volume three

alternative
# ENERGY

# Alternative Energy

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## Volume 1

### Neil Schlager and Jayne Weisblatt, editors

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# Contents

# Introduction

*Alternative Energy* offers readers comprehensive and easy-to-use information on the development of alternative energy sources. Although the set focuses on new or emerging energy sources, such as geothermal power and solar energy, it also discusses existing energy sources such as those that rely on fossil fuels. Each volume begins with a general overview that presents the complex issues surrounding existing and potential energy sources. These include the increasing need for energy, the world's current dependence on nonrenewable sources of energy, the impact on the environment of current energy sources, and implications for the future. The overview will help readers place the new and alternative energy sources in perspective.

Each of the first eight chapters in the set covers a different energy source. These chapters each begin with an overview that defines the source, discusses its history and the scientists who developed it, and outlines the applications and technologies for using the source. Following the chapter overview, readers will find information about specific technologies in use and potential uses as well. Two additional chapters explore the need for conservation and the move toward more energy-efficient tools, building materials, and vehicles and the more theoretical (and even imaginary) energy sources that might become reality in the future.

## ADDITIONAL FEATURES

Each volume of *Alternative Energy* includes the overview, a glossary called "Words to Know," a list of sources for more information, and an index. The set has 100 photos, charts, and illustrations to

enliven the text, and sidebars provide additional facts and related information.

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## COMMENTS AND SUGGESTIONS

We welcome your comments on *Alternative Energy* and suggestions for future editions of this work. Please write: Editors, *Alternative Energy*, U•X•L, 27500 Drake Rd., Farmington Hills, Michigan 48331-3535; call toll free: 1-800-877-4253; fax: 248-699-8097; or send e-mail via www.gale.com.

# Words to Know

## A

**acid rain:** Rain with a high concentration of sulfuric acid, which can damage cars, buildings, plants, and water supplies where it falls.

**adobe:** Bricks that are made from clay or earth, water, and straw, and dried in the sun.

**alkane:** A kind of hydrocarbon in which the molecules have the maximum possible number of hydrogen atoms and no double bonds.

**anaerobic:** Without air; in the absence of air or oxygen.

**anemometer:** A device used to measure wind speed.

**anthracite:** A hard, black coal that burns with little smoke.

**aquaculture:** The formal cultivation of fish or other aquatic life forms.

**atomic number:** The number of protons in the nucleus of an atom.

**atomic weight:** The combined number of an atom's protons and neutrons.

**attenuator:** A device that reduces the strength of an energy wave, such as sunlight.

## B

**balneology:** The science of bathing in hot water.

**barrel:** A common unit of measurement of crude oil, equivalent to 42 U.S. gallons; barrels of oil per day, or BOPD, is a standard measurement of how much crude oil a well produces.

**biodiesel:** Diesel fuel made from vegetable oil.

**bioenergy:** Energy produced through the combustion of organic materials that are constantly being created, such as plants.

**biofuel:** A fuel made from organic materials that are constantly being created.

**biomass:** Organic materials that are constantly being created, such as plants.

**bitumen:** A black, viscous (oily) hydrocarbon substance left over from petroleum refining, often used to pave roads.

**bituminous coal:** Mid-grade coal that burns with a relatively high flame and smoke.

**brine:** Water that is very salty, such as the water found in the ocean.

**British thermal unit (Btu or BTU):** A measure of heat energy, equivalent to the amount of energy it takes to raise the temperature of one pound of water by one degree Fahrenheit.

**butyl rubber:** A synthetic rubber that does not easily tear. It is often used in hoses and inner tubes.

## C

**carbon sequestration:** Storing the carbon emissions produced by coal-burning power plants so that pollutants are not released in the atmosphere.

**catalyst:** A substance that speeds up a chemical reaction or allows it to occur under different conditions than otherwise possible.

**cauldron:** A large metal pot.

**CFC (chlorofluorocarbon):** A chemical compound used as a refrigerant and propellant before being banned for fear it was destroying the ozone layer.

**Clean Air Act:** A U.S. law intended to reduce and control air pollution by setting emissions limits for utilities.

**climate-responsive building:** A building, or the process of constructing a building, using materials and techniques that take advantage of natural conditions to heat, cool, and light the building.

**coal:** A solid hydrocarbon found in the ground and formed from plant matter compressed for millions of years.

**coke:** A solid organic fuel made by burning off the volatile components of coal in the absence of air.

**cold fusion**: Nuclear fusion that occurs without high heat; also referred to as low energy nuclear reactions.

**combustion**: Burning.

**compact fluorescent bulb**: A lightbulb that saves energy as conventional fluorescent bulbs do, but that can be used in fixtures that normally take incandescent lightbulbs.

**compressed**: To make more dense so that a substance takes up less space.

**conductive**: A material that can transmit electrical energy.

**convection**: The circulation movement of a substance resulting from areas of different temperatures and/or densities.

**core**: The center of the Earth.

**coriolis force**: The movement of air currents to the right or left caused by Earth's rotation.

**corrugated steel**: Steel pieces that have parallel ridges and troughs.

**critical mass**: An amount of fissile material needed to produce an ongoing nuclear chain reaction.

**criticality**: The point at which a nuclear fission reaction is in controlled balance.

**crude oil**: The unrefined petroleum removed from an oil well.

**crust**: The outermost layer of the Earth.

**curie**: A unit of measurement that measures an amount of radiation.

**current**: The flow of electricity.

## D

**decay**: The breakdown of a radioactive substance over time as its atoms spontaneously give off neutrons.

**deciduous trees**: Trees that shed their leaves in the fall and grow them in the spring. Such trees include maples and oaks.

**decommission**: To take a nuclear power plant out of operation.

**dependent**: To be reliant on something.

**distillation**: A process of separating or purifying a liquid by boiling the substance and then condensing the product.

