

Electricity

The Nature of Electricity

Electricity is a little different from the other sources of energy that we talk about. Unlike coal, petroleum, or solar energy, electricity is a **secondary source of energy**. That means we must use other primary sources of energy, such as coal or wind, to make electricity. It also means we can't classify electricity as a **renewable** or **nonrenewable** form of energy. The energy source we use to make electricity may be renewable or nonrenewable, but the electricity is neither.

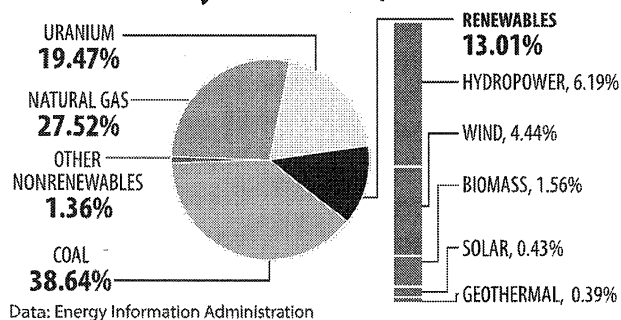
Making Electricity

Almost all electricity made in the United States is generated by large, central power plants. There are about 7,600 power plants in the U.S. Most power plants use coal, nuclear fission, natural gas, or other energy sources to superheat water into steam in a boiler. The very high pressure of the steam (it's 75 to 100 times normal atmospheric pressure) turns the blades of a turbine. (A **turbine** turns the linear motion of the steam into circular motion.) The blades are connected to a **generator**, which houses a large **magnet** surrounded by coiled copper wire. The blades spin the magnet rapidly, rotating the magnet inside the coil producing an **electric current**.

The steam, which is still very hot but now at normal pressure, is piped to a condenser, where it is cooled into water by passing it through pipes circulating over a large body of water or cooling tower. The water then returns to the boiler to be used again. Power plants can capture some of the heat from the cooling steam. In old plants, the heat was simply wasted.

Not all power plants use thermal energy to generate electricity. Hydropower plants and wind farms use motion energy to turn turbines, turning a generator, which produces electricity. Photovoltaic plants use radiant energy to generate electricity directly.

U.S. Electricity Production, 2014



Electricity at a Glance, 2014

Secondary Source of Energy, Energy Carrier

Major Energy Sources Used to Generate Electricity:

- coal, natural gas, uranium, hydropower

U.S. Energy Consumption:

- 39.23%

Net U.S. Electricity Generation:

- 4,093.604 billion kWh

Major Uses of Electricity:

- manufacturing, heating, cooling, lighting

Data: Energy Information Administration

Moving Electricity

We are using more and more electricity every year. One reason that electricity is used by so many consumers is that it's easy to move from one place to another. Electricity can be produced at a power plant and moved long distances before it is used. Let's follow the path of electricity from a power plant to a light bulb in your home.

First, the electricity is generated at the power plant. Next, it goes by wire to a **transformer** that "steps up" the voltage. A transformer steps up the voltage of electricity from the 2,300 to 22,000 volts produced by a generator to as much as 765,000 volts (345,000 volts is typical). Power companies step up the voltage because less electricity is lost along the lines when the voltage is high.

The electricity is then sent on a nationwide network of **transmission lines** made of aluminum. Transmission lines are the huge tower lines you may see when you're on a highway connected by tall power towers. The lines are interconnected, so should one line fail, another will take over the load.

Step-down transformers located at substations along the lines reduce the voltage to 12,000 volts. Substations are small buildings in fenced-in areas that contain the switches, transformers, and other electrical equipment. Electricity is then carried over distribution lines that bring electricity to your home. Distribution lines may either be overhead or underground. The overhead distribution lines are the electric lines that you see along streets.

