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ENERGY EFFICIENCY AND RENEWABLE ENERGY CLEARINGHOUSE

Renewable Energy: An Overview

What is Renewable Energy?

Renewable energy uses energy sources that are continually replenished by nature—the sun, the wind, water, the Earth's heat, and plants. Renewable energy technologies turn these fuels into usable forms of energy—most often electricity, but also heat, chemicals, or mechanical power.

Why Use Renewable Energy?

Today we primarily use fossil fuels to heat and power our homes and fuel our cars. It's convenient to use coal, oil, and natural gas for meeting our energy needs, but we have a limited supply of these fuels on the Earth. We're using them much more rapidly than they are being created. Eventually, they will run out. And because of safety concerns and waste disposal problems, the United States will retire much of its nuclear capacity by 2020. In the meantime, the nation's energy needs are expected to grow by 33 percent during the next 20 years. Renewable energy can help fill the gap.

Even if we had an unlimited supply of fossil fuels, using renewable energy is better for the environment. We often call renewable energy technologies "clean" or "green" because they produce few if any pollutants. Burning fossil fuels, however, sends greenhouse gases into the atmosphere, trapping the sun's heat and contributing to global warming. Climate scientists generally agree that the Earth's average temperature has risen in the past century. If this trend continues, sea levels will rise, and scientists predict that floods, heat waves, droughts, and other extreme weather conditions could occur more often.

Other pollutants are released into the air, soil, and water when fossil fuels are burned. These pollutants take a dramatic toll on the environment—and on humans. Air pollution contributes to diseases like asthma. Acid rain from sulfur dioxide and nitrogen oxides harms plants and fish. Nitrogen oxides also contribute to smog.

National Park Service, NREL/PIX04924

A PV-system at the Pinnacles National Monument in California eliminates a $20,000 annual fuel bill for a diesel generator that produced each year 143 tons of carbon dioxide—a greenhouse gas.

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Hydropower is our most mature and largest source of renewable power…

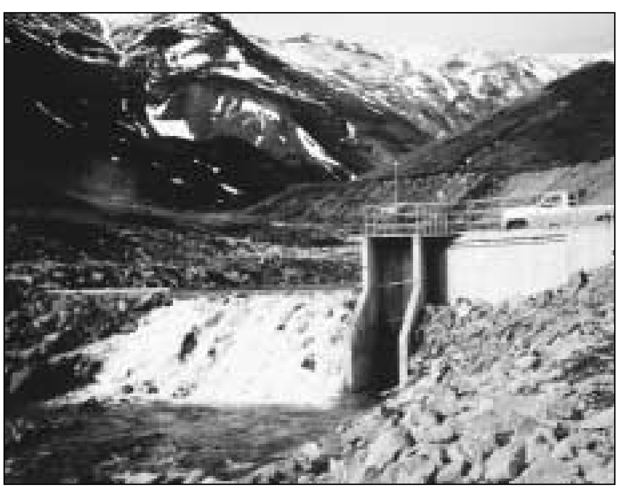
Renewable energy will also help us develop energy independence and security. The United States imports more than 50 percent of its oil, up from 34 percent in 1973. Replacing some of our petroleum with fuels made from plant matter, for example, could save money and strengthen our energy security.

Renewable energy is plentiful, and the technologies are improving all the time. There are many ways to use renewable energy. Most of us already use renewable energy in our daily lives.

Hydropower

Hydropower is our most mature and largest source of renewable power, producing about 10 percent of the nation's electricity. Existing hydropower capacity is about 77,000 megawatts (MW). Hydropower plants convert the energy in flowing water into electricity. The most common form of hydropower uses a dam on a river to retain a large reservoir of water. Water is released through turbines to generate power. "Run of the river" systems, however, divert water from the river and direct it through a pipeline to a turbine.

Hydropower plants produce no air emissions but can affect water quality and wildlife habitats. Therefore, hydropower plants are now being designed and operated to minimize impacts on the river. Some of them are diverting a portion of the flow around their dams to mimic the natural flow of the river. But while this improves the wildlife's river habitat, it also reduces the power plant's output. In addition, fish ladders and other approaches, such as improved turbines, are being used to assist fish with migration and lower the number of fish killed.