**distiller's grain**: Grain left over from the process of distilling ethanol, which can be used as inexpensive high-protein animal feed.

**drag:** The slowing force of the wind as it strikes an object.

**drag coefficient:** A measurement of the drag produced when an object such as a car pushes its way through the air.

## E

**E85:** A blend of 15 percent ethanol and 85 percent gasoline.

**efficient:** To get a task done without much waste.

**electrolysis:** A method of producing chemical energy by passing an electric current through a type of liquid.

**electromagnetism:** Magnetism developed by a current of electricity.

**electron:** A negatively charged particle that revolves around the nucleus in an atom.

**embargo:** Preventing the trade of a certain type of commodity.

**emission:** The release of substances into the atmosphere. These substances can be gases or particles.

**emulsion:** A liquid that contains many small droplets of a substance that cannot dissolve in the liquid, such as oil and water shaken together.

**enrichment:** The process of increasing the purity of a radioactive element such as uranium to make it suitable as nuclear fuel.

**ethanol:** An alcohol made from plant materials such as corn or sugar cane that can be used as fuel.

**experimentation:** Scientific tests, sometimes of a new idea.

## F

**feasible:** To be possible; able to be accomplished or brought about.

**feedstock:** A substance used as a raw material in the creation of another substance.

**field:** An area that contains many underground reservoirs of petroleum or natural gas.

**fissile:** Term used to describe any radioactive material that can be used as fuel because its atoms can be split.

**fission:** Splitting of an atom.

**flexible fuel vehicle (FFV):** A vehicle that can run on a variety of fuel types without modification of the engine.

**flow:** The volume of water in a river or stream, usually expressed as gallons or cubic meters per unit of time, such as a minute or second.

**fluorescent lightbulb:** A lightbulb that produces light not with intense heat but by exciting the atoms in a phosphor coating inside the bulb.

**fossil fuel:** An organic fuel made through the compression and heating of plant matter over millions of years, such as coal, petroleum, and natural gas.

**fusion:** The process by which the nuclei of light atoms join, releasing energy.

## G

**gas:** An air-like substance that expands to fill whatever container holds it, including natural gas and other gases commonly found with liquid petroleum.

**gasification:** A process of converting the energy from a solid, such as coal, into gas.

**gasohol:** A blend of gasoline and ethanol.

**gasoline:** Refined liquid petroleum most commonly used as fuel in internal combustion engines.

**geothermal:** Describing energy that is found in the hot spots under the Earth; describing energy that is made from heat.

**geothermal reservoir:** A pocket of hot water contained within the Earth's mantle.

**global warming:** A phenomenon in which the average temperature of the Earth rises, melting icecaps, raising sea levels, and causing other environmental problems.

**gradient:** A gradual change in something over a specific distance.

**green building:** Any building constructed with materials that require less energy to produce and that save energy during the building's operation.

**greenhouse effect:** A phenomenon in which gases in the Earth's atmosphere prevent the sun's radiation from being reflected back into space, raising the surface temperature of the Earth.

**greenhouse gas:** A gas, such as carbon dioxide or methane, that is added to the Earth's atmosphere by human actions. These gases trap heat and contribute to global warming.

## H

**halogen lamp:** An incandescent lightbulb that produces more light because it produces more heat, but lasts longer because the filament is enclosed in quartz.

**Heisenberg uncertainty principle:** The principle that it is impossible to know simultaneously both the location and momentum of a subatomic particle.

**heliostat:** A mirror that reflects the sun in a constant direction.

**hybrid vehicle:** Any vehicle that is powered in a combination of two ways; usually refers to vehicles powered by an internal combustion engine and an electric motor.

**hybridized:** The bringing together of two different types of technology.

**hydraulic energy:** The kinetic energy contained in water.

**hydrocarbon:** A substance composed of the elements hydrogen and carbon, such as coal, petroleum, and natural gas.

**hydroelectric:** Describing electric energy made by the movement of water.

**hydropower:** Any form of power derived from water.

## I

**implement:** To put something into practice.

**incandescent lightbulb:** A conventional lightbulb that produces light by heating a filament to high temperatures.

**infrastructure:** The framework that is necessary to the functioning of a structure; for example, roads and power lines form part of the infrastructure of a city.

**inlet:** An opening through which liquid enters a device, or place.

**internal combustion engine:** The type of engine in which the burning that generates power takes place inside the engine.

**isotope:** A "species" of an element whose nucleus contains more neutrons than other species of the same element.

## K

**kilowatt-hour:** One kilowatt of electricity consumed over a one-hour period.

**kinetic energy:** The energy associated with movement, such as water that is in motion.

**Kyoto Protocol:** An international agreement among many nations setting limits on emissions of greenhouse gases; intended to slow or prevent global warming.

## L

**lava:** Molten rock contained within the Earth that emerges from cracks in the Earth's crust, such as volcanoes.

**lift:** The aerodynamic force that operates perpendicular to the wind, owing to differences in air pressure on either side of a turbine blade.

**lignite:** A soft brown coal with visible traces of plant matter in it that burns with a great deal of smoke and produces less heat than anthracite or bituminous coal.

**liquefaction:** The process of turning a gas or solid into a liquid.

**LNG (liquefied natural gas):** Gas that has been turned into liquid through the application of pressure and cold.

**LPG (liquefied petroleum gas):** A gas, mainly propane or butane, that has been turned into liquid through the use of pressure and cold.

**lumen:** A measure of the amount of light, defined as the amount of light produced by one candle.

## M

**magma:** Liquid rock within the mantle.

**magnetic levitation:** The process of using the attractive and repulsive forces of magnetism to move objects such as trains.

