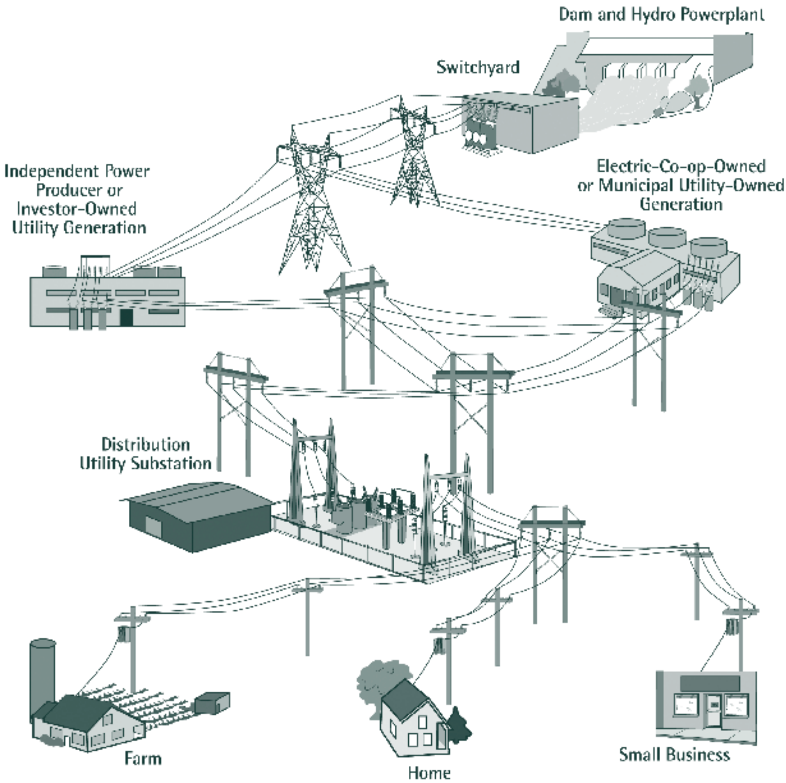
Harnessing Hydropower:

The Earth's Natural Resource

WESTERN AREA POWER ADMINISTRATION

How Electricity Reaches You



The hydropower system begins at a dam, where the powerplant converts the force of flowing water into electricity. Transmission lines carry electricity from the dam to a switchyard, which increases voltage for transmission across the country. Electricity is delivered to local utilities at substations, which decrease voltage for safe distribution to homes and businesses in cities and towns. Electricity also is used by rural consumers. It provides lights, runs electric motors and appliances, and operates pumps to irrigate crops, using the same water originally used to generate that power.

This brochure was published by Western Area Power Administration, a Department of Energy agency that markets and transmits Federal hydroelectric power in 15 western and central states. Western operates and maintains the transmission system from its four regional offices in Billings, Mont.; Phoenix, Ariz.; Loveland, Colo.; and Folsom, Calif. Power is marketed from these regions and our CRSP Management Center in Salt Lake City, Utah.

Introduction

The growth of civilization has been linked to our ability to capture and use the force of flowing water. Power from rushing water was first harnessed to process food and provide energy for factories and plants. Through an evolutionary process, that water power also became useful for efficient hydroelectric generation.

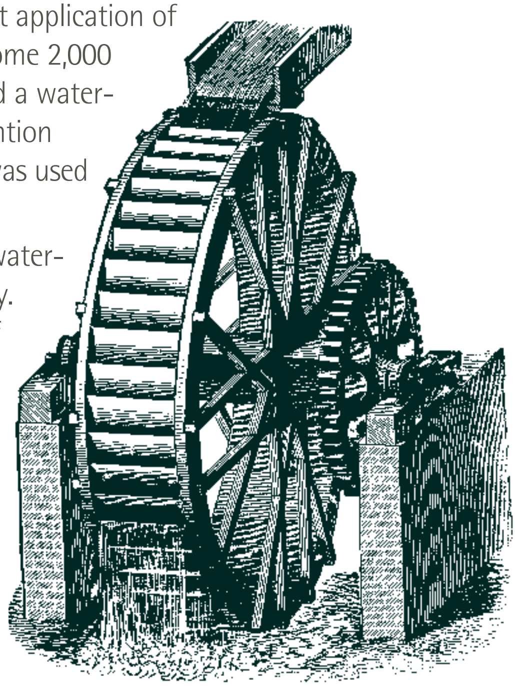
Because the fuel for hydropower is supplied by nature's own self-renewing hydrologic cycle—rain and snow filling the rivers, rivers rushing to the seas and water evaporating again to form clouds—it is an environmentally clean, renewable and economical energy source. Today hydroelectric plants use water power to produce 7 percent of the nation's electrical supply.