Duane Hippe, NREL/PIX04410

A small-scale hydropower system in King Cove, Alaska, provides residents in this remote area with a less expensive source of electricity.

Bioenergy

Bioenergy is the energy derived from biomass (organic matter), such as plants. If you've ever burned wood in a fireplace or campfire, you've used bioenergy. But we don't get all of our biomass resources directly from trees or other plants. Many industries, such as those involved in construction or the processing of agricultural products, can create large quantities of unused or residual biomass, which can serve as a bioenergy source.

Biopower

After hydropower, biomass is this country's second-leading resource of renewable energy, accounting for more than 7,000 MW of installed capacity. Some utilities and power generating companies with coal power plants have found that replacing some coal with biomass is a low-cost option to reduce undesirable emissions. As much as 15 percent of the coal may be replaced with biomass. Biomass has less sulfur than coal. Therefore, less sulfur dioxide, which contributes to acid rain, is released into the air. Additionally, using biomass in these boilers reduces nitrous oxide emissions.

A process called gasification—the conversion of biomass into gas, which is burned in a gas turbine—is another way to generate electricity. The decay of biomass in landfills also produces gas, mostly methane, which can be burned in a boiler to produce steam for electricity generation or industrial processes. Biomass can also be heated in the absence of oxygen to chemically convert it into a type of fuel oil, called *pyrolysis oil.* Pyrolysis oil can be used for power generation and as a feedstock for fuels and chemical production.

Biofuels

Biomass can be converted directly into liquid fuels, called biofuels. Because biofuels are easy to transport and possess high energy density, they are favored to fuel vehicles and sometimes stationary power generation. The most common biofuel is ethanol, an alcohol made from the fermentation of biomass high in carbohydrates. The current largest source of ethanol is corn. Some cities use ethanol as a gasoline additive to help meet air quality standards for

Warren Gretz, NREL/PIX04744

This gasifier in Burlinton, Vermont, converts biomass into a clean gas for electricity production

ozone. Flex-fuel vehicles are also now on the market, which can use a mixture of gasoline and ethanol, such as E85—a mixture of 85 percent ethanol and 15 percent gasoline. Another biofuel is biodiesel, which can be made from vegetable and animal fats. Biodiesel can be used to fuel a vehicle or as a fuel additive to reduce emissions.

Corn ethanol and biodiesel provide about 0.4 percent of the total liquid fuels market. To increase our available supply of biofuels, researchers are testing crop residues—such as cornstalks and leaves—wood chips, food waste, grass, and even trash as potential biofuel sources.

If you've ever burned wood in a fireplace or campfire, you've used bioenergy.

Biobased Products

Biomass—corn, wheat, soybeans, wood, and residues—can also be used to produce chemicals and materials that we normally obtain from petroleum. Industry has already begun to use cornstarch to produce commodity plastics, such as shrinkwrap, plastic eating utensils, and even car bumpers. Commercial development is underway to make thermoset plastics, like electrical switch plate covers, from wood residues.

Geothermal Energy

The Earth's core, 4,000 miles below the surface, can reach temperatures of 9000° F. This heat—geothermal energy—flows outward from the core, heating the surrounding area, which can form underground reservoirs of hot water and steam. These reservoirs can be tapped for a variety of uses, such as to generate electricity or heat buildings. By using geothermal heat pumps (GHPs), we can even take advantage of the shallow ground's stable temperature for heating and cooling buildings.

The geothermal energy potential in the uppermost 6 miles of the Earth's crust amounts to 50,000 times the energy of all oil and gas resources in the world. In the United States, most geothermal reservoirs are located in the western states, Alaska, and Hawaii. GHPs, however, can be used almost anywhere.

Geothermal Electricity Production

Geothermal power plants access the underground steam or hot water from wells drilled a mile or more into the earth. The steam or hot water is piped up from the well to drive a conventional steam turbine, which powers an electric generator. Typically, the water is then returned to the ground to recharge the reservoir and complete the renewable energy cycle.

There are three types of geothermal power plants: dry steam, flash steam, and binary cycle. Dry steam plants draw from reservoirs of steam, while both flash steam and binary cycle plants draw from reservoirs of hot water. Flash steam plants typically use water at temperatures greater than 360°F. Unlike both steam and flash plants, binary-cycle plants transfer heat from the water to what's called a working fluid. Therefore binary cycle plants can operate using water at lower temperatures of about 225° to 360°F.