**mantle:** The layer of the Earth between the core and the crust.

**mechanical energy:** The energy output of tools or machinery.

**meltdown:** Term used to refer to the possibility that a nuclear reactor could become so overheated that it would melt into the earth below.

**mica:** A type of shiny silica mineral usually found in certain types of rocks.

**modular:** An object which can be easily arranged, rearranged, replaced, or interchanged with similar objects.

**mousse:** A frothy mixture of oil and seawater in the area where an oil spill has occurred.

## N

**nacelle:** The part of a wind turbine that houses the gearbox, generator, and other components.

**natural gas:** A gaseous hydrocarbon commonly found with petroleum.

**negligible:** To be so small as to be insignificant.

**neutron:** A particle with no electrical charge found in the nucleus of most atoms.

**NGL (natural gas liquid):** The liquid form of gases commonly found with natural gas, such as propane, butane, and ethane.

**nonrenewable:** To be limited in quantity and unable to be replaced.

**nucleus:** The center of an atom, containing protons and in the case of most elements, neutrons.

## O

**ocean thermal energy conversion (OTEC):** The process of converting the heat contained in the oceans' water into electrical energy.

**octane rating:** The measure of how much a fuel can be compressed before it spontaneously ignites.

**off-peak:** Describing period of time when energy is being delivered at well below the maximum amount of demand, often nighttime.

**oil:** Liquid petroleum; a substance refined from petroleum used as a lubricant.

**organic:** Related to or derived from living matter, such as plants or animals; composed mainly of carbon atoms.

**overburden:** The dirt and rocks covering a deposit of coal or other fossil fuel.

**oxygenate:** A substance that increases the oxygen level in another substance.

**ozone:** A molecule consisting of three atoms of oxygen, naturally produced in the Earth's atmosphere; ozone is toxic to humans.

## P

**parabolic:** Shaped like a parabola, which is a certain type of curve.

**paraffin:** A kind of alkane hydrocarbon that exists as a white, waxy solid at room temperature and can be used as fuel or as a wax for purposes such as sealing jars or making candles.

**passive:** A device that takes advantage of the sun's heat but does not use an additional source of energy.

**peat:** A brown substance composed of compressed plant matter and found in boggy areas; peat can be used as fuel itself, or turns into coal if compressed for long enough.

**perpetual motion:** The power of a machine to run indefinitely without any energy input.

**petrochemicals:** Chemical compounds that form in rocks, such as petroleum and coal.

**petrodiesel:** Diesel fuel made from petroleum.

**petroleum:** Liquid hydrocarbon found underground that can be refined into gasoline, diesel fuel, oils, kerosene, and other products.

**pile:** A mass of radioactive material in a nuclear reactor.

**plutonium:** A highly toxic element that can be used as fuel in nuclear reactors.

**polymer:** A compound, either synthetic or natural, that is made of many large molecules. These molecules are made from smaller, identical molecules that are chemically bonded.

**pristine:** Not changed by human hands; in its original condition.

**productivity:** The output of labor per amount of work.

**proponent:** Someone who supports an idea or cause.

**proton:** A positively charged particle found in the nucleus of an atom.

## R

**radioactive:** Term used to describe any substance that decays over time by giving off subatomic particles such as neutrons.

**RFG (reformulated gasoline):** Gasoline that has an oxygenate or other additive added to it to decrease emissions and improve performance.

**rem:** An abbreviation for "roentgen equivalent man," referring to a dose of radiation that will cause the same biological effect (on a "man") as one roentgen of X-rays or gamma rays.

**reservoir:** A geologic formation that can contain liquid petroleum and natural gas.

**reservoir rock:** Porous rock, such as limestone or sandstone, that can hold accumulations of petroleum or natural gas.

**retrofit:** To change something, like a home, after it is built.

**rotor:** The hub to which the blades of a wind turbine are connected; sometimes used to refer to the rotor itself and the blades as a single unit.

## S

**scupper:** An opening that allows a liquid to drain.

**seam:** A deposit of coal in the ground.

**sedimentary rock:** A rock formed through years of minerals accumulating and being compressed.

**seismology:** The study of movement within the earth, such as earthquakes and the eruption of volcanoes.

**sick building syndrome:** The tendency of buildings that are poorly ventilated, lighted, and humidified, and that are made with certain synthetic materials to cause the occupants to feel ill.

**smog:** Air pollution composed of particles mixed with smoke, fog, or haze in the air.

**stall:** The loss of lift that occurs when a wing presents too steep an angle to the wind and low pressure along the upper surface of the wing decreases.

**strip mining:** A form of mining that involves removing earth and rocks by bulldozer to retrieve the minerals beneath them.

**stored energy:** The energy contained in water that is stored in a tank or held back behind a dam in a reservoir.

**subsidence:** The collapse of earth above an empty mine, resulting in a damaged landscape.

**surcharge:** An additional charge over and above the original cost.

**superconductivity:** The disappearance of electrical resistance in a substance such as some metals at very low temperatures.

## T

**thermal energy:** Any form of energy in the form of heat; used in reference to heat in the oceans' waters.

**thermal gradient:** The differences in temperature between different layers of the oceans.

**thermal mass:** The measure of the amount of heat a substance can hold.

**thermodynamics:** The branch of physics that deals with the mechanical actions or relations of heat.

**tokamak:** An acronym for the Russian-built toroidal magnetic chamber, a device for containing a fusion reaction.

**transitioning:** Changing from one position or state to another.

**transparent:** So clear that light can pass through without distortion.

**trap:** A reservoir or area within Earth's crust made of nonporous rock that can contain liquids or gases, such as water, petroleum, and natural gas.

**trawler:** A large commercial fishing boat.

**Trombé wall:** An exterior wall that conserves energy by trapping heat between glazing and a thermal mass, then venting it into the living area.