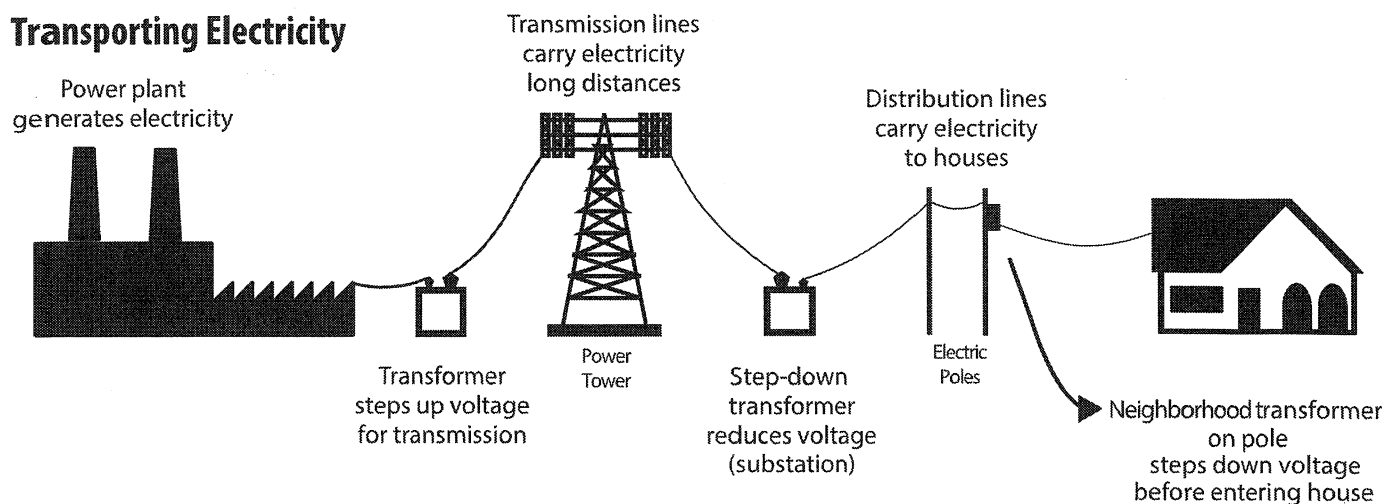
Before electricity enters your house, the voltage is reduced again at another transformer, usually a large gray can mounted on an electric pole. This neighborhood transformer reduces the electricity to 240 and 120 volts, the amount needed to run the appliances in your home.

Electricity enters your house through a three-wire cable. The "live wires" are then brought from the circuit breaker or fuse box to power outlets and wall switches in your home. An electric meter measures how much electricity you use so the utility company can bill you. The time it takes for electricity to travel through these steps—from power plant to the light bulb in your home—is a tiny fraction of one second.



Electricity

Transporting Electricity



Power to the People

Everyone knows how important electricity is to our lives. All it takes is a power failure to remind us how much we depend on it. Life would be very different without electricity—no more instant light from flicking a switch, no more television, no more refrigerators, or stereos, or video games, or hundreds of other conveniences we take for granted. We depend on it, business depends on it, and industry depends on it. You could almost say the American economy runs on electricity.

It is the responsibility of electric utility companies to make sure electricity is there when we need it. They must consider reliability, capacity, baseload, peak demand, and power pools.

Reliability is the capability of a utility company to provide electricity to its customers 100 percent of the time. A reliable electric service is without blackouts or brownouts. To ensure uninterrupted service, laws require most utility companies to have 15 to 20 percent more capacity than they need to meet peak demand. This means a utility company whose peak demand is 12,000 megawatts (MW) must have 14,000 MW of installed electrical capacity. This ensures that there will be enough electricity to meet demand even if equipment were to break down on a hot summer afternoon.

Capacity is the total quantity of electricity a utility company has on-line and ready to deliver when people need it. A large utility company may operate several power plants to generate electricity for its customers. A utility company that has seven 1,000 MW plants, eight 500 MW plants, and 30 100 MW plants has a total capacity of 14,000 MW.

Baseload power is the electricity generated by utility companies around-the-clock, using the most inexpensive energy sources—usually coal, nuclear, and hydropower. Baseload power stations usually run at full or near capacity.