History of Hydropower

The water-driven machine is an ancient invention. In fact, the waterwheel was the first application of power-driven machinery. Some 2,000 years ago, the Romans developed a waterwheel for milling flour. This invention became popular in Europe and was used widely by the 11th century.

Hundreds of years later, the waterwheel had increased its efficiency. However, before the discovery of electricity, machines powered by the wheel had to be directly coupled to it by shafts or belts. Thus, factories were built near rivers.

Even with this limitation, dependence on water power increased. In the United States, water supplied energy for textile industries in New England and



Waterwheels converted the energy of motion to useful energy, allowing people to put power to work.

By 1896, 300 hydroelectric powerplants were operating in the United States.

for the Niagara Falls power system—both of which were constructed before falling water was used to produce electric power.

In its earliest days, the Niagara Falls Power Company channeled water to small wheels of several manufacturers. Within 10 years, the operation grew to become a central powerhouse, transmitting mechanical energy to nearby customers using ropes, belts and shafts. Later, Niagara Falls became the site for the first large hydroelectric installation in the United States.

Then in 1831, Michael Faraday discovered the principles of electromagnetic induction, which led to the invention of the electric generator and the electric transformer. Faraday found that electrical current flowed in a closed loop of wire as it was moved through a magnetic field.

After 50 years of development, an electric generator directly produced hydroelectric power at an English plant in 1881. This hydroelectric facility in Goldaming, England, supplied power for three street lamps.

The first U.S. hydroelectric powerplant began operating in 1882 in Appleton, Wisc. This facility was rated at one horsepower, or 746 watts. It served two paper mills and a residence. Electricity was a new source of power, but how to control this resource was not well understood. Factories remained clustered beside the old waterwheel until ways to transmit hydroelectricity were developed.

In the United States, the first hydroelectric alternating current was transmitted in 1889 along power lines from Oregon City to Portland, Ore., 13 miles away. By 1896, 300 hydroelectric powerplants were operating in the United States.

As the population increased and industry grew, the value and application of this resource became increasingly apparent. Today, more than 1,400 hydroelectric plants in this country supply 7 percent of the nation's electrical energy. Modern turbines and generators efficiently convert water's energy into electricity. High-voltage powerlines span the nation, carrying electrical energy to even the most remote areas.

Nature's Water Cycle

The fuel for hydropower—water—is supplied by nature's own hydrologic cycle. Falling rain and snow fill rivers. Rivers flow to oceans, and the heat of the sun causes evaporation. Water vapor rises in the atmosphere, where it forms clouds. When this water vapor condenses, rain falls again, and the process repeats itself.

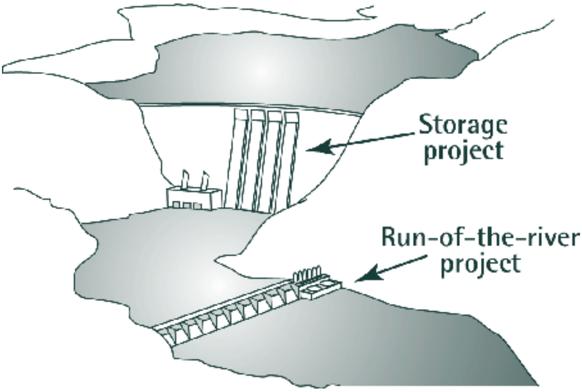
As water flows, it becomes a source of kinetic energy (the energy of motion). The old waterwheel transformed the kinetic energy of flowing water to mechanical (useful) energy.

Snow and rain fuel the hydrologic cycle by flowing downstream to dams where the water power is harnessed for our use.