**turbine:** A device that spins to produce electricity.

## U

**uranium:** A heavy element that is the chief source of fuel for nuclear reactors.

## V

**viable:** To be possible; to be able to grow or develop.

**voltage:** Electric potential that is measured in volts.

## W

**wind farm:** A group of wind turbines that provide electricity for commercial uses.

**work:** The conversion of one form of energy into another, such as the conversion of the kinetic energy of water into mechanical energy used to perform a task.

## Z

**zero point energy:** The energy contained in electromagnetic fluctuations that remains in a vacuum, even when the temperature has been reduced to very low levels.

# Overview

In the technological world of the twenty-first century, few people can truly imagine the challenges faced by prehistoric people as they tried to cope with their natural environment. Thousands of years ago life was a daily struggle to find, store, and cook food, stay warm and clothed, and generally survive to an "old age" equal to that of most of today's college students. A common image of prehistoric life is that of dirty and ill-clad people huddled around a smoky campfire outside a cave in an ongoing effort to stay warm and dry and to stop the rumbling in their bellies.

The "caves" of the twenty-first century are a little cozier. The typical person, at least in more developed countries, wakes up each morning in a reasonably comfortable house because the gas, propane, or electric heating system (or electric air-conditioner) has operated automatically overnight. A warm shower awaits because of hot water heaters powered by electricity or natural gas, and hair dries quickly (and stylishly) under an electric hair dryer. An electric iron takes the wrinkles out of the clean shirt that sat overnight in the electric clothes dryer. Milk for a morning bowl of cereal remains fresh in an electric refrigerator, and it costs pennies per bowl thanks to electrically powered milking operations on modern dairy farms. The person then goes to the garage (after turning off all the electric lights in the house), hits the electric garage door opener, and gets into his or her gasoline-powered car for the drive to work—perhaps in an office building that consumes power for lighting, heating and air-conditioning, copiers, coffeemakers, and computers. Later, an electric, propane, or natural gas stove is used to cook dinner. Later still, an electric

popcorn popper provides a snack as the person watches an electric television or reads under the warm glow of electric light bulbs—after perhaps turning up the heat because the house is a little chilly.

## CATASTROPHE AHEAD?

Most people take these modern conveniences for granted. Few people give much thought to them, at least until there is a power outage or prices rise sharply, as they did for gasoline in the United States in the summer and fall of 2005. Many scientists, environmentalists, and concerned members of the public, though, believe that these conveniences have been taken too much for granted. Some believe that the modern reliance on fossil fuels—fuels such as natural gas, gasoline, propane, and coal that are processed from materials mined from the earth—has set the Earth on a collision course with disaster in the twenty-first century. Their belief is that the human community is simply burning too much fuel and that the consequences of doing so will be dire (terrible). Some of their concerns include the following:

- Too much money is spent on fossil fuels. In the United States, over $1 billion is spent every day to power the country's cars and trucks.
- Much of the supply of fossil fuels, particularly petroleum, comes from areas of the world that may be unstable. The U.S. fuel supply could be cut off without warning by a foreign government. Many nations that import all or most of their petroleum feel as if they are hostages to the nations that control the world's petroleum supplies.
- Drilling for oil and mining coal can do damage to the landscape that is impossible to repair.
- Reserves of coals and especially oil are limited, and eventually supplies will run out. In the meantime, the cost of such fuels will rise dramatically as it becomes more and more difficult to find and extract them.
- Transporting petroleum in massive tankers at sea heightens the risk of oil spills, causing damage to the marine and coastal environments.

Furthermore, to provide heat and electricity, fossil fuels have to be burned, and this burning gives rise to a host of problems. It releases pollutants in the form of carbon dioxide and sulfur into the air, fouling the atmosphere and causing "brown clouds" over cities. These pollutants can increase health problems such as lung

disease. They may also contribute to a phenomenon called "global warming." This term refers to the theory that average temperatures across the globe will increase as "greenhouse gases" such as carbon dioxide trap the sun's heat (as a greenhouse does) in the atmosphere and warm it. Global warming, in turn, can melt glaciers and the polar ice caps, raising sea levels with damaging effects on coastal cities and small island nations. It may also cause climate changes, crop failures, and more unpredictable weather patterns.

Some scientists do not believe that global warming even exists or that its consequences will be catastrophic. Some note that throughout history, the world's average temperatures have risen and fallen. Some do not find the scientific data about temperature, glacial melting, rising sea levels, and unpredictable weather totally believable. While the debate continues, scientists struggle to learn more about the effects of human activity on the environment. At the same time, governments struggle to maintain a balance between economic development and its possible effects on the environment.

## WHAT TO DO?

These problems began to become more serious after the Industrial Revolution of the nineteenth century. Until that time people depended on other sources of power. Of course, they burned coal or wood in fireplaces and stoves, but they also relied on the power of the sun, the wind, and river currents to accomplish much of their work. The Industrial Revolution changed that. Now, coal was being burned in vast amounts to power factories and steam engines as the economies of Europe and North America grew and developed. Later, more efficient electricity became the preferred power source, but coal still had to be burned to produce electricity in large power plants. Then in 1886 the first internal combustion engine was developed and used in an automobile. Within a few decades there was a demand for gasoline to power these engines. By 1929 the number of cars in the United States had grown to twenty-three million, and in the quarter-century between 1904 and 1929, the number of trucks grew from just seven hundred to 3.4 million.

At the same time technological advances improved life in the home. In 1920, for example, the United States produced a total of five thousand refrigerators. Just ten years later the number had grown to one million per year. These and many other industrial and consumer developments required vast and growing amounts of

fuel. Compounding the problem in the twenty-first century is that other nations of the world, such as China and India, have started to develop more modern industrialized economies powered by fossil fuels.