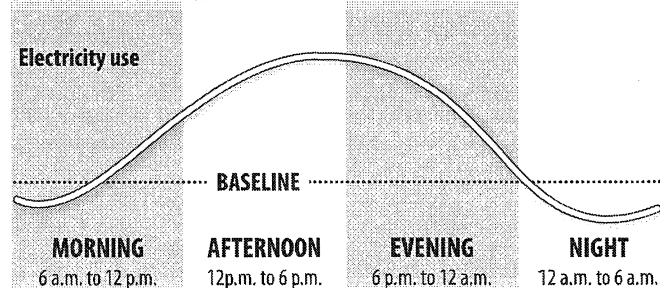
When many people want electricity at the same time, there is a **peak demand**. Power companies must be ready for peak demands so there is enough power for everyone. During the day's peak, between 12:00 noon and 6:00 p.m., additional generators must be used to meet the demand. These peaking generators run on natural gas, diesel, or

hydropower and can be put into operation in minutes because they require little start-up time. The more this equipment is used, the higher our utility bills. By managing the use of electricity during peak hours, we can help keep costs down.

The use of **power pools** is another way electric companies make their systems more reliable. Power pools link electric utilities together so they can share power as it is needed. A power failure in one system can be covered by a neighboring power company until the problem is corrected. There are eight regional power pool networks in North America. The key is to share power rather than lose it.

The reliability of U.S. electric service is excellent, usually better than 98 percent. In some countries, electric power may go out several times a day for several minutes or several hours at a time. Power outages in the United States are usually caused by such random occurrences as lightning, a tree limb falling on electric wires, or a fallen utility pole.

Peak Demand



Peak demand, also called peak load, is the maximum load during a specified period of time.

Demand-Side Management

Demand-side management is all the things a utility company does to affect how much people use electricity and when. It's one way electric companies manage peak load periods. In 2014, through energy efficiency and load management, electric utilities saved over 1,436 billion kilowatt-hours.

We can reduce the quantity of electricity we use by using better conservation measures and by using more efficient electrical appliances and equipment.

What's the difference between **conservation** and **efficiency**? Conserving electricity is turning off the water in the shower while you shampoo your hair. Using electricity more efficiently is installing a better showerhead to decrease water flow.

Demand-side management can also affect the timing of electrical demand. Some utility companies give rebates to customers who allow the utility company to turn off their hot water heaters or set their thermostats (via radio transmitters) during extreme peak demand periods, which occur perhaps 12 times a year.

America's Electric Grid

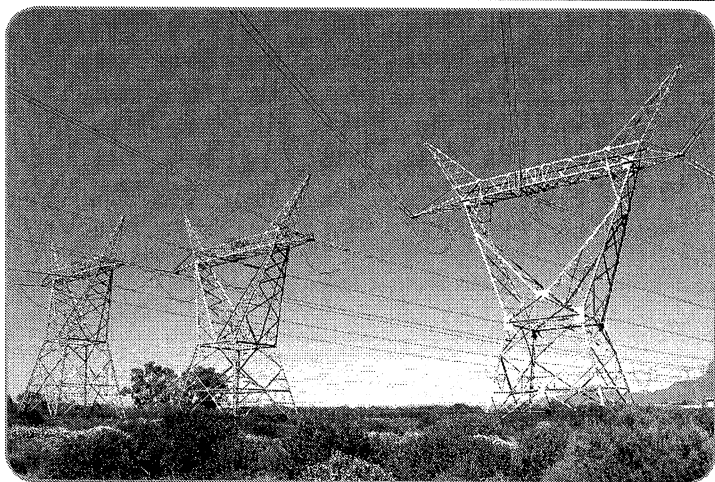
When you walk into a room and flip the switch on the wall, the lights come right on, just as you expected. But did you ever think how the electricity got to your house to give you the power for those lights and the many electrical appliances and products you use at home, ranging from your DVD player to your refrigerator?

Today there are more than 3,300 electric distribution utilities and about 19,745 generating units all over America that produce and distribute electricity to homes, businesses, and other energy users.

To get electricity to its users, there are more than 160,000 miles of high-voltage electric transmission lines across the U.S. They take the electricity produced at power plants to transformers that step up the voltage to reduce energy loss while it travels along the grid to where it is going to be used.

These transmission and distribution lines—whether they are located on poles above ground or buried underground—make up the most visible part of what is called the electric **grid**. The grid consists of the power generators, the power lines that transmit electricity to your home, the needed components that make it all work, your family, and the other homes and businesses in your community that use electricity.