Today, flowing water turns turbines. These rotating devices convert falling water into mechanical energy and are connected to power generators, which change mechanical energy into electrical energy.

Water Into Energy: Hydropower Plants

Two types of hydropower plants exist. The first is a run-of-the-river plant that uses little or no stored water to provide flow through the turbines. Seasonal changes in stream or river flow and weather conditions affect the plant's output.



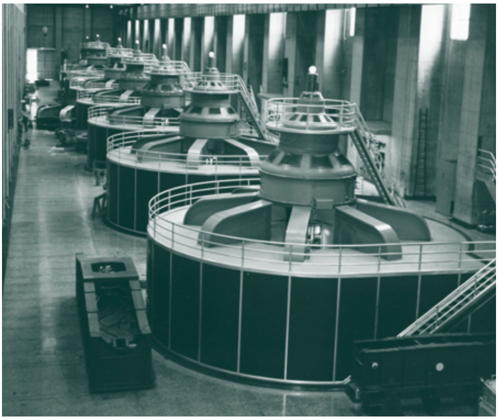
Run-of-the-river plants rely on seasonal water flow instead of stored water to supply electricity.

The second type, a storage plant or reservoir (dam), offers a more constant supply of electricity. A dam on the river stores the water flowing down from the mountains, creating a reservoir. This man-made lake acts much like a battery, holding the power of water in reserve.

Dams do more than just supply water for hydroelectric power, however. Dams regulate rivers for navigation, provide flood control and store water for irrigation, recreational, industrial and household uses.

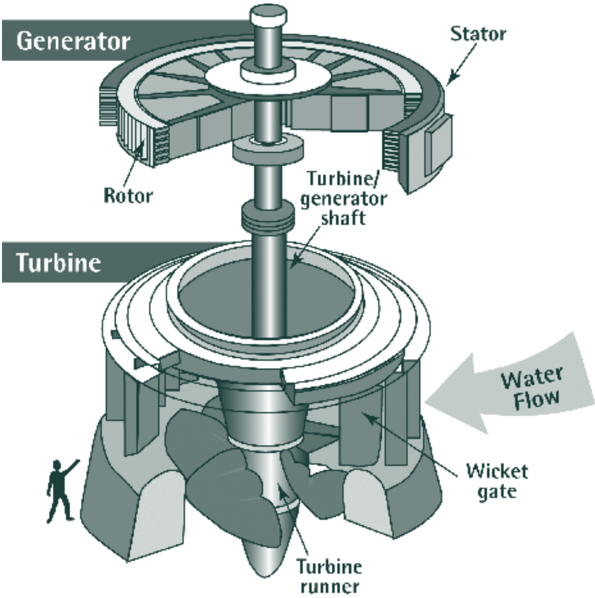
To generate power, this water is released through the powerplant and becomes kinetic energy, or energy in motion.

The energy-producing potential of a hydro powerplant depends on the difference in elevation between the reservoir (forebay) and the water below the dam (tailwater) and the volume of water available for release. The greater volume of water stored in the reservoir, and the greater the difference in elevation, the more potential for energy production.



Turbines convert falling water into mechanical energy. Generators then change it to electrical energy.

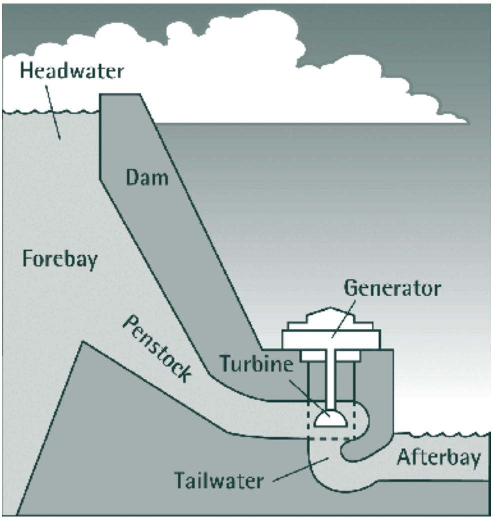
In power generation, water must fall from a higher elevation to a lower one to release its stored energy. The difference between these elevations (the water levels in the forebay and tailbay) is called head. Dams are divided into three categories: high-head (800 or more feet), medium-head (100 to 800 feet) and low-head (100 feet or less). Some plants may operate as a medium-head plant part of the year and as a low-head plant other parts of the year, depending on the amount of rainfall and snow melt.