By the end of World War II in 1945, scientists were beginning to imagine a world powered by fuel that was cheap, clean, and inexhaustible (unable to be used up). During the war the United States had unleashed the power of the atom to create the atomic bomb. Scientists believed that the atom could be used for peaceful purposes in nuclear power plants. They even envisioned (imagined) a day when homes could be powered by their own tiny nuclear power generators. This dream proved to be just that. While some four hundred nuclear power plants worldwide provide about 16 percent of the world's electricity, building such plants is an enormously expensive technical feat. Moreover, nuclear power plants produce spent fuel that is dangerous and not easily disposed of. The public fears that an accident at such a plant could release deadly radiation that would have disastrous effects on the surrounding area. Nuclear power has strong defenders, but it is not cheap, and safety concerns sometimes make it unpopular.

The dream of a fuel source that is safe, plentiful, clean, and inexpensive, however, lives on. The awareness of the need for such alternative fuel sources became greater in the 1970s, when the oil-exporting countries of the Middle East stopped shipments of oil to the United States and its allies. This situation (an embargo) caused fuel shortages and rapidly rising prices at the gas pump. In the decades that followed, gasoline again became plentiful and relatively inexpensive, but the oil embargo served as a wakeup call for many people. In addition, during these years people worldwide grew concerned about pollution, industrialization, and damage to the environment. Accordingly, efforts were intensified to find and develop alternative sources of energy.

## ALTERNATIVE ENERGY: BACK TO THE FUTURE

Some of these alternative fuel sources are by no means new. For centuries people have harnessed the power of running water for a variety of needs, particularly for agriculture (farming). Water wheels were constructed in the Middle East, Greece, and China thousands of years ago, and they were common fixtures on the farms of Europe by the Middle Ages. In the early twenty-first century hydroelectric dams, which generate electricity from the power of rivers, provide about 9 percent of the electricity in the

United States. Worldwide, there are about 40,000 such dams. In some countries, such as Norway, hydroelectric dams provide virtually 100 percent of the nation's electrical needs. Scientists, though, express concerns about the impact such dams have on the natural environment.

Water can provide power in other ways. Scientists have been attempting to harness the enormous power contained in ocean waves, tides, and currents. Furthermore, they note that the oceans absorb enormous amounts of energy from the sun, and they hope someday to be able to tap into that energy for human needs. Technical problems continue to occur. It remains likely that ocean power will serve only to supplement (add to) existing power sources in the near future.

Another source of energy that is not new is solar power. For centuries, people have used the heat of the sun to warm houses, dry laundry, and preserve food. In the twenty-first century such "passive" uses of the sun's rays have been supplemented with photovoltaic devices that convert the energy of the sun into electricity. Solar power, though, is limited geographically to regions of the Earth where sunshine is plentiful.

Another old source of heat is geothermal power, referring to the heat that seeps out of the earth in places such as hot springs. In the past this heat was used directly, but in the modern world it is also used indirectly to produce electricity. In 1999 over 8,000 megawatts (that is, 8,000 million watts) of electricity were produced by about 250 geothermal power plants in twenty-two countries around the world. That same year the United States produced nearly 3,000 megawatts of geothermal electricity, more than twice the amount of power generated by wind and solar power. Geothermal power, though, is restricted by the limited number of suitable sites for tapping it.

Finally, wind power is getting a closer look. For centuries people have harnessed the power of the wind to turn windmills, using the energy to accomplish work. In the United States, wind-operated turbines produce just 0.4 percent of the nation's energy needs. However, wind experts believe that a realistic goal is for wind to supply 20 percent of the nation's electricity requirements by 2020. Worldwide, wind supplies enough power for about nine million homes. Its future development, though, is hampered by limitations on the number of sites with enough wind and by concerns about large numbers of unsightly wind turbines marring the landscape.

## ALTERNATIVE ENERGY: FORWARD TO THE FUTURE

While some forms of modern alternative energy sources are really developments of long-existing technologies, others are genuinely new, though scientists have been exploring even some of these for up to hundreds of years. One, called bioenergy, refers to the burning of biological materials that otherwise might have just been thrown away or never grown in the first place. These include animal waste, garbage, straw, wood by-products, charcoal, dried plants, nutshells, and the material left over after the processing of certain foods, such as sugar and orange juice. Bioenergy also includes methane gas given off by garbage as it decomposes or rots. Fuels made from vegetable oils can be used to power engines, such as those in cars and trucks. Biofuels are generally cleaner than fossil fuels, so they do not pollute as much, and they are renewable. They remain expensive, and amassing significant amounts of biofuels requires a large commitment of agricultural resources such as farmland.

Nothing is sophisticated about burning garbage. A more sophisticated modern alternative is hydrogen, the most abundant element in the universe. Hydrogen in its pure form is extremely flammable. The problem with using hydrogen as a fuel is separating hydrogen molecules from the other elements to which it readily bonds, such as oxygen (hydrogen and oxygen combine to form water). Hydrogen can be used in fuel cells, where water is broken down into its elements. The hydrogen becomes fuel, while the "waste product" is oxygen. Many scientists regard hydrogen fuel cells as the "fuel of the future," believing that it will provide clean, safe, renewable fuel to power homes, office buildings, and even cars and trucks. However, fuel cells are expensive. As of 2002 a fuel cell could cost anywhere from $500 to $2,500 per kilowatt produced. Engines that burn gasoline cost only about $30 to $35 for the same amount of energy.

All of these power sources have high costs, both for the fuel and for the technology needed to use it. The real dreamers among energy researchers are those who envision a future powered by a fuel that is not only clean, safe, and renewable but essentially free. Many scientists believe that such fuel alternatives are impossible, at least for the foreseeable future. Others, though, work in laboratories around the world to harness more theoretical sources of energy. Some of their work has a "science fiction" quality, but these scientists point out that a few hundred years ago the airplane was science fiction.