TRANSMISSION LINES



Generating Electricity

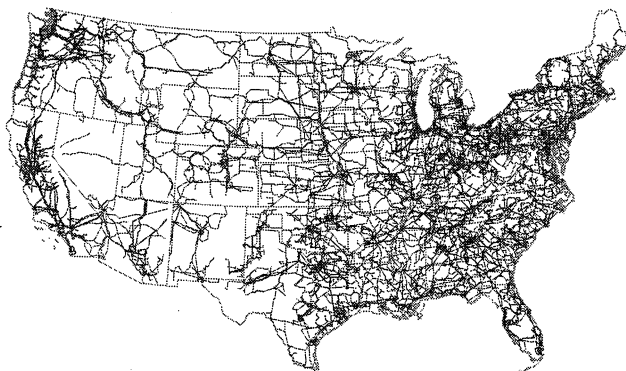
Three basic types of **power plants** generate most of the electricity in the United States—fossil fuel, nuclear, and hydropower. There are also wind, geothermal, waste-to-energy, and solar power plants, but together they generate about 6.25 percent of the electricity produced in the United States.

Fossil Fuel Power Plants: Fossil fuel plants burn coal, natural gas, or petroleum. These plants use the chemical energy in fossil fuels to superheat water into steam, which drives a **steam generator**. Fossil fuel plants are sometimes called thermal power plants because they use heat to generate electricity. Coal is the fossil fuel of choice for most electric companies, producing 38.64 percent of total U.S. electricity. Natural gas plants produce 27.52 percent. Petroleum produces 0.74 percent of the electricity in the U.S.

Nuclear Power Plants: Nuclear plants generate electricity much as fossil fuel plants do, except that the furnace is a **reactor** and the fuel is uranium. In a nuclear plant, a reactor splits uranium atoms into smaller elements, producing a great amount of heat in the process. The heat is used to superheat water into high-pressure steam, which drives a turbine generator. Like fossil fuel plants, nuclear power plants are thermal plants because they use heat to generate electricity. Nuclear energy produces 19.47 percent of the electricity in the U.S.

Hydropower Plants: Hydropower plants use the gravitational force of falling water to generate electricity. Hydropower is the cheapest way to produce electricity in this country, but there are few places where new dams can be built economically. There are many existing dams that could be retrofitted with turbines and generators. Hydropower is called a renewable energy source because it is renewed continuously during the natural water cycle. Hydropower produces five to ten percent of the electricity in the U.S., depending upon the amount of precipitation. In 2014, hydropower generated 6.19 percent of U.S. electricity.

The Continental U.S. Electric Grid



Data: Energy Information Administration



Electricity

The process starts at the power plant that serves your community, and ends with wires running from the distribution lines into your home. Outside your home is a meter with a digital read-out or an analog series of dials that measure the flow of energy to determine how much electricity you are using. Of course, there are many more parts to this process, ranging from substations and wires for different phases of current to safety devices and redundant lines along the grid to ensure that power is available at all times. You can see why the U.S. National Academy of Engineering has called America's electric grid "the greatest engineering achievement of the 20th century."

While this basic system of electricity transmission has worked well since the late 1880s, the increase in electric use in recent years has put a strain on the country's electric grid. The grid we use today was designed and put into place in the 1950s and 1960s, with much of the equipment planned to handle far smaller electrical use. More than 50 years later, a great deal of the equipment is reaching the end of its lifespan. At the same time, our electricity use has increased tremendously, putting a huge load on the system. Just look around your home at the TVs, DVRs, DVD players, computers, gaming consoles, lamps, air conditioners, and all the other appliances found in the typical home today, and you'll see a tremendous demand for electricity far above the basic lights and products used in homes back when today's system was set up.

The surge in demand for electricity has far exceeded the creation of new transmission facilities and equipment over the years. Compounding the problem is the fact that about two-thirds of the electricity produced in our power plants never reaches potential users because of losses in energy conversion and transmission. Because of the complexity and importance of the country's electric grid, many new governmental regulations increase the time needed to plan and install additional equipment to meet today's demands.

In the past few years, many parts of the country have experienced brief "brown outs" or longer periods of power outages, increasing public concern about the future of the system we use today. Think about this: right now, our electric grid is actually 98 percent reliable, meaning the power is usually there when we want it. But that very tiny percentage of time when the grid isn't working at its full capability costs consumers an estimated \$119 billion each year, including stoppages in automated equipment, computers that crash, and even the brief interruptions in the flow of energy and information in today's digital world that affect our work and our leisure activities.

