable electricity projects by 2030.[27]
- Renewable energy growth is also driven by important federal incentives such as the Investment Tax Credit, which offsets upfront costs by 10-30%, as well as state incentives such as tax credits, grants, and rebates.[30]
- Eliminating subsidies for fossil and nuclear energy would encourage renewable energy. Congress allocated over $5.7 billion in tax relief to the oil and gas industries for fiscal years 2020-2024.[31] Studies estimate that the Price-Anderson Act, which limits the liability of U.S. nuclear power plants in the case of an accident, amounts to a subsidy of $366 million to $3.5 billion annually.[32]
- Net metering enables customers to sell excess electricity to the grid, eliminates the need for on-site storage, and provides an incentive for installing renewable energy devices. Thirty-nine states, the District of Columbia, and four U.S. territories have some form of net metering program.[33]

Engage the Industrial, Residential, and Commercial Sectors

- Renewable Energy Certificates (RECs) are sold by renewable energy producers in addition to the electricity they produce; for a few cents per kilowatt hour, customers can purchase RECs to "offset" their electricity usage and help renewable energy become more cost competitive.[34] Around 850 utilities in the U.S. offer consumers the option to purchase renewable energy, or "green power."[35]
- Many companies purchase renewable energy as part of their environmental programs. Microsoft, Google, T-Mobile, Intel, and The Proctor & Gamble Company were the top five users of renewable energy as of April 2022.[36]

kWh = kilowatt hour. One kWh is the amount of energy required to light a 100 watt light bulb for 10 hours.
Btu = British Thermal Unit. One Btu is the amount of energy required to raise the temperature of a pound of water by 1° Fahrenheit.
Quad = quadrillion (10^{15}) Btu. One Quad is equivalent to the annual energy consumption of ten million U.S. households.

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NCF-Envirothon 2024 New York

Current Issue Part A Study Resources

Key Topic #5: Local Action and Energy Equity

19. Identify actions that can be taken on the individual and local level to support renewable energy.
20. Define Energy Justice, and describe its connection to environmental justice and climate justice.
21. Explain the components of Energy Justice and how these interact with the transition to renewable energy.

Study Resources

Resource Title	Source	Located on
How Expensive is it to Switch to Lower-Carbon Energy in My Own Home?	*Kathryn Tso – Ask MIT Climate, 2020*	Pages 176 - 177
Planning for Home Renewable Energy Systems	*US Department of Energy – Office of Energy Efficiency and Renewable Energy, 2023*	Pages 178 - 181
Residential Consumers Can Drive Demand for Green Power	*US Department of Energy and US Environmental Protection Agency, 2018*	Pages 182 - 184
VIDEO: Using Indigenous Knowledge to Tackle Climate Change (2 minutes)	*CBC News – The National, 2022*	Page 185
Community Ownership of Renewable Energy: United States	*Institute for Human Rights and Business, 2022*	Pages 186 - 189
The Energy Justice Workbook	*Initiative for Energy Justice, 2019*	Pages 190 - 199
Energy Justice and the Energy Transition	*National Conference of State Legislatures, 2022*	Pages 200 - 204

<u>Study Resources begin on the next page!</u> ➡

How Expensive is it to Switch to Lower-Carbon Energy in My Own Home?

By Kathryn Tso – Ask MIT Climate – December 1, 2020

If you can afford to make some investments upfront, you may actually save money in the long run by using lower-carbon energy.

If you own your own home and car, you might be looking for big ways to lower your carbon footprint. Solar panels and electric vehicles are two of the most popular, but these are large pieces of high-tech hardware that might seem unaffordable at first glance. But in fact, investments like these could potentially save you money in the long run, says Dr. Apurba Sakti, a research scientist at the MIT Energy Initiative who studies economic and technological aspects of energy storage systems. It's important to "really just look at your options and see what the actual costs would be for making the switch."

First, let's talk about buying clean power directly from the electric grid. Many electric utilities let their customers choose to buy low-carbon electricity from renewable energy sources, often marketed as "green power." Depending on where you live, this can be quite cheap: in 2016, the average added cost was about $16.25 a month to power an average-sized home.1 Even if your utility doesn't give you that option, you can buy "renewable energy certificates" that fund the building of new solar farms and wind turbines.

But these options will always cost at least a little more than your normal electricity bill. Remember, utilities are already trying to make power as cheaply as possible: if adding more solar or wind is cheaper than your normal energy mix, your utility will make those investments on its own. So if you want to lower your carbon footprint while also lowering your electric bill, you may need to install solar panels.

The cost of making energy with solar panels has dropped by roughly 90% since 2011, making this a much more accessible option than it used to be for ordinary homes.2 "Research and global market size are two main factors driving down the cost," says Sakti. Solar cell research has led to more efficient panels that can make much more electricity from the same amount of sunlight. And as solar panels have grown in popularity, more factories invest in manufacturing them, making them cheaper for buyers.

Buying solar panels is still a large upfront expense, but there are ways to offset that cost. For anyone considering solar panels, either to lower their electricity costs or to help combat climate change, Sakti recommends "looking into local incentives and checking how wide the range of options is." Everyone in the U.S. can claim a 26% federal tax credit for the price of installing solar panels, and many states offer additional state tax credits. If that still doesn't bring the cost down to a point you can afford, there is also the option of leasing solar panels instead of buying them outright. "You'll just pay the company a monthly rate for electricity, which is usually lower than what you already have," Sakti says.

Electric vehicles (EVs) are also beginning to fall in price. Many models now sell in the $30,000 range, even before tax credits. This might still be more than you're used to paying for a car, especially if you normally buy used. But you'll also save money on less maintenance, and the fact that electric charging stations are less expensive than filling gas. One factor to keep in mind, says Sakti, is the source of the electricity you’re charging your electric vehicle with. “EVs can have a lower carbon footprint compared to internal combustion engine vehicles, depending on whether the electricity used to charge the batteries come from lower-carbon sources,” says Sakti. In other words, if the electricity in your home still comes from coal power, an electric vehicle might not be the right choice to lower your personal carbon emissions.

Solar panels and electric vehicles are only expected to become more efficient and cheaper in the future. Other potential low-carbon hardware to look into includes electric heat pumps, which can heat your home without natural gas or oil, and home battery systems, to make the most of rooftop solar panels even when the sun isn't shining.

Planning for Home Renewable Energy Systems

US Department of Energy – Office of Energy Efficiency and Renewable Energy – 2023

Planning for a home renewable energy system is a process that includes analyzing your existing electricity use, looking at local codes and requirements, deciding if you want to operate your system on or off of the electric grid, and understanding technology options you have for your site.

Maybe you are considering purchasing a renewable energy system to generate electricity at your home. Although it takes time and money to research, buy, and maintain a system, many people enjoy the independence they gain and the knowledge that their actions are helping the environment.

A renewable energy system can be used to supply some or all of your electricity needs, using technologies like:

- Small solar electric systems
- Small wind electric systems
- Microhydropower systems
- Small hybrid electric systems (solar and wind)

Planning for a home renewable energy system is a process that includes analyzing your existing electricity use (and considering energy efficiency measures to reduce it), looking at local codes and requirements, deciding if you want to operate your system on or off of the electric grid, and understanding technology options you have for your site.

If you're designing a new home, work with the builder and your contractor to incorporate your small renewable energy system into your whole-house design, an approach for building an energy-efficient home.

Analyzing Your Electricity Loads

Calculating your electricity needs is the first step in the process of investigating renewable energy systems for your home or small business. A thorough examination of your electricity needs helps you determine the following:

- The size (and therefore, cost) of the system you will need
- How your energy needs fluctuate throughout the day and over the year
- Measures you can take to reduce your electricity use

Conducting a load analysis involves recording the wattage and average daily use of all of the electrical devices that are plugged into your central power source such as refrigerators, lights, televisions, and power tools. Some loads, like your refrigerator, use electricity all the time, while others, like power tools, use electricity intermittently. Loads that use electricity intermittently are often referred to as selectable loads. If you are willing to use your selectable loads only when you have extra power available, you may be able to install a smaller renewable energy system.

To determine your total electricity consumption:

- Multiply the wattage of each appliance by the number of hours it is used each day (be sure to take seasonal variations into account). Some appliances do not give the wattage, so you may have to calculate the wattage by multiplying the amperes times the volts. Generally, power use data can be found on a sticker, metal plate, or cord attached to the appliance.
- Record the time(s) of day the load runs for all selectable loads.

Considering energy efficiency measures in your home before you buy your renewable energy system will reduce your electricity use and allow you to buy a smaller and less expensive system. For information about determining the overall energy efficiency of your home, see energy assessments.

Local Codes and Requirements for Small Renewable Energy Systems

Each state and community has its own set of codes and regulations that you will need to follow to add a small renewable energy system to your home or small business. These regulations can affect the type of renewable energy system you are allowed to install and who installs it. They can also affect whether you decide to connect your system to the electricity grid or use it in place of grid-supplied electricity as a stand-alone system.