One of these energy sources is magnetism, already used to power magnetic levitation ("maglev") trains in Japan and Germany. Another is perpetual motion, the movement of a machine that produces energy without requiring energy to be put into the system. Most scientists, though, dismiss perpetual motion as a violation of the laws of physics. Other scientists are investigating so-called zero-point energy, or the energy that surrounds all matter and can even be found in the vacuum of space. But perhaps the most sought-after source of energy for investigators is cold fusion, a nuclear reaction using "heavy hydrogen," an abundant element in seawater, as fuel. With cold fusion, power could be produced literally from a bucket of water. So far, no one has been able to produce it, though some scientists claim to have come very close.

None of these energy sources is a complete cure for the world's energy woes. Most will continue to serve as supplements to conventional fossil fuel burning for decades to come. But with the commitment of research dollars, it is possible that future generations will be able to generate all their power needs in ways that scientists have not even yet imagined. The first step begins with understanding fossil fuels, the energy they provide, the problems they cause, and what it may take to replace them.

# Fossil Fuels

## INTRODUCTION: WHAT ARE FOSSIL FUELS?

Nearly 90 percent of the world's energy comes from fossil fuels. Because fossil fuels are the main source, they are not alternative energy sources. Fossil fuels include coal, natural gas, and petroleum (puh-TROH-lee-uhm), which is often called oil. People use fossil fuels to meet nearly all of their energy needs, such as powering cars, producing electricity for light and heat, and running factories. Because their use is so widespread, it is important to understand fossil fuels in order to make informed decisions about present and future alternative energy sources.

Fossil fuels are a popular source of energy because they are considered convenient, effective, plentiful, and inexpensive, but a few nations have most of the world's fossil fuels, a fact that often causes conflicts. Nevertheless, as of 2006, there are no practical and available alternatives to fossil fuels for most energy needs, so they continue to be heavily used.

### Types of fossil fuels

Fossil fuels are substances that formed underground millions of years ago from prehistoric plants and other living things that were buried under layers of sediment, which included dirt, sand, and dead plants. To turn into fossil fuels, this organic matter (matter that comes from a life form and is composed mainly of the element carbon) was crushed, heated, and deprived of oxygen. Under the right conditions and over millions of years, this treatment turns dead plants into fossil fuels.

The three main types of fossil fuels correspond to the three states of matter—solid, liquid, and gas:

- Coal is a solid.

## Words to Know

**Alkane** A kind of hydrocarbon in which the molecules have the maximum possible number of hydrogen atoms and no double bonds.

**Barrel** A common unit of measurement of crude oil, equivalent to 42 U.S. gallons; barrels of oil per day, or BOPD, is a standard measurement of how much crude oil a well produces.

**Catalyst** A substance that speeds up a chemical reaction or allows it to occur under different conditions than otherwise possible.

**Clean Air Act** A U.S. law intended to reduce and control air pollution by setting emissions limits for utilities.

**Emissions** The by-products of fossil fuel burning that are released into the air.

**Global warming** A phenomenon in which the average temperature of the Earth rises, melting icecaps, raising sea levels, and causing other environmental problems.

**Greenhouse effect** A phenomenon in which gases in the Earth's atmosphere prevent the sun's radiation from being reflected back into space, raising the surface temperature of the Earth.

**Octane rating** The measure of how much a fuel can be compressed before it spontaneously ignites.

**Ozone** A molecule consisting of three atoms of oxygen, naturally produced in the Earth's atmosphere; ozone is toxic to humans.

**Seismology** The study of movement within the earth, such as earthquakes and the eruption of volcanoes.

- Petroleum is a liquid.
- Natural gas is a gas.

Several fossil fuels are made by refining petroleum or natural gas. These fuels include gases such as propane, butane, and methanol.

### *Natural Gas Versus Gasoline*

Natural gas is not sold at gas stations. The fuel used in cars is liquid petroleum, or gasoline. Although most people call it "gas," this fuel is not the same thing as natural gas. The word *gas* refers to natural gas, not gasoline. The word *oil* refers to petroleum.

Whether a fossil fuel formed as a solid, liquid, or gas depends on the location, the composition of the materials, the length of time the matter was compressed, how hot it became, and how long it was buried. Coal formed from accumulated layers of plants that died in swamps and were buried for millions of years. Petroleum and natural gas formed from microscopic plants and bacteria in the oceans. Both petroleum and natural gas formed in places that could contain them: pockets, or reservoirs (reh-zuh-VWARS), in the undersea rock.

### Dinosaurs in the Gas Tank

It is unlikely that fossil fuels are made of dinosaurs. Most fossil fuels formed about 300 million years ago, and most of them are made mainly of plant matter. Dinosaurs did not appear until about 230 million years ago, so the first dinosaur was not born until the youngest petroleum had already formed. Dinosaur fossils, however, do have something in common with fossil fuels. Fossils, whether they are dinosaurs or coal, are the hardened remains of animals and plants preserved in Earth's crust from an earlier age. Dinosaur fossils formed when dinosaurs were buried in sand or dirt, and their skeletons were hardened by minerals that seeped in through tiny holes in the bone.

Earth has a lot of fossil fuels. Scientists in 2005 estimated that the ground contains about ten trillion metric tons of coal, enough to fuel human energy needs for hundreds of years. Petroleum and natural gas deposits are not nearly so extensive. Most scientists believe that if people keep using up oil and gas at 2005 rates, all known petroleum and gas reserves will be used up by the beginning of the twenty-second century.

At the end of the twentieth century, petroleum supplied about 40 percent of the energy needs of the United States. Another 22 percent was covered by coal and 24 percent by natural gas. The International Energy Agency (IEA) has predicted that the world will need almost 60 percent more energy in 2030 than it did in 2002. The IEA believes that fossil fuels will still be supplying most of those needs by 2030.