Flowing water turns the turbine which then converts the water into mechanical energy.

Turbines and Generators

As energy is needed for power generation, water stored behind the dam flows through a penstock, or tunnel, to a turbine-driven generator below the dam. A turbine converts falling water into mechanical energy. The force of water on the turbine blades spins the turbines, which, in turn, drive a rotor (the moving part of a generator). The rotor contains coils of wire, wound on an iron frame to create a strong magnetic field. As the rotor's mag-



Power is generated from water behind the dam which flows through a pipe called a penstock. The water then turns a turbine that drives a generator.

netic field sweeps past the generator's stationary coil, it converts mechanical energy into electrical energy.

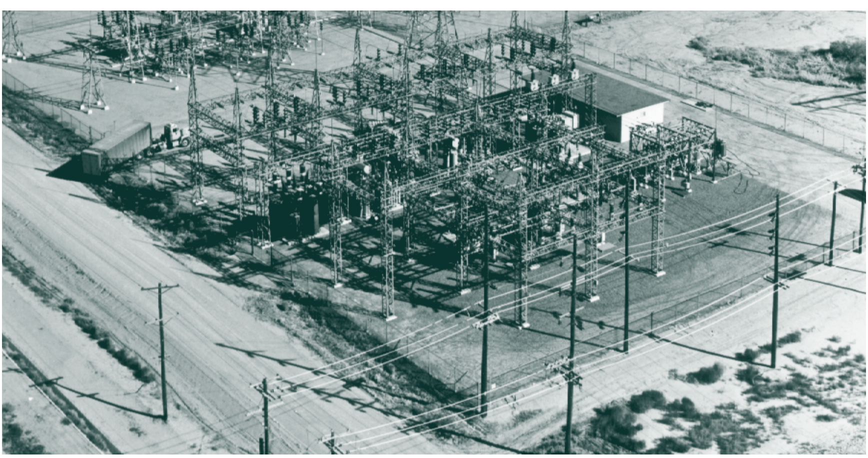
After the water passes over the turbine blades, it exits through an exhaust structure under the turbine called the draft tube. The water then flows back into the riverbed in an area called the tail-race or afterbay and on down the river.

From the Powerplant to the Line

Hydropower plants generate electricity. A transmission system carries it from the plant to homes and businesses that depend on a reliable power source.

Electricity undergoes several changes along the way. The low-voltage (13.8 kV for example) electricity produced by the generator at the powerplant flows through a large electrical conductor, or line, to a powerplant switchyard. In the switchyard, devices called transformers increase voltage to a level required for efficient transmission.

High voltage (the pressure of the electrical current) is needed to transmit power efficiently over long distances. As the electrical charge, known as current, flows through the conductor, some of it gets used up as heat. This energy converted to heat is known as "losses." The greater the current, the higher the losses will be.

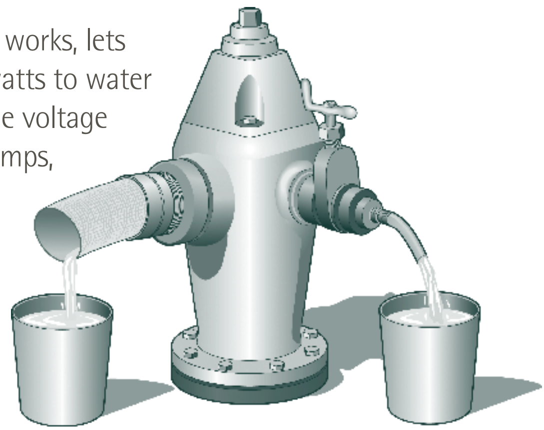


Transmission lines carry electricity from the dam to a switchyard, which increases voltage for transmission across the country.

Power is the product of voltage times current, and losses are related to current (not voltage); thus, it is more efficient to transmit power with higher voltages and lower current.

To keep losses small, transformers in switchyards increase electrical voltage. The transformers in the switchyard "step up" (increase) the voltage to 115 kilovolts or higher for cross-country transmission to homes and businesses. Stepping up voltage does not increase the amount of power. The electrical wattage or power level stays constant.