A local renewable energy company or organization, your state energy office, or your local officials should be able to tell you about the requirements that apply in your community. If you want to connect your system to the electricity grid, these groups may also be able to help you navigate your power provider's grid-connection requirements. Here are some of the state and community requirements you may encounter:

- Building codes
- Easements
- Local covenants and ordinances
- Technology-specific requirements

Electrical and building inspectors ensure that your system complies with standards. Building inspectors are interested in making sure the structure you are adding is safe. Your system may be required to pass electrical and/or plumbing inspections to comply with local building codes.

Many building code offices also require their zoning board to grant you a conditional-use permit or a variance from the existing code before they will issue you a building permit. Check with your building code office before you buy a renewable energy system to learn about their specific inspection requirements.

You are most likely to gain the inspector's approval if you or your installer follow the National Electrical Code (NEC); install pre-engineered, packaged systems; properly brief the inspector on your installation; and include a complete set of plans as well as the diagrams that come with the system. In addition, you should be sure your system is composed of certified equipment, and that it complies with local requirements and appropriate technical standards (the links at the bottom of the page provide more information on technical standards).

Easements

Some states permit easements, which are a voluntary, legally binding agreement between owners of adjacent land regarding use of the land. For example, you might seek an easement specifying that no structure which blocks the renewable resource necessary to run a renewable energy system will be built. These agreements are binding regardless of changing land ownership. In addition, you may want to do a title search of your deed to determine if any prior easements or other agreements exist that could prevent you from adding a renewable energy system to your own property.

Local Covenants and Ordinances

Some communities have covenants or other regulations specifying what homeowners can and can't do with their property. Sometimes these regulations prohibit the use of renewable energy systems for aesthetic or noise-control reasons. However, sometimes these regulations have provisions supporting renewable energy systems. Check with your homeowners association or local government for details. In addition, you may want to discuss your intentions with your neighbors to avoid any future public objections.

Grid-Connected or Stand-Alone System

Some people connect their systems to the grid and use them to reduce the amount of conventional power supplied to them through the grid. A grid-connected system allows you to sell any excess power you produce back to your power provider.

For grid-connected systems, aside from the major small renewable energy system components, you will need to purchase some additional equipment (called "balance-of-system") to safely transmit electricity to your loads and comply with your power provider's grid-connection requirements. This equipment may include power conditioning equipment, safety equipment, and meters and instrumentation.

Other people, especially those in remote areas, use the electricity from their systems in place of electricity supplied to them by power providers (i.e., electric utilities). These are called stand-alone(off-grid) systems.

For stand-alone systems, balance-of-system components include batteries and a charge controller in addition to power conditioning equipment, safety equipment, and meters and instrumentation.

Choosing the Right Renewable Energy Technology

To begin choosing the right small renewable electric system for your home, you will need a basic understanding of how each technology works, as well as:

- Renewable energy resource availability
- Economics and costs
- System siting
- System sizing
- Codes and regulations
- Installation and maintenance considerations

Remember that all of these technologies can be used by themselves, combined, or used in conjunction with a fossil fuel system. When these technologies are combined or used with a fossil fuel generator, the result is a hybrid system.

Technology options include solar, wind, microhydropower, and hybrid electric systems (solar and wind).

- Small solar electric systems -- A small solar electric or photovoltaic system can be a reliable and pollution-free producer of electricity for your home or office. Small photovoltaics systems also provide a cost-effective power supply in locations where it is expensive or impossible to send electricity through conventional power lines.
- Small wind electric systems -- Small wind electric systems are one of the most cost-effective home-based renewable energy systems. They can also be used for a variety of other applications, including water pumping on farms and ranches.
- Microhydropower systems -- Microhydropower systems usually generate up to 100 kilowatts of electricity, though a 10-kilowatt system can generally provide enough power for a large home, small resort, or a hobby farm.
- Small “hybrid” solar and wind electric systems -- Because the peak operating times for wind and solar systems occur at different times of the day and year, hybrid systems are more likely to produce power when you need it.

Residential consumers can drive demand for green power

Residential electricity consumers looking to reduce their environmental impacts and increase the demand for cleaner sources of power can contribute to the growing green power industry. Depending on their location, there are several ways that residential electricity consumers can purchase green power and drive demand-side change on the grid.

Renewable Energy Certificates (RECs) are used in the United States to track the delivery and consumption of renewable energy and substantiate all green power generation and use claims, something that would otherwise not be possible on a shared distribution network or utility grid. Each REC represents the environmental attributes associated with one megawatt-hour (MWh) of renewable energy generation, and can be sold together with or separately from physical electricity. These energy attribute certificates include the location and type of generation (e.g. wind, solar, geothermal, hydropower) and any emissions associated with generation source. In aggregate and over time, RECs allow electricity consumers to choose renewable energy, which can drive change in the electricity market through the increased development of renewable energy source to meet increasing REC demand.

All green power purchasing options must include RECs in order for consumers to claim the environmental attributes and use of green power and to have an impact on transforming the market towards cleaner sources of energy. The options below allow consumers to purchase green power from the electric grid without having to install renewable generation equipment themselves, such as rooftop solar photovoltaic panels.

Purchasing Options for Residential Consumers

Purchasing green power through a retail electricity supplier

In some areas of the U.S., residential customers may be able to sign up for an optional green power service to procure a bundled electricity and REC product from their utility or default service provider. These types of default utility provider supply options are called "green pricing programs" and are often structured in a range of ways to include a small premium of up to a few cents per kilowatt-hour above the utility's standard electricity service, be sold in blocks of kilowatt-hours or as a percentage of the consumer's total electricity use at a fixed cost.

In other areas of the country, some residential customers have the option to choose an electricity provider who may not always be their local distribution utility. Consumers that can competitively choose a retail supplier who is not their local distribution utility do so through "green power marketing programs." Consumers will often pay a premium for green power marketing products, though in some regions, competitive green power products may be price competitive with default electricity options.

In either case, suppliers will often offer a range of green power products, allowing customers to choose levels of renewable energy often up to 100% green power. In either case, all green power products involve renewable energy certificates. Many consumers will seek out suppliers and products that are third-party certified (see below).

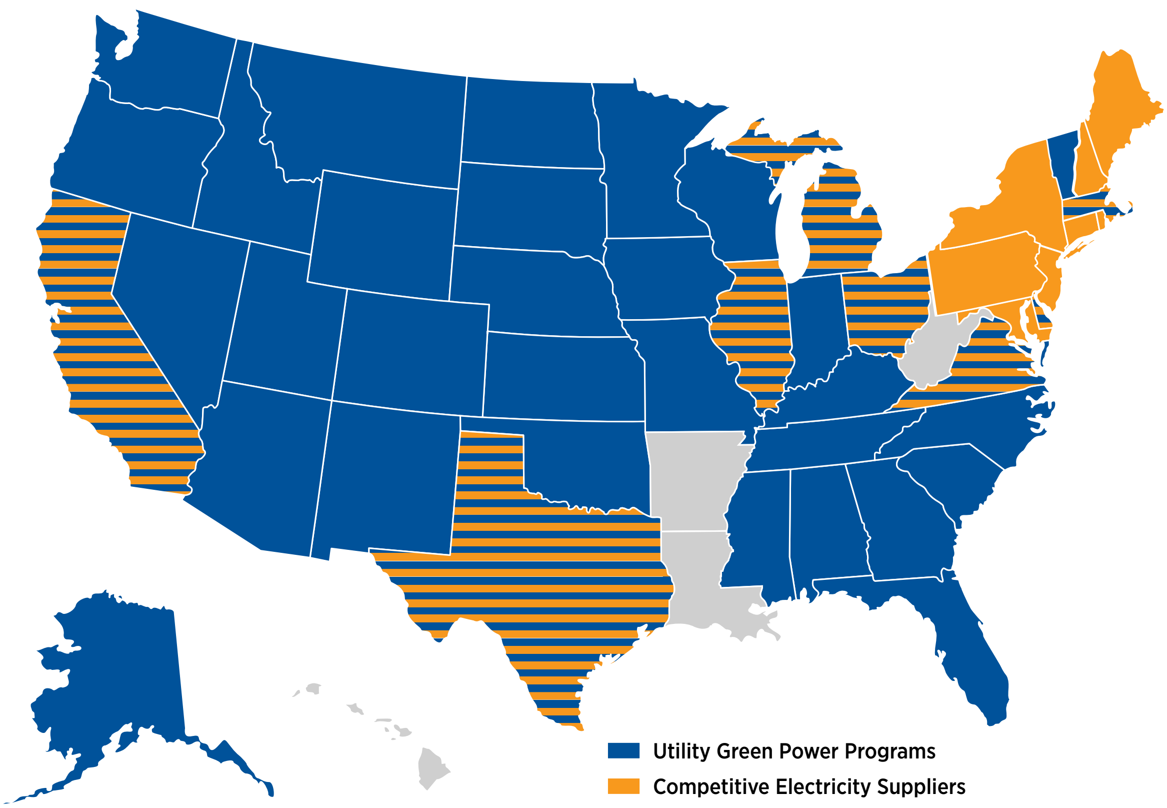
Receiving green power through a community choice aggregation

Some residential customers may be automatically enrolled in a green power option that has formed under a "community choice aggregation." This occurs in a few states where policy or legislation have authorized community choice aggregation, which allows a municipality or local jurisdiction to purchase green power on the behalf of the community at-large. Community choice aggregations are generally structured as an "opt-out" option for residential customers, meaning that residential consumers will receive green power unless they choose to not participate, which tends to be uncommon. Due to the ability of community choice aggregations to drive scale, some customers may receive their green power service at or below standard electricity rates. Residential consumers generally have little to no control over the green power selected under a community choice aggregation approach, including the ability of the consumer to choose the resource type or location.