For many years, America's electric grid has been a shining example of our technology and ability, and a major part of the country's prosperity, comfort, and security. To meet the country's growing electricity needs today and in the future, changes need to be made to the grid and the equipment it uses.

Economics of Electricity

How much does electricity cost? The answer depends on the cost to generate the power (65 percent), the cost of transmission (9 percent), and local distribution (25 percent). The average cost of electricity is about 12.5 cents per kWh (12.52¢) for residential customers, almost eleven cents (10.74¢) for commercial customers, and a little more than seven cents (7.10¢) for industrial customers. A major key to cost is the fuel used to generate the power. Electricity produced from natural gas, for example, costs more than electricity produced from uranium or hydropower. Location plays a part in electricity costs. Hawaii and New York residents can pay as much as 37 cents and 20 cents per kWh, respectively, while residents of Washington State pay only 8.7 cents per kWh.

Another consideration is how much it costs to build a power plant. A plant may be very expensive to construct, but the cost of the fuel can make it competitive to other plants, or vice versa. Nuclear power plants, for example, are very expensive to build, but their fuel—uranium—is very cheap. Coal-fired plants, on the other hand, are much less expensive to build than nuclear plants, but their fuel—coal—is more expensive.

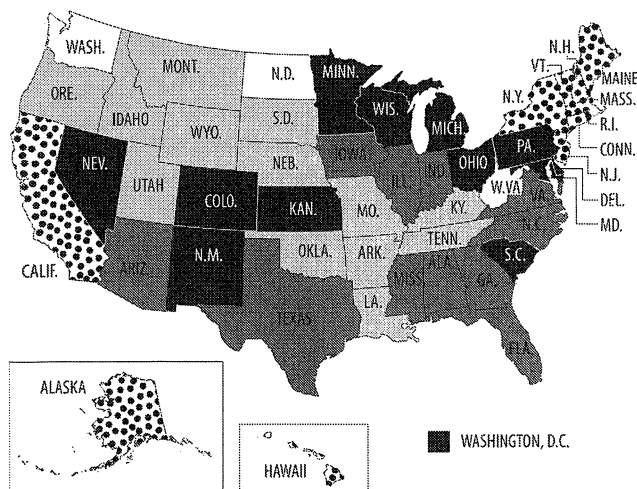
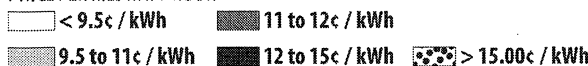
When calculating costs, a plant's efficiency must also be considered. In theory, a 100 percent energy efficient machine would change all the energy put into the machine into useful work, not wasting a single unit of energy. But converting a primary energy source into electricity involves a loss of usable energy, usually in the form of thermal energy. In general, it takes three units of fuel to produce one unit of electricity from a thermal power plant.

In 1900, most power plants were only four percent efficient. That means they wasted 96 percent of the fuel used to generate electricity. Today's thermal power plants are over eight times more efficient with efficiency ratings around 35 percent. Still, this means 65 percent of the initial thermal energy used to make electricity is lost. You can see this waste heat in the clouds of steam pouring out of giant cooling towers on newer power plants. A modern coal plant burns about 4,500 tons of coal each day, and about two-thirds of the energy in this is lost when the chemical energy in coal is converted into thermal energy, then into electrical energy. A hydropower plant, on the other hand, is about 90 percent efficient at converting the kinetic energy of moving water into electricity.

Secondary Energy Infobook

Average Residential Price for Electricity, 2014

PRICE PER KILOWATT-HOUR



Data: Energy Information Administration

But that's not all. Between three and eight percent of the electricity generated at a power plant must be used to run equipment. And then, even after the electricity is sent over electrical lines, another seven percent of the electrical energy is lost in transmission. Of course, consumers pay for all the electricity generated, lost or not.

The cost of electricity is affected by what time of day it is used. During a hot summer afternoon from noon to 6 p.m., there is a peak of usage when air-conditioners are working harder to keep buildings cool. Electric companies charge their industrial and commercial customers more for electricity during these peak load periods because they must turn to more expensive ways to generate power.

Deregulation and Competition

Beginning in the 1930s, most electric utilities in the U.S. operated under state and federal regulations in a defined geographical area. Only one utility provided service to any one area. Consumers could not choose their electricity provider. In return, the utilities had to provide service to every consumer, regardless of profitability.