To understand how this works, lets compare volts, amps and watts to water running through a hose. The voltage is the water pressure. The amps, or current, is the flow of water, and watts are the amount of water. So, if you increase the size of the hose (current or amps), the water pressure (voltage) would drop if the amount of water (watts) running through the hose remains the same.

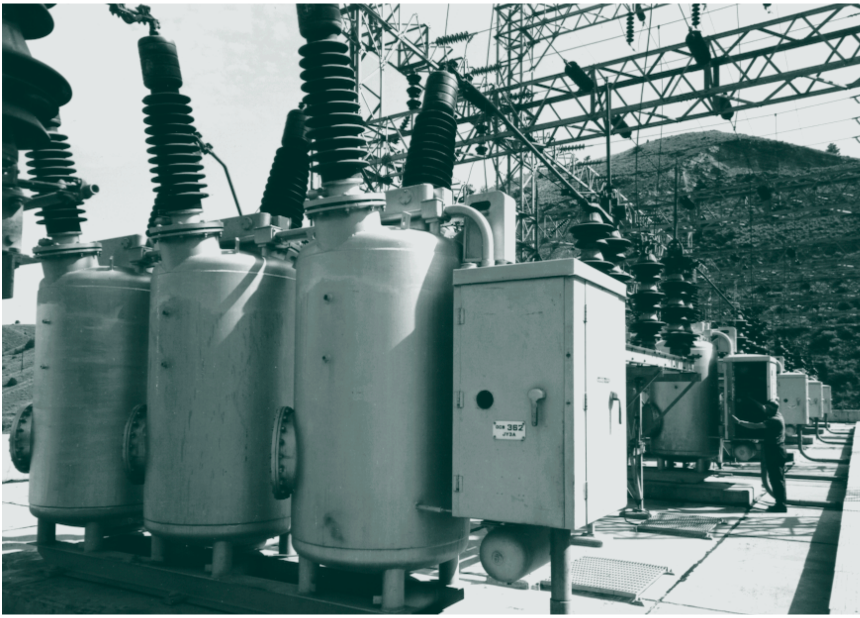


To understand how voltage works, think of water running through a hose. If you increase the hose size (current or amps), the water pressure (voltage) would drop if the amount of water (watts) through the hose remains the same.

Transmission Systems

High-voltage transmission lines act much like a highway system. Instead of cars, the lines carry electrical energy from hydropower, fossil fuel and nuclear plants and other generators to local utilities across the country. These utilities send electricity to homes and businesses.

A transmission system includes more than just transmission lines. Like a road system, the traffic on a transmission system must be controlled. Relays, circuit breakers and other types of equipment act as traffic control devices.



Circuit breakers help protect the power grid from damage.

Relays react quickly to problems on the transmission line. They work with circuit breakers to protect the power grid from damage. Lightning strikes, downed lines and other conditions that cause sudden increases or decreases in voltage can damage other parts of the system if they aren't isolated quickly.

When a circuit breaker is closed, it provides a connection between two sections of transmission line. If lightning strikes a line, for example, the relay will note the change in voltage and current and then close. As the relay closes, it opens a circuit breaker, stopping the flow of electricity between sections of a transmission system. Opening the breaker isolates the line damaged by the lightning from the rest of the system, protecting the flow of power.

Of course, if a circuit breaker opens on a line serving a city or town, it can cause a loss of electrical service. When that happens, power system dispatchers must work to provide power through an alternate route. Just as highway repairs can cause cars to take a detour, faults in a power system mean dispatchers have to find a different way to get electricity to where we use it.

The System's Nerve Center

A power dispatching center serves as the brain of a transmission system. Dispatchers monitor demand for electricity and potential water power available to supply it. They communicate with powerplant operators and tell them when to increase generation and when to decrease it based on demand.

Each dispatch center controls electrical transmission in a specific area. Marketing staff sell and buy power to meet the needs of local utilities and schedule generation and transmission. Meters, graphs, displays and computer terminals tell dispatchers about generation at various plants, load demand and problems affecting the system. If part of the system is taken out of service resulting in service interruptions, dispatchers work to restore power to customers.