Joel Renner, INEEL, NREL/PIX07658

The Steamboat Hills geothermal power plant in Steamboat Springs, Nevada has an electricity generation capacity of 13.5 MW.

All of the U.S. geothermal power plants are in California, Nevada, Utah, and Hawaii. Altogether about 2800 MW of geothermal electric capacity is produced annually in this country.

Geothermal Direct Use

If you've ever soaked in a natural hot spring, you're one of millions of people around the world who has enjoyed the direct use of geothermal energy. Direct-use applications require geothermal temperatures between about 70° to 302°F—lower than those required for electricity generation. The United States already has about 1,300 geothermal direct-use systems in operation.

Altogether about 2800 MW of geothermal electric capacity is produced annually in this country.

In a direct-use system, a well is drilled into a geothermal reservoir, which provides a steady stream of hot water. Some systems use the water directly, but most pump the water through what's called a *heat exchanger.* The heat exchanger keeps the water separate from a working fluid (usually water or a mixture of water and antifreeze), which is heated by the geothermal water. The working fluid then flows through piping, distributing the heat directly for its intended use.

The heated water or fluid can be used in a building to replace the traditional heat source—often natural gas—of a boiler, furnace, and hot water heater. Some cities and towns actually have large direct-use heating systems—called district heating—that provide many buildings with heat. Geothermal direct use is also used in agriculture—such as for fish farms and to heat greenhouses—and for industrial food processing (vegetable dehydration).

Geothermal Heat Pumps

While air temperatures can vary widely through the seasons, the temperatures of the shallow ground only range from 50° to 70°F depending on latitude. GHPs draw on this relatively stable temperature as a source for heating buildings in the winter and keeping them cool in the summer.

Warren Gretz, NREL/PIX06537

This homeowner in Aurora, Colorado, uses a GHP to heat and cool his home.

Through underground piping, a GHP discharges heat from inside a building into the ground in the summer, much like a refrigerator uses electricity to keep its interior cool while releasing heat into your kitchen. In the winter, this process is reversed; the GHP extracts heat from the ground and releases it into a building.

Because GHPs actually move heat between homes and the earth, instead of burning fuels, they operate very cleanly and efficiently. In fact, GHPs are at least three times more efficient than even the most energy-efficient furnaces on the market today.

Solar Energy

Solar technologies tap directly into the infinite power of the sun and use that energy to produce heat, light, and power.

Passive Solar Lighting and Heating

People have used the sun to heat and light their homes for centuries. Ancient Native Americans built their dwellings directly into south-facing cliff walls because they knew the sun travels low across the southern sky in the Northern Hemisphere during the winter. They also knew the massive rock of the cliff would absorb heat in winter and protect against wind and snow. At the same time, the cliff-dwelling design blocked sunlight during the summer, when the sun is higher in the sky, keeping their dwellings cool.

The modern version of this sun-welcoming design is called *passive solar* because no pumps, fans, or other mechanical devices are used. Its most basic features include large, south-facing windows that fill the home with natural sunlight, and dark tile or brick floors that store the sun's heat and release it back into the home at night. In the summer, when the sun is higher in the sky, window overhangs block direct sunlight, which keeps the house cool. Tile and brick floors also remain cool during the summer.

Passive solar design combined with energy efficiency will go even further. Energy-efficient features such as energy-saving windows and appliances, along with good insulation and weatherstripping, can make a huge difference in energy and cost savings.

Solar Water Heating

Solar energy can be used to heat water for your home or your swimming pool. Most solar water-heating systems consist of a solar collector and a water storage tank.

Solar water-heating systems use collectors, generally mounted on a south-facing roof, to heat either water or a heat-transfer fluid, such as a nontoxic antifreeze. The heated water is then stored in a water tank similar to one used in a conventional gas or electric water-heating system.

The Four Times Square Building in New York City uses thin-film PV panels to reduce the building's power load from the utility grid.