Direct Purchase of Renewable Energy Certificates

All electricity consumers have the option to purchase renewable energy certificates as a stand-alone product that are unbundled, or sold separately, from the physical electricity delivered to the consumer over the grid. Because RECs can be unbundled from the underlying electricity at the point of generation, RECs can be sold and consumed anywhere within the U.S. electricity market. REC instruments help solve the challenge of knowing the origin or source of the electricity delivered over the grid, since physical electricity is undifferentiated (e.g., it all looks the same). REC instruments are used to assign ownership to generation delivered to the grid, while offering consumers the flexibility to specify among other things, exactly what type of resource and the location of the generator they prefer to have serving their demand. Buying RECs separately does not affect the consumer's existing utility service relationship, but does result in two separate billings from both their electricity and REC suppliers, unlike retail utility supply options that involve bundled products. Consumers that buy RECs as a green power product can legally claim to be using renewable electricity based on the attributes conveyed by the RECs and the generator that produced them to meet demand. All green power supply options include RECs, so there is little difference if you purchase the REC bundled or unbundled from the underlying electricity.

Figure C-1. U.S. Residential Green Power Purchasing Options



Notes
1. Unbundled Renewable Energy Certificates (RECs) are available nationally
2. Community Choice Aggregation (CCA) programs are available in CA, IL, MA, NJ, NY, OH, and RI
3. Not all indicated options are available statewide

Verification and Certification

Because voluntary sales and purchases of renewable energy are not subject to governmental oversight, it is important that residential customers look for green power options that are certified by an independent third party. The non-profit Center for Resource Solutions developed the Green-e standard and certification program to help consumers identify high quality renewable energy products. Green-e verifies that all green power product sales are substantiated with RECs and that ultimately each REC is only issued to one buyer or consumer. This also involves making sure that RECs purchased by voluntary residential consumers are also not counted towards a mandate, which gives consumers assurances that their purchase goes above and beyond what would otherwise have occurred due to regulation (also known as regulatory surplus). Finally, Green-e requires that customers receive accurate and transparent disclosures about what they are purchasing (including resource types and facility locations). Additionally, Green-e conducts regular reviews of marketing and promotional materials for truth in advertising by certified suppliers. It is considered a consumer best practice to seek out third party certified green power products from eligible suppliers. To learn more about Green-e or find a certified product in your area, visit http://www.green-e.org.

Green Power Purchasing Preferences

Residential customers may express preferences for certain green power options and products in terms of the following:

- Resource Type – for example, generation from solar, wind, geothermal, or low-impact hydropower.
- Resource emissions rate – for example, a resource type that generates electricity at a low or zero emissions rate.
- Facility Location – for example, a specific project, generation from the same state, a certain region of the country, or national (no preference).
- Facility Age – for example, generation from facilities that were built in the last 5 to 10 years or that are new or yet to be built.
- Facility Size – for example, generation from large, utility-scale facilities vs. small, distributed generation.
- Length of Commitment – for example, enrollment in a utility program to pay monthly with the option to opt out at any time vs. entering into a 5-year purchase contract vs. making a one-time purchase of unbundled RECs.
- Other Considerations – for example, supporting generation from renewable facilities that may have broader system effects such as job, security, and reliability benefits. Some buyers may choose to support local renewable facilities or facilities in regions where the grid is considered to be more polluting.
- Cost – the cost of green power will vary based on all of the preferences listed above, as well as other factors.

Residential consumers may also find some of the information in the Guide to Purchasing Green Power useful when selecting a supply option despite the Guide being focused on non-residential consumers.

Using Indigenous Knowledge to Tackle Climate Change

CBC News – The National, 2022

Video: https://youtu.be/SjSzx0_7yPY

Community Ownership of Renewable Energy: United States

Institute for Human Rights and Business, 2022

Climate Ambition

- The current administration has established the goal of 100% clean electricity by 2035 and net-zero greenhouse gas (GHG) emissions no later than 2050.
- It also announced a 2030 aim of reducing net GHG emissions by 50-52% from 2005 levels.
- The United States (US) has committed to deploying 30 gigawatts of offshore wind by 2030 and a target goal of permitting at least 25 gigawatts of onshore renewable energy by 2025.
- Renewable energy has seen rapid growth in recent years due to low costs and policy support.
- The International Renewable Energy Agency (IRENA) notes that the US has the technical potential to increase its share of renewables in the US energy mix to 27% by 2030. By way of illustration, about 20.1% of the nation's utility-scale electricity production in 2021 came from renewable energy sources.

Renewable Sources

- Wind power offers the greatest potential for renewables growth in the US and is currently the largest renewable energy generator, accounting for around 43% of all renewable energy in 2020. Texas has the highest installed wind power potential, followed by Iowa and Oklahoma.
- Wind energy is predicted to increase from 63 GW (in 2014) to 314 GW by 2030.
- Hydropower is the largest source of renewable power generation in the US, but IRENA predicts limited potential for large-scale developments.
- Solar power resources vary across regions in the US, but IRENA predicts that the total installed capacity of solar photovoltaics (PV) could reach 135 GW by 2030.
- Biomass and biogas technologies also have significant potential in the US, with a possible 84 GW by 2030.

Indigenous People & Culture

There are around 5.2 million Native Americans (including American Indians and Alaska Natives) making up 2 percent of the U.S. population. Of this number, 78% reside in small towns or rural regions outside reservations, primarily in California, Arizona, and Oklahoma. There are presently 574 federally recognised Nations and the largest are the Navajo Nation and Cherokee Nation.

Since the United States was founded, Native Americans have faced atrocities and dispossession as part of settler colonialism. It forcibly drove them away from their native homelands, and they encountered unfair agreements and government actions that later centred on forced assimilation.

Although Native Nations have long been acknowledged as sovereign, they continue to face barriers in obtaining political and legal autonomy to define and enforce institutions such as property law in Indian country.

Legal Framework and Institutions

At the domestic level, The United States recognises the inherent sovereignty of tribal communities and the United States Code has a section which governs the relationship between the United States and all the federally recognised Nations. The Indian Reorganisation Act (IRA) created the formal infrastructure to recognise Native Nations and the parameters within which Native Nations could write their own constitutions. In this sense, the US is the only country in the world which provides "legibility and visibility" to Native Nations within its domestic law.

However, the United States Congress and the Supreme Court have the power to limit (or even divest) tribal sovereignty. The Court has historically sanctioned the dispossession of Indian lands, the exploitation of Indian resources by outsiders and the curtailment of tribal government. With respect to property rights, tribal lands or reservations are held "in trust" by the United States government for the use of specific Nations (which includes approximately 56.2 million acres of land). This means that the majority of Native Americans cannot sell the natural resources that the land holds and have limited control over leasing out or encumbering tribal territory. Native Nations cannot secure environmental and cultural preservation, engage in development and management choices, or negotiate favourable conditions.

At the international level, The United States has adopted the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP), recognising the rights of indigenous peoples to free, prior and informed consent (FPIC), land, and resources. However, UNDRIP is not binding law in the United States and the right to FPIC is not properly implemented in practice. Similarly, the American Declaration on the Rights of Indigenous Peoples was adopted by the Organisation of American States (OAS) in 2016. Similar to UNDRIP, it is a human rights document that upholds the right to self-determination, self-government, cultural expression, land areas, territories, and natural resources.

Challenges and Opportunities for Indigenous Ownership of Renewable Energy

Indian tribes rely on the development of the reservation's natural resources as one of the primary means of economic development. Despite this importance and the extensive mineral resource base on tribal lands, tribal control over the development and use of such resources has historically been limited. While decision-making power for tribes has increased in recent decades, tribal sovereignty (both practical and political) remains fragile.