Through regular maintenance, many problems can be prevented before they happen. Maintenance staff routinely check all substation equipment and perform maintenance according to manufacturer requirements. They also X-ray cables, check for deterioration of wooden poles, test connections and perform many other functions.

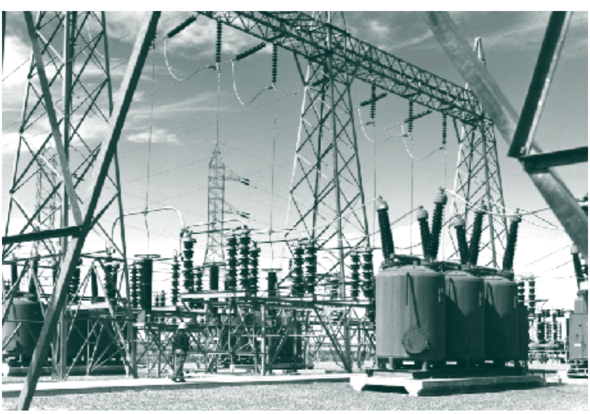
At a dispatch center, dispatchers monitor the demand for electricity and the power available to meet the demand.

From the Utility to You, the Consumer

Before electricity reaches homes or businesses, substation transformers reduce voltage from transmission levels to distribution levels. Substations work like a railroad switchyard, directing electrical current toward its destination. At a substation, a transmission line leads to a high-voltage bus, which is a rigid line that connects equipment of the same voltage. Step-down transformers connected to the bus lower voltage to a level safe for transporting through city streets. Another line carries electricity from a high-voltage bus to a low-voltage bus connected to the utility's main distribution system. From there, lines carry the power throughout the utility's service area.

The wires of the primary system may be carried on poles above the ground or laid underground through a system of cables and ducts. The method depends on the number of customers served, the number of transformers needed, access for operating and repairing lines, cost and the appearance of the area served.

These main distribution lines carry power to secondary lines. At the connection between the primary and secondary lines, a small transformer immediately outside the residence or business steps down the voltage one last time, to 240/120 volts for homes and up to 600 volts for industrial and commercial customers, depending on their needs.



At substations, voltage is reduced for local distribution.

Wires leading to various buildings tap the secondary circuits. For an overhead system, the tap occurs at the nearest pole. Current flows through wires from the pole to customers' homes and businesses. These wires pass through a metal conduit, or tube, to the customer's meter and fuse (or circuit breaker) box.

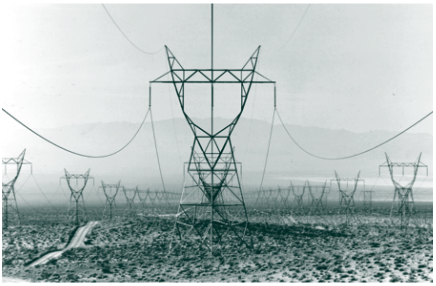
In an underground distribution system, the customer's line taps the circuit at the nearest connection box or manhole. The current goes through wires in a duct to the customer's home. The duct may pierce the basement wall, or it may go up through the surface of the ground and connect to a box on the wall. The wires in the duct connect with the meter and fuse box.

Small transformers outside a home or business step down voltage one last time.

In either case, the customer's wiring finishes the delivery from the fuse box, carrying electricity to wall plugs, light fixtures and other outlets.

The Power Grid

Transmission lines throughout the United States are connected to each other. Your utility's power comes from the same lines as the power in neighboring communities, and even neighboring states. This system of transportation for electricity is called the "power grid."



The system for transporting electricity is called the power grid.

Hydropower plants provide only part of the nation's electricity. Powerplants that burn fossil fuels create steam to power turbines and run generators. Nuclear plants use energy from splitting atoms to produce electricity. Solar and wind-powered systems convert energy from the sun and wind to produce electricity. These sources all use the same transmission lines to bring power to your home. This power grid allows electricity to be shared so that varying demands can be met.