There are basically three types of solar collectors for heating water: flat-plate, evacuated-tube, and concentrating. The most common type, *a flat-plate collector,* is an insulated, weatherproof box containing a dark absorber plate under a transparent cover. *Evacuated-tube collectors* are made up of rows of parallel, transparent glass tubes. Each tube consists of a glass outer tube and an inner tube, or absorber, covered with a coating that absorbs solar energy but inhibits heat loss. *Concentrating collectors* for residential applications are usually parabolic-shaped mirrors (like a trough) that concentrate the sun's energy on an absorber tube called a receiver that runs along the axis of the mirrored trough and contains a heat-transfer fluid.

Passive solar building techniques turn homes into huge solar collectors.

All three types of collectors heat water by circulating household water or a heat-transfer fluid such as a nontoxic antifreeze from the collector to the water storage tanks. Collectors do this either passively or actively.

Passive solar water-heating systems use natural convection or household water pressure to circulate water through a solar collector to a storage tank. They have no electric components that could break, a feature that generally makes them more reliable, easier to maintain, and possibly longer lasting than active systems.

An *active* system uses an electric pump to circulate water or nontoxic antifreeze through the system. Active systems are usually more expensive than passive systems, but they are also more efficient. Active systems also can be easier to retrofit than passive systems because their storage tanks do not need to be installed above or close to the collectors. Also, the moving water in the system will not freeze in cold climates. But because these systems use electricity, they will not function in a power outage. That's why many active systems are now combined with a small solar-electric panel to power the pump.

The amount of hot water a solar water heater produces depends on the type and size of the system, the amount of sun available at the site, proper installation, and the tilt angle and orientation of the collectors. But if you're currently using an electric water heater, solar water heating is a cost-effective alternative. If you own a swimming pool, heating the water with solar collectors can also save you money.

Solar Electricity

Solar electricity or photovoltaic (PV) technology converts sunlight directly into electricity. Solar electricity has been a prime source of power for space vehicles since the inception of the space program. It has also been used to power small electronics and rural and agricultural applications for three decades. During the last decade, a strong solar electric market has emerged for powering urban grid-connected homes and buildings as a result of advances in solar technology along with global changes in electric industry restructuring.

Although many types of solar electric systems are available today, they all consist of basically three main items: *modules* that convert sunlight into electricity; *inverters* that convert that electricity into alternating current so it can be used by most household appliances; and possibly or sometimes *batteries* that store excess electricity produced by the system. The remainder of the system comprises equipment such as wiring, circuit breakers, and support structures.

Today's modules can be built into glass skylights and walls. Some modules resemble traditional roof shingles, but they generate electricity, and some come with built-in inverters. The solar modules available today are more efficient and versatile than ever before.

In over 30 states, any additional power produced by a PV system, which is not being used by a home or building, can be fed back to the electric grid through a process known as *net metering.* Net metering allows electricity customers to pay only for their "net" electricity, or the

Bill Timmerman, NREL/PIX08982

This dish/Stirling solar power system in Arizona is capable of producing 25 kW of electricity.

Wind energy has been the fastest growing source of energy since 1990…

amount of power consumed from their utility minus the power generated by their PV system. This metering arrangement allows consumers to realize full retail value for 100 percent of the PV energy produced by their systems.

Grid-connected PV systems do not require batteries. However, some grid connected systems use them for emergency backup power. And of course in remote areas, solar electricity is often a economic alternative to expensive distribution line extensions incurred by a customer first connecting to the utility grid. Electricity produced by solar electric systems in remote locations is stored in batteries. Batteries will usually store electricity produced by a solar-electric system for up to three days.

What type of system to purchase will depend on the energy-efficiency of your home, your home's location, and your budget. Before you size your system, try reducing energy demand through energy-efficient measures. Purchasing energy-saving appliances and lights, for example, will reduce your electrical demand and allow you to purchase a smaller solar-electric system to meet your energy needs or get more value from a larger system. Energy efficiency allows you to start small and then add on as your energy needs increase.

Solar Thermal Electricity

Unlike solar-electric systems that convert sunlight into electricity, solar thermal electric systems convert the sun's heat into electricity. This technology is used primarily in large-scale power plants for powering cities and communities, especially in the Southwest where consistent hours of sunlight are greater than other parts of the United States.