At the policy level, the United States Department of Energy (DOE) Office of Indian Energy supports indigenous energy and economic infrastructure through policies and programs by offering funding through grants, technical support, training, and capacity building. DOE has contributed over $114 million since 2010 to approximately 200 indigenous energy projects spread across the United States. The Obama administration made many pledges to indigenous clean energy through financial and technical support programs and capacity-building training for Native Alaskan and American Indian communities.

At the legal level, the Indian Tribal Energy and Self-Determination Act (ITEDSA) of 2008 offers Native Nations the power to make the ultimate decision about specific development activities, including the development of renewable energy sources such as wind. While this is a positive development, ITEDSA does not address tribal concerns such as enhancing their access to financial, technical and scientific resources to ensure that tribes approach negotiations with businesses on an equal footing. Furthermore, Native Nations are still required to engage in a public consultation process with government officials, which dilutes and contradicts the sovereignty of the Nations. From a practical perspective, energy development in the native territory has also been hampered by government departments' poor administration, long review periods and other bureaucratic hurdles. Such issues lengthen the development process and result in missed opportunities and income. Tribes also do not have access to the financial resources and incentives currently accessible to private companies and local governments.

Profile Cases

The Oceti Sakowin Power Project in South Dakota

To produce renewable energy and become self-sufficient, six Sioux tribes in South Dakota—the Cheyenne River, Flandreau Santee, Oglala, Rosebud, Standing Rock, and Yankton Sioux—have established their wholly-owned multi-tribal power authority, known as Oceti akowi (OSPA). OSPA created the largest native wind projects in the United States in a cooperative venture with a wind developer, Apex Clean Energy.

OSPA has a majority stake in the company and participates actively in decisions to ensure a longer-term view and meaningful aligned with native teachings. While Apex assisted with necessary federal criteria and standards for approving the wind farms and power connections, OSPA provided its strong expertise and understanding in acquiring land, cultural and ecological concerns, and local legislation.

The wind farms' construction, operation, and funding were done jointly by OSPA and Apex. To retain tribal ownership, financing was secured through the issuance of utility revenue bonds, aimed at institutional investors. The Bush Foundation, the Clinton Global Initiative, and the Northwest Area Foundation are some of the partners.

In addition to creating jobs, sustainable development, and a prosperous future for the Native Nations, the project aims to promote Tribal self-sufficiency. The Sioux will equally split the financial gains from selling power to the Southwest Power Pool. It is estimated that the project could bring in $20 million in tax and fee revenue for the tribes which OSA and its member Tribes will reinvest in other communities for the planning, financing, ownership and management of community-scale renewable energy projects.

"Our dream is that this [wind project] will bring income to our people where we can be more self-sufficient." - Faith Spotted Eagle, a member of OSPA's Council of Elders.

(https://www.apexcleanenergy.com/insight/apex-clean-energy-recognized-best-largest-pipeline-wind-projects-u-s-2/)

“We want to use our revenue to invest back into the wind farms, so we can retain more ownership and more control of our projects,” Lyle Jack, Chairman of the Oceti Sakowin Power Project. (https://www.lakotatimes.com/articles/oceti-sakowin-wind-power-project/)

Fire Island Wind Project in Alaska

The Fire Island Wind Project in Anchorage is owned and run by Fire Island Wind LLC, a subsidiary of Cook Inlet Region, Inc. (CIRI). With assets amounting to almost a billion dollars and approximately nine thousand stockholders representing the Alaska Native cultures, CIRI is one of the Alaska Native corporations formed by Congress.

CIRI now owns 75% of the property on Fire Island. The project encountered several difficulties, took seven years to complete, and required 120 permits to be built. However, the project was completed eight months after the Regulatory Commission of Alaska authorised the 25-year power purchase deal with Chugach Electric Association, the biggest electric cooperative in Alaska. In 2012, the project started supplying up to seven thousand houses across Anchorage with clean energy.

The Chaninik Wind Group in Alaska

In 2005, the four Native tribes of Kongiganak, Kwigilliingok, Tuntutuliak, and Kipnuk came together to create the Chaninik Wind Group. The organisation wanted to build renewable energy and smart infrastructure, including wind energy, to combat growing fuel prices and provide Native communities with economic independence and income through employment and revenues. The organisation created the necessary technical competence to carry out the projects independently with the aid of regional utility managers and energy specialists. Federal funding was provided to the organisation to set up smart grid equipment and track the village's power consumption. The completed projects have lowered the cost of residential home heating and decreased their reliance on fossil fuels.

Introduction

Around the country, states have begun to act in the absence of clear federal guidance on climate. We are witnessing a sea change through a suite of policy actions, from ambitious renewable energy targets, to rooftop solar programs, community energy legislation, and market innovations such as community choice aggregation. In the face of this rapidly-evolving landscape, those disproportionately harmed by the fossil-fuel based energy system ("frontline communities") and more broadly, marginalized communities (including, but not limited to, environmental justice communities, indigenous communities, low-income and working-class communities, and communities of color)—seek to place equity and distributive justice at the heart of new policies addressing the transition away from fossil fuels to clean and renewable energy sources. As noted by industry observers and community activists alike, this energy transition offers an opportunity to reshape the socio-economic relationships created by energy policy choices. It creates an opening to center the concerns of frontline communities in the creation of energy policy. For example, the energy transition offers an opportunity for communities to own and control clean energy resources while reducing localized environmental and health impacts associated with the burning of fossil fuels.

Energy justice has emerged as both a field of study and practice to guide the energy transition, but the inconsistency surrounding definitions and use threatens the coherency of the field and the ability to advance clear policy guidance actually rooted in energy justice. Scholars in both social science and law have begun to grapple with the theoretical aspects of energy justice as well as its practical applications. In parallel, advocates have also begun to engage in a diversity of activities connected to energy justice and its corollaries, energy equity and energy democracy. Although scholars and practitioners frequently rely on energy justice and energy equity to animate parallel strands of study and practice, these two constituencies are not in active conversation and these parallel strands rarely, if ever, intersect. In light of the varied landscape, we choose to use the term, "energy justice" because we find it to be the most unifying terminology for this overarching concept that can synthesize and lift up both the traditions of justice-based scholarship, and recent activist practice around energy equity and energy democracy.

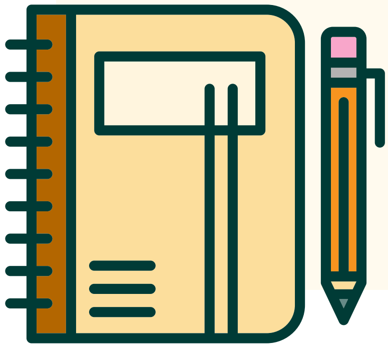
Taking advantage of the opportunity for structural transformation in our energy system requires that equity be placed at the center of emerging policy frameworks; however, community participants in policy debates concerning the energy transition often lack concrete details for energy policies that actually do place equity at the center. Similarly, policymakers lack theoretical grounding and practical frameworks to create and implement equity-centered energy policy. This Workbook addresses these gaps, and builds a bridge between theories and practices of energy justice to facilitate operationalizing energy justice through energy policy. The key audiences for this Workbook include community advocates and policy makers. The Workbook should serve as a guide for activists and advocates on the ground working for energy justice at the state level, and to assist policymakers seeking to understand how to incorporate energy justice into their emerging energy policy frameworks.

How to use this Workbook

The pages that follow provide a broad overview of "energy justice," synthesizing energy justice (and similar terms) as framed by practitioners in the field, as well as by scholars explicitly writing about energy justice.

The Workbook proceeds in four sections. Section 1 provides an overview and synthesis of energy justice, as discussed by frontline advocates, social scientists, and legal scholars. The section ends with a summary of the key energy justice principles that should animate transitional energy policy. Section 2 lays out an energy justice scorecard that may be used by advocates and policymakers to evaluate and design transitional energy policy. Section 3 uses the scorecard developed in Section 2 to evaluate emerging community energy policy in California and New York. We have also included a Glossary and Appendix for easy access to commonly used terms and the data we've relied on in our analysis.

The energy policy landscape is dynamic, and energy justice is context specific. However, basic principles of justice endure. We designed this Workbook to be highlighted, dog-eared, and referenced as the policy landscape evolves. The framework provided herein should be used to provide key benchmarks to guide energy policy discussions. We also designed this Workbook to address the question that frequently arises in the context of equity and energy policy: **What is energy justice?**



Section 1

Defining Energy Justice: Connections to Environmental Justice, Climate Justice, and the Just Transition

Summary: **Energy justice** refers to the goal of achieving **equity** in both the **social** and **economic** participation in the energy system, while also **remediating** social, economic, and health **burdens** on those historically harmed by the energy system ("frontline communities"). Energy justice explicitly centers the concerns of marginalized communities and aims to make energy more accessible, affordable, clean, and democratically managed for all communities. The practitioner and academic approaches to energy justice emphasize these process-related and distributive justice concerns.