Under this model, utilities generated the power, transmitted it to the point of use, metered it, billed the customer, and provided information on efficiency and safety. The price was regulated by the state.

As a result, the price of a kilowatt-hour of electricity to residential customers varied widely among the states and utilities, from a high of 16 cents to a low of four cents. The price for large industrial users varied, too. The types of generating plants, the cost of fuel, taxes, and environmental regulations were some of the factors contributing to the price variations.

Measuring Electricity

Power is the rate (time) of doing work. A **watt** is a measure of the electric power an electrical device uses. Most electrical devices require a certain number of watts to work correctly. Light bulbs, for example, are rated by watts (13, 32, 60, 75, 100 watts), as are appliances, such as a 1500-watt hairdryer.

A **kilowatt** is 1,000 watts. A **kilowatt-hour** is the amount of electricity used in one hour at a rate of 1,000 watts. Visualize adding water to a pool. In this analogy, a kilowatt is the rate at which water is added to the pool; a kilowatt-hour is the amount of water added to the pool in a period of time.

Just as we buy gasoline in gallons or wood in cords, we buy electricity in kilowatt-hours. Utility companies charge us for the kilowatt-hours we use during a month. If an average family of four uses 900 kilowatt-hours in one month, and the utility company charges 12 cents per kilowatt-hour, the family will receive a bill for \$108.00. ($900 \times \$0.12 = \108.00)

Electric utilities use **megawatts** and **gigawatts** to measure large amounts of electricity. Power plant capacity is usually measured in megawatts. One megawatt is equal to one million watts or one thousand kilowatts.

Gigawatts are often used to measure the electricity produced in an entire state or in the United States. One gigawatt is equal to one billion watts, one million kilowatts, or one thousand megawatts.

In the 1970s, the energy business changed dramatically in the aftermath of the Arab **oil embargos**, the advent of nuclear power, and stricter environmental regulations. Independent power producers and **cogenerators** began making a major impact on the industry. Large consumers began demanding more choice in providers.

In 1992, Congress passed the Energy Policy Act to encourage the development of a competitive electric market with open access to transmission facilities. It also reduced the requirements for new non-utility generators and independent power producers.

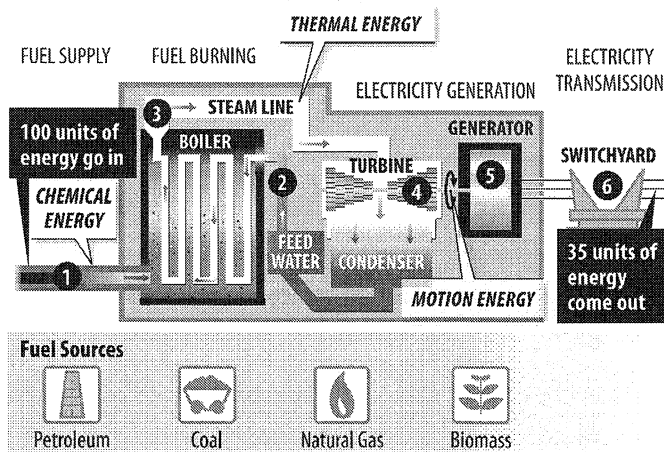
The **Federal Energy Regulatory Commission (FERC)** began changing rules to encourage competition at the wholesale level. Utilities and private producers could, for the first time, market electricity across state lines to other utilities.

Some state regulators are encouraging broker systems to provide a clearinghouse for low-cost electricity from under-utilized facilities. This power is sold to other utilities that need it, resulting in lower costs to both the buyer and seller. This wholesale marketing has already brought prices down in some areas.

Many states now have competition in the electric power industry. This competition can take many forms, including allowing large consumers to choose their provider and allowing smaller consumers to join together to buy power.

Efficiency of a Power Plant

Most thermal power plants are about 35 percent efficient. Of the 100 units of energy that go into a plant, 65 units are lost as one form of energy is converted to other forms. The remaining 35 units of energy leave the plant to do usable work.