Other kinds of fossil fuels exist, but none of them can be extracted, recovered, or used efficiently. These fossil fuels include:

- Gas hydrates, which are deposits of methane and water that form crystals in ocean sediments. There is currently no technology for extracting methane from the crystals, so gas hydrates are not yet considered a part of world energy reserves.
- Tar sands, which are patches of tar in sandstone. Petroleum sometimes gets embedded in sandstone, and the bacteria in the sandstone and the surrounding water make the petroleum turn into tar. Tar sands are difficult to recover and use.

- Oil shale, which is a kind of rock full of a waxy organic substance called kerogen (KEHR-uh-juhn). Kerogen formed from the same microscopic plants and bacteria that make up petroleum, but it never reached the pressure or temperature that would have turned it into oil. It is not currently practical to recover or use oil shale.

### How fossil fuels work

Fossil fuels generate energy by burning. This energy can serve a variety of purposes from heating homes to powering automobiles. The simplest devices that use fossil fuels burn them so that people can take advantage of the heat. For example, some homes are heated by furnaces that burn natural gas. The heat from the burning gas warms the house. Camping stoves often burn propane that is fed to the stove burners from an attached bottle. Coal stoves burn lumps of coal.

Most fossil fuel-powered operations, however, use the burning of the fossil fuel to power much more complex machines, such as internal combustion engines. In many cases, other fuels could supply the necessary heat; for example, locomotives could be powered by burning wood instead of burning coal, and power plants can be powered by water instead of coal. The advantage of fossil fuels in these situations is that they produce large amounts of heat for their volume, and they are currently widely available, with some liquid and gas fuels available at pumps.

#### *The internal combustion engine*

Automobiles use fossil fuel (gasoline) to power their internal combustion engines. An internal combustion engine burns a fuel to power pistons, which make the engine turn. Internal combustion engines have been around since the 1860s. The four-stroke "Otto" engine was invented in 1867 by Nikolaus August Otto (1832–1891), a German engineer. Another German engineer, Rudolph Diesel (1858–1913), invented the diesel engine in 1892. The basic principles of internal combustion have not changed since then.

An engine contains several cylinders (most cars have between four and eight) that make the engine move. A four-stroke cylinder works like this:

1. The intake valve opens to let air and fuel into the cylinder while the piston is down. This is called the intake stroke.

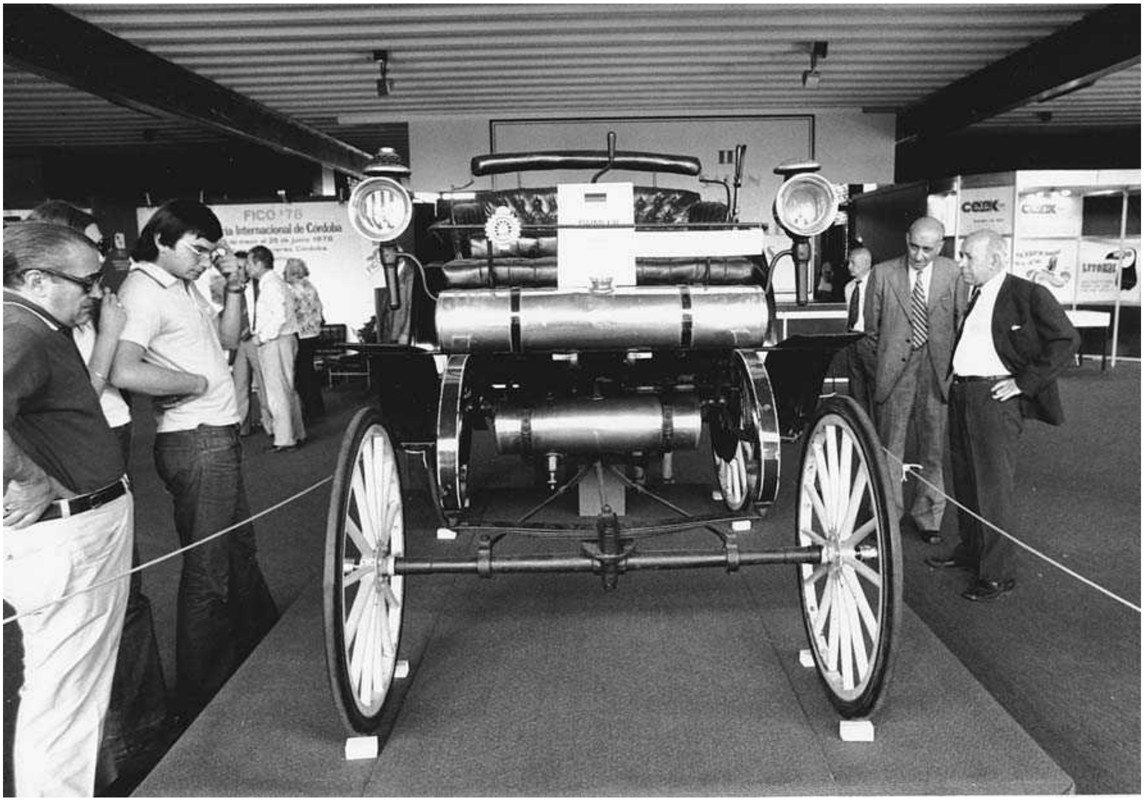



Photo of the original 1891 gasoline-engined Daimler automobile. In 1885, Karl Benz and Gottlieb Daimler developed an internal combustion engine, building the first motorcycle and cars using gasoline. © *AP Images.*

2. The piston begins traveling back up. The intake valve closes and the piston compresses the air and fuel in the cylinder. This is called the compression stroke.
3. The spark plug creates a spark, which ignites the fuel and air so that it explodes. The explosion pushes the piston down. The piston rotates the crankshaft, which turns the engine. This is called the power stroke.
4. The exhaust valve opens. The piston moves back up, forcing the burned gases out through the exhaust valve. The piston travels back down, the exhaust valve opens, and the intake stroke begins again. This is called the exhaust stroke.