Energy justice connects to, and builds upon, the deep scholarly and grassroots traditions of the environmental justice and climate change movements.[1] Those involved in the movement for the transition away from fossil fuels to renewable energy often frame energy justice, energy equity, and energy democracy as a part of a broader "**just transition**" to a low-carbon regenerative economy that will remedy the injustices of the fossil-fuel energy system and extractive economy across multiple sectors.[2] Advocates engaged in just transition work, through the leadership of the Climate Justice Alliance and the support of Movement Generation, have adopted the following model to reflect their efforts.

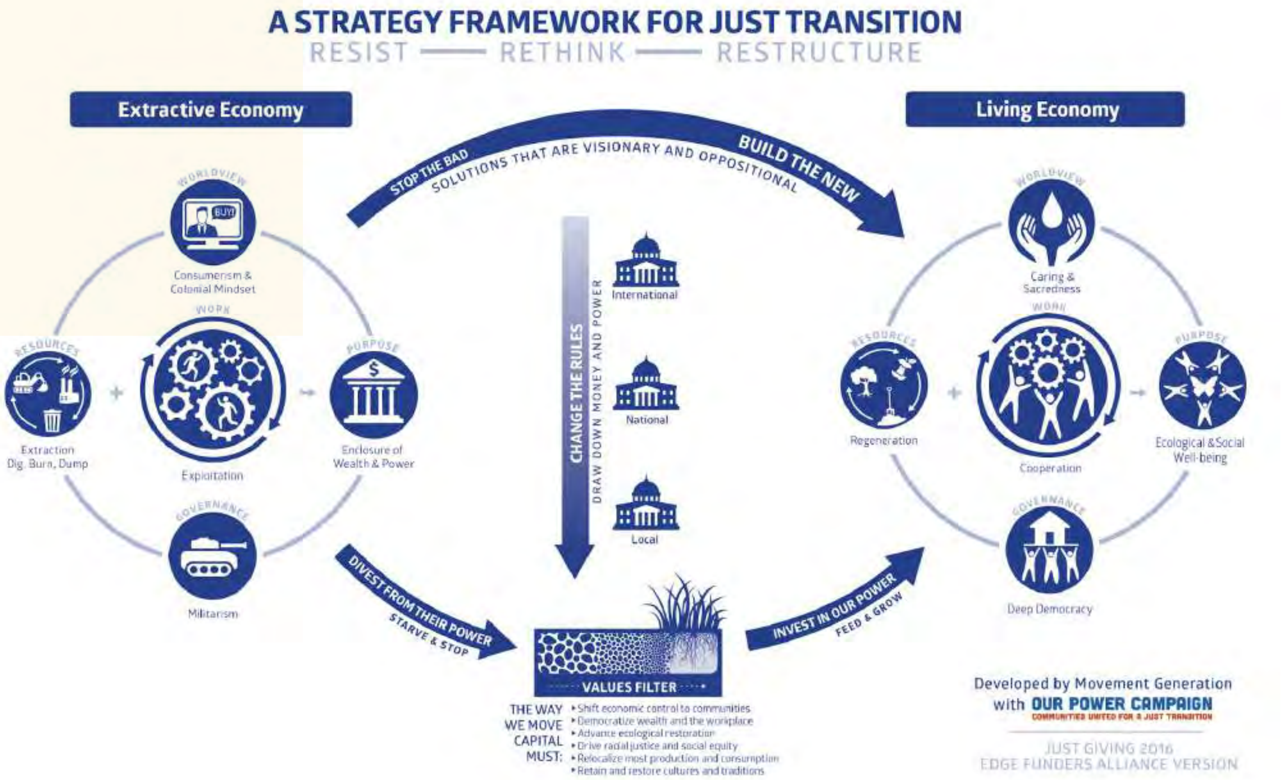


Diagram 1: Movement Generation Just Transition Framework [3]

Energy justice (also referred to as "energy equity") is integral to the just transition, as it addresses fairness and equity concerns within the current, extractive energy system, and incorporates aspects of "deep democracy," cooperation, and regeneration that feature in the just transition frame. Energy justice has several dimensions, itncluding:

- **energy burden**, which refers to the expense of energy expenditures relative to overall household income;[4]
- **energy insecurity**, which refers to the hardships households face when meeting basic household needs;
- **energy poverty**, which refers to a lack of access to energy itself;[5] and
- **energy democracy**, the notion that communities should have a say and agency in shaping their energy future.[6]

Issues of racial, economic, and social justice are not new aspects of political discourse in the United States; however, their nexus with issues of energy and the environment is a relatively recent phenomenon. Furthermore, the focus on "equity" within the energy justice frame indicates that policy approaches should work to level the playing field for those long disadvantaged under the existing energy system, rather than simply provide for "equal" opportunities for all under the new system.

Diagram 2 illustrates the framing of energy justice within the broader movement for a just transition, as well as how the component parts of energy justice fit together.

What is the origin of energy justice?

Energy justice closely connects to terms familiar to both practitioners and scholars in the field: **environmental justice** and **climate justice**. Environmental justice emerged in the early 1980's as both an activist practice and field of scholarship in the wake of damning evidence that communities of color often faced disproportionate environmental burdens, and that the suite of recently passed environmental laws did little to protect such communities from environmental harm.[7] Eventually, in response to a mounting body of evidence produced by activists[8] and academics alike,[9] in 1994, President Bill Clinton issued Executive Order 12898 directing federal agencies, to "the greatest extent practicable and permitted by law . . . make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations in the United States. . . ."[10] Although some scholars have questioned the efficacy of the environmental justice movement, as well as its utility as a policy tool,[11] others have noted the importance of relying on the environmental justice movement to inform the current transition away from fossil fuels.[12] In any case, environmental justice spawned the climate justice movement, which addresses the acute climate change issues facing communities of color and working class communities.

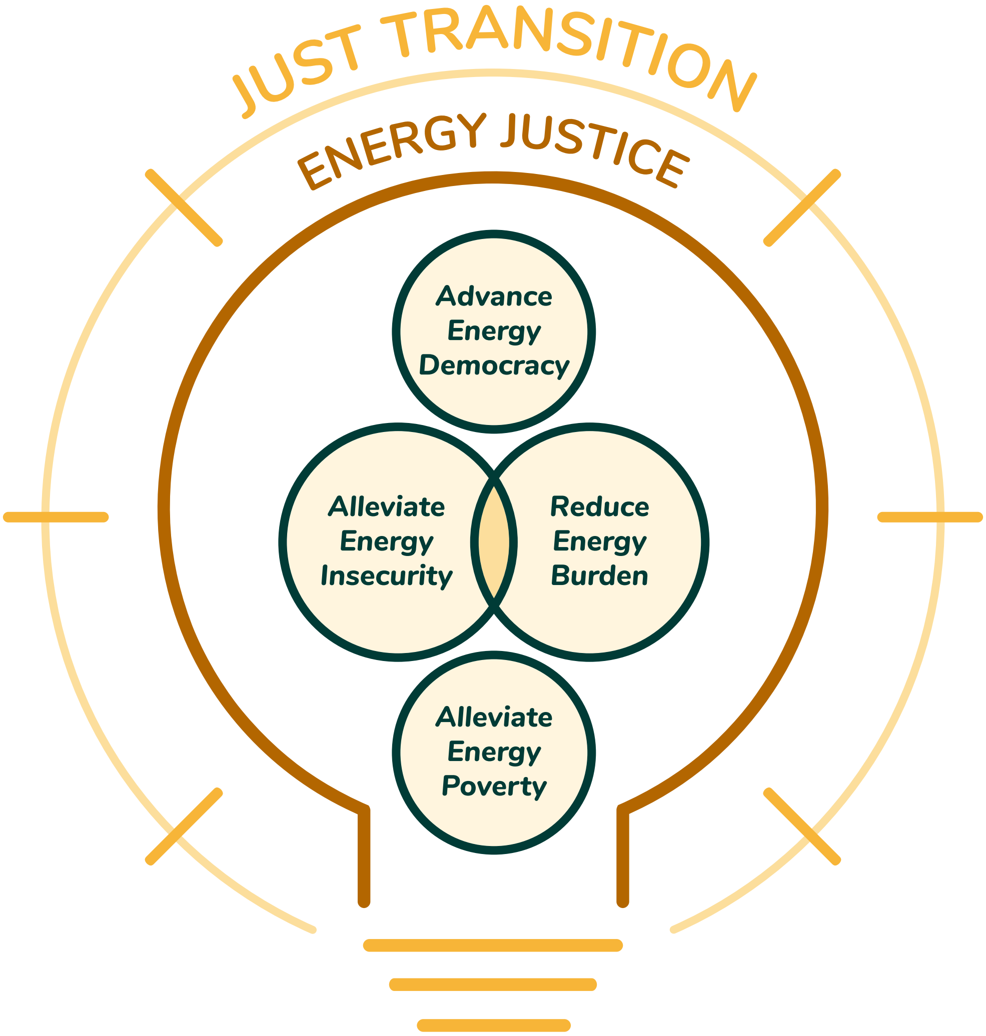


Diagram 2: The Goals of Energy Justice

While environmental justice might be seen as more of a domestic, United States-centric, movement focused on local concerns,[13] climate justice is decidedly global in scope. The movement emerged in the late 1990's and 2000's in light of the recognition that climate change would disproportionately affect those in the Global South, who did very little to contribute to creating the problem of climate change in the first instance.[14] Around the world, those with the least ability to respond to the impacts of climate change—the poor and people of color, including island nations and indigenous peoples—would bear the brunt of its effects. In the United States, climate justice advocates broadly recognize that the poor and people of color in this country will suffer the deepest impacts of climate change, given legacies of legalized segregation, redlining, and disinvestment that have left communities of color and the poor on land and in economic circumstances that make them the most vulnerable to climate change impacts. Moreover, such communities lack the economic resources to easily "bounce back" from climate change related events.[15]