Concentrating solar power (CSP) technologies convert solar energy into electricity by using mirrors to focus sunlight onto a component called a receiver. The receiver transfers the heat to a conventional engine-generator—such as a steam turbine—that generates electricity.

There are three types of CSP systems: power towers (central receivers), parabolic troughs, and dish/engine systems. A *power tower system* uses a large field of mirrors to concentrate sunlight onto the top of a tower, where a receiver sits. Molten salt flowing through the receiver is heated by the concentrated sunlight. The salt's heat is turned into electricity by a conventional steam generator. *Parabolic-trough systems* concentrate the sun's energy through long, parabolic-shaped mirrors. Sunlight is focused on a pipe filled with oil that runs down the axis of the trough. When the oil gets hot, it is used to boil water in a conventional steam generator to produce electricity. A *dish/engine system* uses a mirrored dish (similar in size to a large satellite dish). The dish-shaped surface focuses and concentrates the sun's heat onto a receiver at the focal point of the dish (above and center of the collectors). The receiver absorbs the sun's heat and transfers it to a fluid within an engine, where the heat causes the fluid to expand against a piston to produce mechanical power. The mechanical power is then used to run a generator or alternator to produce electricity.

Concentrating solar technologies can be used to generate electricity for a variety of applications, ranging from remote power systems as small as a few kilowatts (kW) up to grid-connected applications of 200 MW or more. A 354-MW power plant in Southern California, which consists of nine trough power plants, meets the energy needs of more than 350,000 people and is the world's largest solar energy power plant.

Wind Energy

For hundreds of years, people have used windmills to harness the wind's energy. Today's wind turbines, which operate differently from windmills, are a much more efficient technology.

Wind turbine technology may look simple: the wind spins turbine blades around a central hub; the hub is connected to a shaft, which powers a generator to make electricity. However, turbines are highly sophisticated power systems that capture the wind's energy by means of new blade designs or *airfoils.* Modern, mechanical drive systems, combined with advanced generators, convert that energy into electricity.

Wind turbines that provide electricity to the utility grid range in size from 50 kW to

Green Mountain Power Corporation, NREL/PIX05768

The 6-MW Green Mountain power plant in Searsburg, Vermont, consists of eleven 550-kW wind turbines.

1 or 2 MW. Large, utility-scale projects can have hundreds of turbines spread over many acres of land. Small turbines, below 50 kW, are used to charge batteries, electrify homes, pump water for farms and ranches, and power remote telecommunications equipment. Wind turbines can also be placed in the shallow water near a coastline if open land is limited, such as in Europe, and/or to take advantage of strong, offshore winds.

Wind energy has been the fastest growing source of energy in the world since 1990, increasing at an average rate of over 25 percent per year. It's a trend driven largely by dramatic improvements in wind technology. Currently, wind energy capacity amounts to about 2500 MW in the United States. Good wind areas, which cover 6 percent of the contiguous U.S. land area, could supply more than one and a half times the 1993 electricity consumption of the entire country.

California now has the largest number of installed turbines. Many turbines are also being installed across the Great Plains, reaching from Montana east to Minnesota and south through Texas, to take advantage of its vast wind resource. North Dakota alone has enough wind to supply 36 percent of the total 1990 electricity consumption of the lower 48 states. Hawaii, Iowa, Minnesota, Oregon, Texas, Washington, Wisconsin, and Wyoming are among states where wind energy use is rapidly increasing.

NASA, NREL/PIX03814

NASA uses liquid hydrogen to launch its space shuttles and hydrogen fuel cells to provide them with electricity

Hydrogen

Hydrogen is high in energy, yet its use as a fuel produces water as the only emission. Hydrogen is the universe's most abundant element and also its simplest. A hydrogen atom consists of only one proton and one electron. Despite its abundance and simplicity, it doesn't occur naturally as a gas on the Earth.

Hydrogen is high in energy, yet its use as a fuel produces water as the only emission.

Today, industry produces more than 4 trillion cubic feet of hydrogen annually. Most of this hydrogen is produced through a process called *reforming*, which involves the application of heat to separate hydrogen from carbon. Researchers are developing highly efficient, advanced reformers to produce hydrogen from natural gas for what's called *Proton Exchange Membrane* fuel cells.