How a Thermal Power Plant Works

1. Fuel is fed into a boiler, where it is burned to release thermal energy.
2. Water is piped into the boiler and heated, turning it into steam.
3. The steam travels at high pressure through a steam line.
4. The high pressure steam turns a turbine, which spins a shaft.
5. Inside the generator, the shaft spins coils of copper wire inside a ring of magnets. This creates an electric field, producing electricity.
6. Electricity is sent to a switchyard, where a transformer increases the voltage, allowing it to travel through the electric grid.



Electricity

In some states, individual consumers have the option of choosing their electric utility, much like people can choose their telephone carrier or internet service provider. Their local utility would distribute the power to the consumer and maintain the infrastructure.

This competition created new markets and new companies when a utility would separate its operation, transmission, and retail operations into different companies.

Future Demand

Home computers, microwave ovens, and video games have invaded our homes and they are demanding electricity! Electronic devices are part of the reason why Americans use more electricity every year.

The U. S. Department of Energy predicts the nation will need to increase its current generating capacity of 1,063,033 megawatts by one-fifth in the next 20 years. Demand for electricity is projected to increase in the future despite technological energy efficiency improvements in electric devices and appliances.

Some parts of the nation, especially California, have begun experiencing power shortages. Utilities can resort to rolling blackouts—planned power outages to one neighborhood or area at a time—because of the limited power. Utilities often warn that there will be increasing outages nationwide during the summer months even if consumers implement energy conservation techniques. However, well planned and managed energy efficiency and conservation programs can help avoid these electricity shortages.

Conserving electricity and using it more efficiently will help, but everyone agrees we need more power plants now. That's where the challenge begins. Should we use coal, natural gas, or nuclear power to generate electricity? Can we produce more electricity from renewable energy sources such as wind or solar? And where should we build new power plants? No one wants a power plant in his backyard, but everyone wants the benefits of electricity.

Right now, most new power generation comes from natural gas and wind. Natural gas is a relatively clean fuel and is abundant in the United States. Natural gas combined-cycle turbines use the waste heat they generate to turn a second turbine. Using this waste heat increases efficiency to 50 or 60 percent, instead of the 35 percent efficiency of conventional power plants.

Smart Grids

Another way to meet future demand is to update the electric grid and create a smart grid. The existing electric grid has worked well for many years, but developing a new, more efficient grid will help meet growing electricity demand. Updating the current grid and transmission lines would not only improve current operations, but would also open new markets for electricity generated by renewable energy sources.

Independent Power Producers

The business of generating electricity once was handled solely by electric utility companies, but today many others are generating—and selling—electricity. Independent power producers, sometimes called private power producers or non-utility generators, generate electricity using many different energy sources.

Independent power producers (IPPs) came on strong after the oil crisis of the 1970s. At that time, Congress wanted to encourage greater efficiency in energy use and the development of new forms of energy. In 1978, Congress passed the Public Utility Regulatory Policies Act or PURPA. This law changed the relationship between electric utilities and smaller IPPs. Under the law, a public utility company cannot ignore a nearby IPP. A utility must purchase power from an IPP if the utility has a need for the electricity, and if the IPP can make electricity for less than what it would cost the utility to make it.

The relationship between IPPs and utilities varies from state to state. Some utilities welcome the IPPs because they help them meet the growing demand for electricity in their areas without having to build new, expensive power plants. Other utilities worry that power from IPPs will make their systems less reliable and increase their costs. They fear that this may cause industries to think twice before locating to their areas.

For different reasons, some environmentalists also worry that IPPs may not be subject to the same pollution control laws as public utilities. In reality, the opposite is true. Because they are generally the newest plants, IPPs are subject to the most stringent environmental controls. In any case, most experts predict that IPPs will produce more and more electricity. Today, IPPs generate 37.96 percent of the nation's electricity.

A special independent power producer is a **cogenerator** (combined heat and power, CHP)—a plant that produces electricity and uses the waste heat to manufacture products. Industrial plants, paper mills, and fast-food chains can all be cogenerators. These types of plants are not new. Thomas Edison's plant was a cogenerator. Plants generate their own electricity to save money and ensure they have a reliable source of energy that they can control. Now, some cogenerators are selling the electricity they do not use to utilities. The electric utilities supply that energy to their customers. So, even though your family's electric bill comes from a utility company, your electricity may have been made by a local factory. Today, 3.83 percent of the electricity produced in the U.S. is cogenerated.