High water marks of the climate justice movement include:

- **2010:** The creation of the People's Agreement in Cochabamba, Bolivia in 2010, where participants called for the creation of an International and Climate Environmental Justice Tribunal with the legal capacity to "prevent, judge, and penalize States, industries and people that by commission or omission contaminate and provoke climate change."[16] The People's Agreement was the product of the People's Conference on Climate Change and the Rights of Mother Earth after the disastrous 2009 United Nations meeting in Copenhagen to address climate change;

- **2014:** The People's Climate March organized by activist groups, where 400,000 people gathered in New York City to center "the leadership of Indigenous communities, communities of color, and working-class white communities" in the climate movement;[17] and

- **2019:** In the summer of 2019, a coalition of environmental justice organizations and national organizations aligned to create an "Equitable and Just National Climate Platform" which set forth a "bold national climate policy agenda" to advance "economic, racial, climate, and environmental justice."[18] The Platform calls for a commitment to limit global warming to 1.5 degrees Celsius through the mobilization of community, government, science and research, and industry resources "toward the development of just, equitable, and sustainable long-term comprehensive solutions" that "acknowledge and repair the legacy of environmental harms on communities inflicted by fossil fuel and other industrial pollution."[19] The Platform further argues for new leadership to "advance solutions in ways that meaningfully involve and value the voices and positions of [environmental justice communities]."[20]

Both environmental justice and climate justice weave together the requirements of procedural and substantive (or distributive) justice. In the case of environmental justice, key principles of the movement include fair distribution of the burdens of development, and involvement in all aspects of "the development, implementation and enforcement of environmental laws, regulations and policies."[21] Climate justice proponents, on the other hand, argue for policies that address the disproportionate burdens that will be borne by vulnerable communities due to climate change, even going so far as to argue for distributive justice in the form of reparations.[22] Further, as noted by the Climate Justice Alliance, *actual* climate justice requires that voices of communities of color, indigenous peoples, and the working-class be placed at the forefront of discussions concerning climate.[23]

Energy justice emerges from this rich history. As Eleanor Stein elegantly summarizes, the general view of scholars is that an energy just world involves equitable sharing of benefits and burdens involved in the production and consumption of energy services.[24] It is also one that is fair in how it treats people and communities in energy decision-making.[25] Further, key concerns of the field are:

- issues of access,
- distribution of harms,
- fairness of energy decision-making to ensure that decisions do not infringe on human rights and civil liberties, and
- informed participation.[26]

Sections 1.1 and 1.2 provide an in-depth review of the conceptual underpinnings of energy justice theory and practice. **Diagram 3** illustrates the environmental justice, climate justice, and energy justice movements, as well as the primary claims within each. As the diagram reflects, the movements and analytical frameworks are rooted in similar ideologies and goals. Moreover, they run on parallel and overlapping paths.

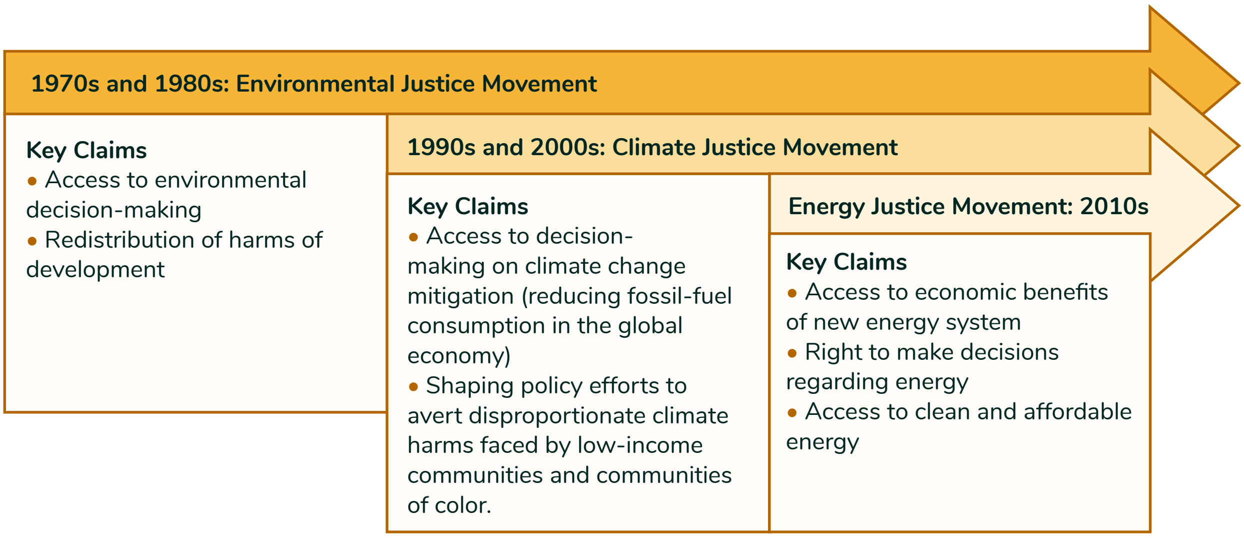


Diagram 3: Movements for Environmental Justice, Climate Justice, and Energy Justice

The following Section discusses how "energy justice" and the range of terms associated with it are used in practice as well as in academic circles (mainly social scientists and legal scholars). Before that discussion, however, we offer a synopsis of terms used in this section and the sections that follow:

Frequently Used Terms	Definition
Climate Justice	Remediation of the impacts of climate change on poor people and people of color, and compensation for harms suffered by such communities due to climate change.[27]
Energy Burden	Amount of overall household income spent to cover energy costs.[28]
Energy Democracy	The notion that communities should have a say and agency in shaping and participating in their energy future.[29]

Frequently Used Terms	Definition
Energy Insecurity	"The inability to meet basic household energy needs"[30] due to the high cost of energy.
Energy Justice (and Energy Equity)	The goal of achieving equity in both the social and economic participation in the energy system, while also remediating social, economic, and health burdens on those historically harmed by the energy system.
Energy Poverty	A lack of access to basic, life-sustaining energy.
Environmental Justice	Recognition and remediation of the disproportionately high and adverse human health or environmental effects on communities of color and low-income communities.[31]
Just Transition	A transition away from the fossil-fuel economy to a new economy that provides "dignified, productive, and ecologically sustainable livelihoods; democratic governance; and ecological resilience."[32]

Section 1.1 - Energy Justice In Practice

In *Framing Energy Justice: Perspectives from Activism and Advocacy*, Sara Fuller and Darren McCauley interrogate energy justice in the context of activist and advocacy movements, seeking to illuminate for the scholarly community the ways that energy justice is defined by those on the ground and the communities that experience the direct impacts of the energy system from "cradle to grave." The authors observed "energy justice on the ground," and found no consistent, "single energy justice frame." Instead, they found "the existence of multiple and diverse mobilizations around energy justice[,]" and localized expressions of justice. Rather than attempt to explain practitioner and advocate approaches to energy justice using tools designed by scholars, this Workbook acknowledges the unique perspectives and understandings of energy justice as defined by those engaged in the work on the ground. This expertise, grounded in the lived experiences of advocates, provides an invaluable perspective to inform equity-centered energy policy.

Our Approach

Summary: We reviewed the public-facing statements of practitioners and advocates engaged in advocacy work around energy policy. We also met with frontline leaders and organizations engaged in energy policy efforts. With a few notable exceptions,[33] practitioners and advocates tend to rely less on "**energy justice**" and more on terms like "**energy equity**" and "**energy democracy**" in their work. Although the terminology differs, the usage commonly focuses on frontline-led approaches to energy policy that center the economic, social, and health concerns of marginalized communities.