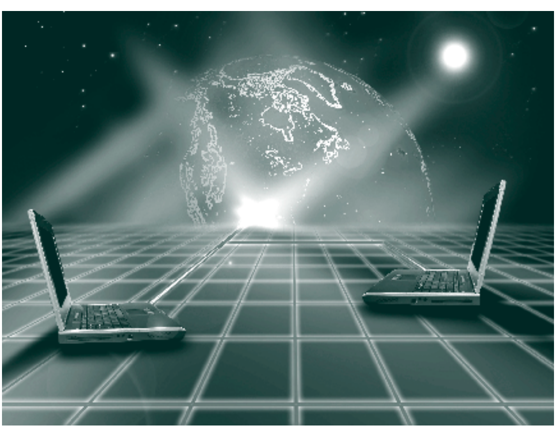
The United States has three main power grids. One serves the eastern states, one serves the western states and one serves Texas. Utilities in each of these areas have access to the same high-voltage lines. If one utility's generation falls short of customer demand, another utility provides additional power. Linking utilities together provide more reliable electrical service.

Hydropower in the 21st Century

Hydroelectric generation has evolved into a sophisticated and complex science. Weather satellites provide data to predict rainfall and stream-flow long before water actually reaches reservoirs. Snowfall and stream-flow measurements also indicate the amount of water expected during spring runoff. Although meteorologists compile plans and forecasts months in advance, some factors affecting water levels remain unpredictable. Rain, temperature and wind all influence reservoir levels, and these elements may change from day to day.

Water levels in each storage reservoir are planned far in advance, and the process is complex; sometimes it involves interstate and international agreements. When planning water releases, engineers must consider that irrigation, recreation, navigation, domestic uses and wildlife conservation also depend on the flow of rivers and the depths of reservoirs.

Additionally, computers have become vital tools for power systems. Today, controlling transmission and finding problems quickly are exact sciences. Previously, dispatchers made these transactions over the telephone. Now, microwave transmitters and other communication equipment send split-second messages to control generation and control and to report trouble.



Computers process data about supply and demand and the system then gives instructions to remote powerplants or substations.

Computers also predict how much power consumers will use. They process data about supply and demand and the economics of using one power supply over another. This system in the power-control center then gives instructions to remote powerplants or substations.

Energy and the Environment

Energy is essential to the world today. We fuel our energy needs with natural resources, such as coal, nuclear fuel, oil, gas and hydropower. Most of these sources are fossil fuels, which are not renewable and exist in limited amounts. To reach them, we drill oil wells, tap natural gas supplies or mine coal and uranium. To put water to work on a large scale, we build storage dams.

Americans want clean air and water and a pleasing environment, but we also need energy to heat and light homes and run machines. Balancing these two goals is a challenge.

The situation seems simple: Either the demand for electrical power must be curbed, or more power must be produced in ways that don't destroy the environment. Neither solution is easy.

Conservation helps us save electricity, but our population continues to grow. Growth increases demand for electrical power. Natural resources will continue to be used, so the wisest solution is continued conservation combined with careful planning—or assessing all the choices and picking the best ones.

Hydroelectric generation is an economical, renewable-energy source that has been proven safe and nonpolluting. It is the most efficient converter of solar energy presently available and can provide energy upon a moment's notice.

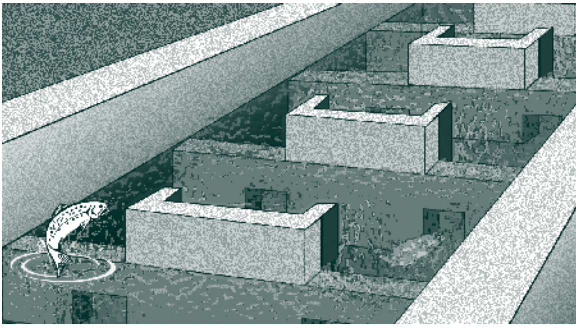
Hydropower offers many advantages over other power sources:

Reservoirs offer many recreational opportunities, such as boating. Balancing the need for a pleasing environment and the energy we need for everyday functions is a challenge.

- Hydroelectric powerplants use renewable resources.
- Hydropower does not contribute to air, land or water pollution.
- Hydropower generators have low outage rates and low maintenance and operating costs.
- Hydro turbines can provide startup power quickly if a systemwide failure occurs. They can be operated automatically and by remote control.
- Hydropower generators have a long life expectancy.