You can think of fuel cells as batteries that never lose their charge. Today, hydrogen fuel cells offer tremendous potential to produce electrical power for distributed energy systems and vehicles. In the future, hydrogen could join electricity as an important "energy carrier": storing, moving, and delivering energy in a usable form to consumers. Renewable energy sources, like the sun, can't produce energy all the time. But hydrogen can store the renewable energy produced until it's needed.

Eventually, researchers would like to directly produce hydrogen from water using solar, wind, and biomass and biological technologies.

Ocean Energy

The ocean can produce two types of energy: *thermal energy* from the sun's heat, and *mechanical energy* from the tides and waves.

Ocean thermal energy can be used for many applications, including electricity generation. Electricity conversion systems use either the warm surface water or boil the seawater to turn a turbine, which activates a generator.

The electricity conversion of both tidal and wave energy usually involves mechanical devices. A dam is typically used to convert tidal energy into electricity by forcing the water through turbines, activating a generator. Meanwhile, wave energy uses mechanical power to directly activate a generator, or to transfer to a working fluid, water, or air, which then drives a turbine/generator.

Most of the research and development in ocean energy is happening in Europe.

Resources

The following are sources of additional information on renewable energy. The list is not exhaustive, nor does the mention of any resource constitute a recommendation or endorsement.

Ask an Energy Expert
DOE's Energy Efficiency and Renewable Energy Clearinghouse (EREC)
P.O. Box 3048
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Online submittal form: www.eren.doe.gov/menus/energyex.html
Consumer Energy Information Web site: www.eren.doe.gov/consumerinfo/

Energy experts at EREC provide free general and technical information to the public on many topics and technologies pertaining to energy efficiency and renewable energy.

DOE's Energy Efficiency and Renewable Energy Network (EREN)
Web site: www.eren.doe.gov

Your comprehensive online resource for DOE's energy efficiency and renewable energy information.

Organizations

Center for Energy Efficiency and Renewable Energy (CEERT)
1100 Eleventh St., Suite 311
Sacramento, CA 95814
Phone (916) 442-7785; Fax (916) 447-2940
E-mail: info@ceert.org
Web site: www.cleanpower.org

Promotes the development of renewable energy technologies and resources.

National Renewable Energy Laboratory (NREL)
1617 Cole Blvd.
Golden, CO 80401
Web site: www.nrel.gov

DOE-lab devoted to researching and developing renewable energy and energy efficiency technologies.

Renewable Energy Policy Project (REPP)
1612 K St. NW, Suite 202
Washington, DC 20006
Phone: (202) 293-2898; Fax: (202) 293-5857
Web site: www.repp.org

Works to advance renewable energy technologies.

Web Sites

CADDET Renewable Energy
Web site: www.caddet-re.org

Provides technical information on renewable energy projects and technologies from around the world.

Clean Energy Basics
NREL
Web site: www.nrel.gov/clean_energy/

Provides basic information on renewable energy technologies, including specific links for homeowners, small business owners, students, and teachers.

European Renewable Energy Exchange (EuroREX)
Web site: www.eurorex.com

Features information and news on renewable energy technology developments in Europe and around the world.

Planet Energy—The Renewable Energy Trail
United Kingdom Department of Trade and Industry
Web site: www.dti.gov.uk/renewable/ed_pack/index.html

Specifically gears its information for students and teachers, from grade school through high school.

Solstice
Center for Renewable Energy and Sustainable Technology (CREST)
Web site: http://solstice.crest.org

Provides an online source of information on renewable energy and technology development.

Further Reading

Achieving Energy Independence—One Step at a Time, J. Yago, Dunimis Technology, 1999, 190 pp.

Charging Ahead: The Business of Renewable Energy and What It Means for America, J. Berger and L. Thurow, University of California Press, 1998, 416 pp.

Clean Energy Choices: Tips on Buying and Using Renewable Energy at Home, DOE Office of Energy Efficiency and Renewable Energy, 2000, 48 pp. Print copy available from EREC (see "Ask an Energy Expert" above), and a PDF is available at www.nrel.gov/docs/fy00osti/27684.pdf.

The Real Goods Solar Living Sourcebook: The Complete Guide to Renewable Energy Technologies and Sustainable Living, D. Pratt ed., Real Goods, 1999, 562 pp.