Our Survey of the Field

Energy justice mirrors the distributive and procedural justice demands of the environmental justice and climate justice movements, and encompasses several goals including:

- Transitioning the power and control over the means of energy production into the hands of the community,
- Ensuring fair and equitable distribution of the benefits and burdens of energy production activities, and
- Centering the concerns of marginalized communities.

To gain an understanding of existing community-based approaches to and understandings of energy justice, we relied mainly on a review of advocacy statements concerning "energy justice." Our own experiences working with frontline organizations around the country also informed our understandings of energy justice practice. Our approach to understanding what was happening in the field began with a simple, internet-based search to cast a wide net for activist groups using the terms "energy justice," "energy democracy," or "energy equity" in their mission statements. The search was then narrowed to groups that specifically defined these terms in a way that creates a framework for their mission. Additional sources were found by looking at sources cited in academic papers about community activism and energy justice frameworks. Another key search method was working from a list of known organizations based on past association with the authors of this Workbook, which helped to fill in gaps in regional representation.

Originally, our search included only those organizations that specifically used the term "energy justice" in their work. However, many advocacy groups favor the phrase "energy democracy" when talking about issues pertaining to developing energy transition frameworks with a social and environmental justice focus. We then expanded the search to include this terminology, as well as the phrase "just transition," which is also used to describe the transition away from an extractive economy to a regenerative one. The use of these terms – energy justice, energy democracy, and just transition – provides much the same frame for advocacy groups as the phrase "energy justice" provides for academic investigations. The resulting list, further discussed in Appendix B, represents a nation-wide survey of U.S. organizations.

Our own experience in the field mirrors what we found in the written material. As a whole, practitioners and advocates at nonprofit organizations we work with don't use the term "energy justice" in common practice, but show general receptivity toward it. This includes individuals we know in different regions around the country, including the South, Northeast, Midwest, and West. Some advocates occasionally use the term energy justice themselves, and others are part of alliances that have member organizations within their alliance that use the term. Some colleagues use the term "energy justice" interchangeably with a "just energy system," while others use "just energy" but not "energy justice."

Many of our partners use the term "energy equity" in a way that is either entirely or substantially interchangeable with how we define energy justice in this Workbook. Some practitioners use the term equity when talking about energy, though not necessarily "energy equity" as a phrase. For example, some use specific phrases such as "equitable deep decarbonization" and "equitable energy system."

Despite the work of organizations clearly falling under the umbrella of "energy justice," this term is almost never used in their mission statements or writing. Generally, the word "justice" is used only to incorporate a social, racial, or environmental justice approach to the energy transition framework, rather than to aid in the development of a new framework specifically for the just energy transition. Therefore, while activist groups are clearly contributing to the dialogue on what achieving energy justice looks like, they are currently not working with the vocabulary utilized within the academic community. This disconnect threatens the efficacy of scholarship to reach practitioners, and could lead to broader confusion concerning the meaning of energy justice among policymakers.

> *"The disconnect between practice and academia could lead to broader confusion concerning the meaning of energy justice among policymakers."*

Prevalence of "Energy Democracy"

With respect to our analysis of practitioner approaches, the term most often used to describe the missions of organizations engaged in equity-based energy policy work is "energy democracy." Based on our research, it seems that "energy democracy" is especially favored among groups in the U.S. advocating for a community-empowerment component to energy transition activities. The use of the term "democracy" within the U.S. context could serve two strategic purposes within the movement.

First, energy democracy might portray the importance that involvement from the community plays in these groups' vision for just energy systems. It is clear that these organizations feel that justice in energy generation, distribution, and transition activities will be achieved only if the decision-making power and control over the systems lies in the hands of the community affected by that system.[34] A way of accomplishing that goal is by putting that system under democratic control and allowing for social and economic participation in that system. Further, as emphasized by Denise Fairchild and Al Weinrub in *Energy Democracy*, "deep democracy," meaning, centering the engagement of poor people, people of color, and groups traditionally marginalized within energy transition policy discussions, goes further than mere economic and social participation in the energy system.[35] Under the Fairchild and Weinrub analysis, energy democracy requires not only basic participation in the design of the new energy system, but a deeper structural transformation of the social and economic structures underpinning the energy system.[36]

The second purpose of using "energy democracy" could relate to the long, and frequently problematic, history of the term "democracy" in the American context. Democracy is a core value in American political and social systems, and linking this concept, which evokes feelings of patriotism and equity, to the energy transition movement is likely to yield more positive outcomes than linking the movement to "social justice" or "racial justice", which can evoke a more negative, or polarized, response. The use of patriotic phrasing could therefore be strategically important in policy advocacy efforts, where public and political support is crucial.[37]

Groups using the term "energy democracy" tend to include the following concepts of community empowerment in their work.

- **Community Ownership:** the community owning and controlling the sources of energy production;
- **Community Decision-making:** community having a democratic say in the means of energy production and distribution; and
- **Power Decentralization:** Empowerment of those closest to the means of production, geographically, socially and economically.

These concepts indicate a desire to redistribute economic and political power away from centralized energy producers to smaller subsections of society. Advocates press for meaningful community involvement to eradicate many of the inequalities and injustices that currently plague the energy system, such as the disproportionate ecological, economic, and social harms that currently affect low-income communities and communities of color.[38]

A significant number of nonprofit professionals we work with also use the term energy democracy. Most appear to view energy democracy as meaning something at least slightly distinct from energy justice or energy equity. Some view energy democracy as a component within a larger frame of energy equity. More specifically, some view energy democracy as focusing on ownership of distributed generation, while energy equity considers the entire energy system, including utility-scale generation and transportation energy. Others consider energy democracy as describing the tangible objectives within the broader, intersectional vision of energy equity.

While energy democracy appears to be the most commonly used term among those working at the intersection of equity and energy, many use energy equity to mean something slightly broader in scope than energy democracy: using energy policy to actually center the concerns of those harmed by the existing energy system. Some advocates either use or resonate with energy justice as perhaps a more holistic and compelling frame.

In the advocacy sphere, advocates place less emphasis on a uniformity of terminology describing the work than scholars of energy justice and, appropriately, more emphasis on the outcomes associated with the work. What is echoed among all of the groups we reviewed is a desire for upheaval in the current energy system, a shift towards more democratically controlled systems, and a new emphasis on social inclusiveness and equity.

> *"What is echoed among all of the groups we reviewed is a desire for upheaval in the current energy system, a shift towards more democratically controlled systems, and a new emphasis on social inclusiveness and equity."*

Advocates are also concerned about the impacts of the energy system and focus on the following key concepts:

- **Equitable Distribution of Benefits and Harms:** Equitable distribution of both the benefits and harms of the energy system, which again relates to alleviating the pressure that currently disproportionately affects low-income communities and communities of color;
- **Economic Benefits:** Some groups believe allowing frontline communities to economically benefit from the new energy system could remedy many of the social issues currently being experienced by such communities[39] and lead to social and political empowerment through job creation and local control of economic resources. Moreover, improving energy efficiency can lower the overall cost of living.
- **Decreasing Pollution:** Other distributive concerns include limiting pollution to decrease negative health impacts.
- **Centering Frontline Voices and Control:** Another method of ensuring this equity is by putting the power in the hands of the people most affected by the decisions.[40] The idea is that these groups will be most motivated to responsibly manage the benefits and risks of energy production and distribution.

These distributive and procedural justice frames are echoed throughout the social science and legal literature as well.

Energy Justice and the Energy Transition

May 30, 2022 – National Conference of State Legislatures

Introduction

Energy justice is an emerging topic that is receiving attention at the federal and state levels. The U.S. Department of Energy is actively working to implement the Biden administration's Justice40 Initiative , a goal that 40% of the overall benefits from federal investments in climate and clean energy flow to disadvantaged communities. At the state level, some state legislatures have considered measures related to energy justice. Building off the tenets of environmental justice, energy justice refers to the concepts of equity, affordability, accessibility and participation in the energy system and energy transition regardless of race, nationality, income or geographic location.

Advocates for energy justice promote policy measures aimed at reducing energy costs and burdens on low-income customers, avoiding disproportionate impacts and ensuring the equitable distribution of the benefits of energy generation, transmission and transition, access to reliable and clean energy, and participation for communities in energy sector decision-making and development. This paper will examine recent state policy related to energy justice, including energy affordability, infrastructure siting, community renewable energy development, and the incorporation of energy justice considerations into broader emissions reduction and renewable energy programs.

Energy Affordability and Access

The affordability of and access to reliable energy is at the heart of energy justice. Referred to as an "energy burden," studies have shown that communities of color and low-income families pay a significantly higher share of their income in energy costs. National data show that on average, low-income households pay nearly 9% of their income in energy costs—three times more than non-low-income households. An estimated 25% of households have a high energy burden, considered to be above 6% of household income. An additional 13% of American households have a severe energy burden of paying more 10% of their income on energy. The energy burden has been an issue for communities and legislators for decades and is the impetus behind federal programs such as LIHEAP and other state programs that provide direct financial assistance for low-income families' energy bills.