The reservoir of a hydroelectric project can provide many benefits not possible with other forms of generation. Reservoirs have scenic and recreation value for campers, fishing enthusiasts and those who enjoy water sports. The water gives a home to fish and wildlife, and reservoirs provide domestic water supplies, irrigation for agriculture and flood control. Dams can improve downstream conditions by allowing mud and other debris to settle out.

Responding to Environmental Concerns



Fish ladders help salmon migrate upstream.

Western has participated in many innovative programs in recent years to ensure that hydropower generation protects the downstream environment, such as fish and wildlife. For example, fish screens have been added to prevent fish from swimming through dam turbines and fish ladders have been constructed to assist salmon in migrating upstream.

Western is committed to continue searching for innovative ways to protect the hundreds of plant and animal species that depend on the rivers, lands and reservoirs.

Meeting Peak Demands

Millions of barrels of oil are saved by "peaking" with hydropower. Demands for power vary greatly at different times of the day, and from season to season. Often, energy use reaches its highest level, or peak, during summer daylight hours when air conditioners are running. In farm communities, peaks can occur when grain-drying machinery operates, or irrigation pump use is great.

Because they start easily and quickly and change power output rapidly, hydroelectric plants are ideal for times of peak demand. They also complement large thermal plants (coal and nuclear), which are most efficient in serving base power loads.

Usually, a utility company would have to build additional fossil-fueled powerplants (oil or gas) to meet peak demand. Through planning and cooperation between public and private utilities and the government, hydropower may eliminate the need for more plants by providing needed power during peak periods.

On farms, peak demands for power can occur when irrigation pumps are running.

Lighting the Future

Currently, we're using only a part of hydropower's potential. Studies show that many potential sites for conventional hydropower could be developed. If all these sites could be used, hydropower output might double.

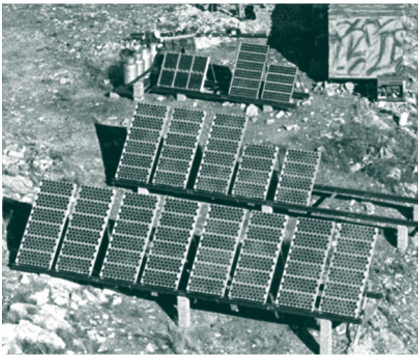
However, not all these sites can be developed. Unfavorable terrain eliminates some; society's concern about the environment eliminates others. Public resistance to building dams that would flood scenic or agricultural land is increasing. Sites for new, large dams are becoming non-existent.

Other ways to increase hydropower output include:

- Increasing output at existing plant
- Using pumped storage systems
- Tying hydropower to other forms of energy (such as solar)
- Improving existing equipment at many existing hydropower plants can increase capacity and, sometimes, lower generating costs. By "uprating," generators can made make the most of available stored water, increasing output.
- Uprating can be much less expensive than adding to the capacity of fuel-burning plants. Also, uprating can save fossil fuel.
- Adding generating units at existing plants can also increase output. Sometimes, additional powerplants can be built.

Another promising source of energy is low-head hydropower. Large, high-head dams produce more power at lower costs than low-head dams, but construction may be limited by lack of suitable sites, environmental concerns or cost.

In contrast, many existing small dams offer ideal sites for small generating plants. New low-head dams also could increase output. The ability to generate power where it is needed, reducing losses from transmission, makes these plants useful.



Photovoltaic panels, like the ones pictured on the left, harness the sun's energy and provide one alternative to meeting the increasing demand for electricity. Low-head dams like the one at Nimbus in California, pictured at the right, are also a promising source of energy.

An Important Source of Energy

Hydroelectric generators use a renewable resource. They do not pollute the air. They operate reliably, adapt easily to different needs and require a minimum of manpower. Low maintenance costs and outage rates and long life expectancy are other benefits.

Hydropower is a valuable resource that has evolved from the simple idea of the waterwheel. Through the years, technology improvements have made it efficient and reliable. Today, hydrosystem generation remains one of our nation's important sources of energy. Through careful planning, use and management, Western is committed to seeing that consumers receive the benefits of this resource.

The constant renewal of the hydrological cycle through rain and snow makes water a valuable energy resource for today and tomorrow.

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