Siting of Infrastructure / Participation in Development

Energy justice advocates are also concerned with the siting of energy facilities and infrastructure. Borrowing from decades of environmental justice advocacy, energy justice is concerned with potential pollution, noise or health impacts from energy generation or transmission facilities. On the other hand, communities may benefit in some ways from the siting of certain energy facilities. For example, some states are pursuing the transition away from coal facilities by siting solar (Illinois) or nuclear power (Wyoming) on those former coal sites in an effort to keep jobs and economic development in the community.

Regardless of the impacts associated with the siting of infrastructure within low-income or marginalized communities, participation and representation in the decision-making process surrounding the siting of energy infrastructure is a major tenet of energy justice. Many states have been pursuing legislation that promotes community participation or the consideration of energy justice issues during energy facility siting decisions.

Some states, such as New York, have established councils or task forces aimed at including energy justice and other equity issues in decisions surrounding the state's energy transition. The state's Climate Justice Working Group is comprised of representatives from "environmental justice communities" that advise the state regarding the economic and environmental impacts of the state's transition to clean energy, including clean energy development, energy efficiency programs and low-income energy assistance.

New Jersey enacted SB 232 in 2020 to require the state's Department of Environmental Protection to evaluate environmental and public health stressors for "overburdened communities" when issuing permits or licenses for regulated activities and facilities. Applicants must submit an environmental justice impact statement for any new or expanded facility, which would include certain energy facilities and infrastructure.

Virginia enacted SB 851 to promote a clean energy transition that benefits low-income and historically economically disadvantaged communities. There are numerous provisions addressing energy justice issues in the bill, including an expansion of the state's PIPP to reduce energy costs. Notably, the bill also requires the state PUC to ensure the development of new or expanding energy facilities does not have a disproportionate impact on historically economically disadvantaged communities. Additionally, the commission should consider whether the placement of renewable energy facilities provides benefits to those communities and displaced fossil fuel workers.

Community Solar

The Biden Administration announced the national community solar partnership to make rooftop solar more accessible and affordable and create $1 billion in energy cost savings by 2025. Community renewable energy can promote energy justice by making clean energy more affordable and accessible, and by giving power and ownership of energy generation to members of disadvantaged communities. Many states are enabling or expanding their community renewable energy policies to focus on benefits and accessibility for low-income customers.

Colorado, one of the nation's leading community solar states, has developed policies around ensuring that low-income customers can realize the benefits of community solar. For example, The state's community solar statute requires the state PUC to develop policies that encourage the use of community solar gardens for low-income customers. Colorado also enacted HB 1003 in 2019 to expand the generation capacity limits for community solar arrays from 2 MW to 5 MW and remove certain siting requirements to allow more customers access to community solar services.

Sen. Chris Hansen, a primary sponsor of HB 1003 (2019), says the bill "demonstrates the continued efforts by Colorado to address energy and environmental justice by expanding access to community solar gardens." Before the enactment of HB 1003, community solar gardens in Colorado had to be located in the same or adjacent county as the subscribers they served. By removing those siting requirements, Colorado residents now have a "greater opportunity to invest in clean energy generation while also realizing the financial benefits afforded to them by community solar gardens." Hansen also notes that the bill allows customers who "do not own a home or have the right configuration for rooftop solar to participate and enjoy the benefits of the clean energy transition."

Similarly, Massachusetts' community solar program incentivizes community solar access for low-income customers by providing "adders" to the base rates that utilities pay for electricity. Under the Solar Massachusetts Renewable Target (SMART) program, utilities in the state must purchase a certain amount of their electricity from solar facilities developed under this program, including community solar facilities. The base rate at which utilities purchase electricity from SMART facilities is higher than the typical retail rate, thereby incentivizing solar developers to build solar arrays. To incentivize the build out of community solar facilities in low-income areas, the state has established "adders" on top of the base SMART rate. These adders provide developers with an additional financial compensation on top of the base SMART rate for solar facilities with certain characteristics. For instance, a community solar facility in a low-income area sells its electricity at a rate $0.06 higher than the base SMART rate.

New Mexico established their community solar program in 2021 by enacting SB 84. The bill provides incentives for community solar facilities that serve low-income and tribal customers. There is a carve-out that requires 30% of the electricity produced from each community solar facility to be reserved for low-income customers; the state PUC plans to track and evaluate low-income customer participation in the community solar programs.

A handful of other states have also enacted legislation that aims to promote community solar access for low-income or disadvantaged communities. Maryland enacted HB 473 which allows community solar subscribers to maintain their subscription despite a change of address, a provision that is particularly useful to customers who rent homes. New York's SB 3521A specifically addresses low-income customers' access to the state's community solar program by allowing customers who live in one utility territory to subscribe to community solar facilities in different utility areas. This encourages more people to access community solar, particularly those living in New York City, where land and property to build community solar arrays is scarce. Virginia's HB 573 established a low-income community solar pilot program. The bill requires each electric utility participating in the state's community solar program to locate at least one generation facility in a low-income community.

Equity and Broader Clean Energy Legislation

States including Illinois, Oregon, North Carolina, Washington, New York and Virginia have enacted broad clean energy or emissions reduction legislation in the past few years. As states pass these large energy bills, they often consider issues of energy justice and equity.

California was one of the first states to consider issues of energy justice in broad energy and emissions reduction legislation. In 2012, California enacted SB 535 , which added certain provisions to its Global Warming Solutions Act of 2006. Those amendments included consideration of disadvantaged communities when distributing funds under the bill. SB 535 requires that 25% of available funds benefit disadvantaged communities and that 10% of those funds are used for projects that are specifically located in those communities.

New York's major energy transition and emissions reduction legislation (SB 6599) focuses on many equity and justice issues. For instance, it directs the state to invest 40% percent of the overall benefits of spending from the bill to disadvantaged communities. This includes investment in clean energy and energy efficiency programs, low-income energy assistance, pollution reduction and workforce development. Colorado's Renewable Portfolio Standard also has a requirement that utilities prioritize at least 40% of their expenditures on renewable energy investment to address historical equity issues concerning access by low-income customers to renewable energy.

Similarly, Washington's Climate Commitment Act enacted in 2021 set the state's climate and emissions goals. That legislation, Washington SB 5126, establishes a carbon trading market for the state. Termed as a "cap-and-invest" program, the state will take proceeds from the auction of emissions credits and invest in community programs that address energy justice issues in overburdened and tribal communities.

Illinois enacted the Climate and Equitable Jobs Act in 2021. SB 2408 is a comprehensive and ambitious clean energy and emissions reduction bill that considers many equity and justice issues. Illinois Senate Deputy Minority Leader Sue Rezin touts the bill's commitment to a carbon-free future while ensuring that the state did not lose vital energy sector jobs. Rezin notes that SB 2408 is "landmark legislation that could serve as a model for the nation" and that the "new law created not only a realistic path to 100% carbon-free energy in Illinois but also preserved [the] state's nuclear fleet and saved thousands of good-paying jobs." Workforce development issues, many of which are synonymous with energy justice issues, can sometimes be overlooked in broad clean energy transition policies, but those issues were a central component to the enactment of SB 2408.

For instance, it provides over $180 million to support clean energy workforce development, including a Clean Jobs Workforce Network Hub to establish 13 "hub" sites that are aimed at providing resources, information and support to workers and communities impacted by the clean energy transition. SB 2408 also establishes incubator programs designed to provide capital and financial support for community-owned renewable energy projects and environmental justice projects. There are also numerous provisions designed to lower costs for low-income utility customers, such as the elimination of late fees and deposit requirements for those customers, and a study of whether current low-income discount rate programs are accurate and effective.

Oregon adopted HB 2021, the nation's most ambitious clean energy legislation, which aims for 100% emissions-free energy production by 2040. Equity issues and environmental justice are a primary concern throughout the bill; the state hopes to achieve its clean energy targets in a manner that minimizes burdens for environmental justice communities. As utilities submit plans to reach Oregon's clean energy targets, they must convene a Community Benefits and Impact Advisory Group that includes members from environmental justice and low-income communities to assess the impacts of the utility's proposed plan. Additionally, the bill establishes grants for community renewable energy projects which seek to provide benefits such as energy resilience, cost savings and economic development to disadvantaged communities by involving community groups in decisions regarding the siting, planning and design of community renewable energy projects.

Conclusion

Issues of energy affordability, access and infrastructure development will continue to be concerns for legislators as the country undergoes an energy transition over the coming years. Energy justice is a complex issue with economic, racial, geographic and social implications. As such, it is unlikely that these issues will be resolved through a singular policy or approach but may be considered in the context of many energy-related policies. The Biden administration is prioritizing energy and environmental justice issues through federal action, and state legislatures are likely to continue to consider whether and how to address these issues over the course of the ongoing energy transition.