One complete cycle of a four-stroke engine will turn the crankshaft twice. A car engine's cylinders can fire hundreds of times in a minute, turning the crankshaft, which transmits its energy into turning the car's wheels. The more air and fuel that can get into a cylinder, the more powerful the engine will be.

## What does Octane Mean?

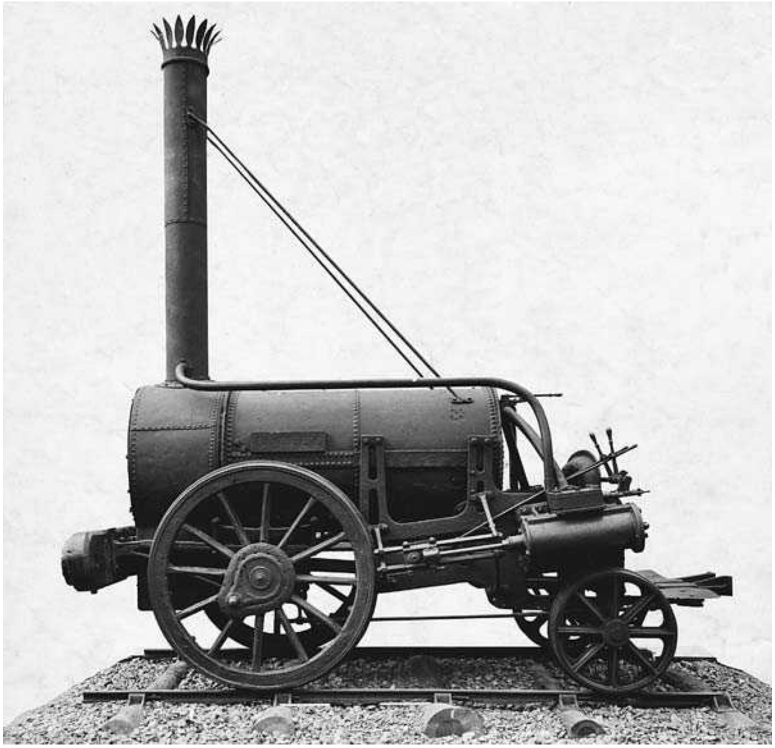
Gasoline comes in several varieties labeled with words such as ''regular'' or ''supreme,'' each with a number. The higher the number on the gasoline, the more expensive it is. That number is the gasoline's octane rating, which tells how much the fuel can be compressed before it will spontaneously ignite. In a car engine, gasoline is supposed to ignite in one of the engine's cylinders when it is lit by a spark plug; it is not supposed to ignite on its own. When it ignites on its own, the engine ''knocks.'' This can damage the engine. High-performance cars, though, increase their horsepower by increasing the amount of compression in the engine, which makes knocking more likely. That is why high-performance cars have to use expensive, high octane gasoline.

Most engines that run on gasoline can also be powered with natural gas or LPGs (liquefied petroleum gas), with some minor modifications to the fuel delivery system. The basic method of combustion is the same.

A diesel engine is similar to a gasoline engine except that only air enters the cylinder during the intake stroke, and only air is compressed during the compression stroke. The fuel is sprayed into the cylinder at the end of the compression stroke, when the air temperature is high enough to cause it to ignite spontaneously without a spark. Diesel engines are usually heavier and more powerful than gasoline engines and have better fuel efficiency; they are used in buses, trucks, ships, and some automobiles. In Europe, a large proportion of personal automobiles are powered by diesel fuel, but diesel fuel is less common in the United States because of clean-air laws. Diesel fuel has more exhaust emissions than gasoline.

### *Coal-burning engines*

Using coal for heat and cooking can be as straightforward as putting coal in a stove and setting it on fire; the coal burns slowly and emits steady heat. But the way coal really had an effect on people's lives was through its use as a fuel for engines, such as steam engines that powered locomotives that pulled trains. Coal-burning locomotives used steam to power their wheels. A locomotive works like this:



Side view of George Stephenson's *Rocket* locomotive. The train was designed and built in 1829 and is considered the forerunner of all other steam locomotives. © *Hulton-Deutsch Collection/Corbis.*

1. In order to keep the fire burning, the locomotive has to carry a large pile of coal, which a person called the fireman constantly shovels into the firebed. (More modern locomotives have mechanical shovels to feed the fires.)
2. The ashes left over from the burning coal fall through grates into an ashpan below the firebed. The ashes are dumped at the end of the train's run.
3. This basic process was not only used in trains. Steam engines also powered riverboats, steamships, and factories.

Most trains in the twenty-first century are powered by diesel fuel or electricity. China still uses coal-burning trains for normal transportation, but in Europe and the United States steam locomotives are only used as part of museum displays to entertain tourists.

***Where electricity comes from***

Fossil fuels are important for the production of electricity. Most power plants have generators that spin to create electricity, which is then sent out through the wires and poles that distribute it to consumers. Something has to power those generators. The vast majority of power plants burn fossil fuels for this purpose. (The rest use nuclear power or hydroelectric power.)

About one-half of the electricity in the United States comes from coal-burning power plants. These plants store their coal in giant outdoor piles. People driving bulldozers push the coal onto conveyor belts that carry it up to silos or bunkers. The coal is typically crushed so it can be fed into most power station furnaces. Then it is fed into giant burners that burn night and day to create steam to turn the generator. Most plants need constant deliveries of coal to have enough fuel to keep the burners running at all times. They produce large amounts of ash. One of the jobs of plant operators is to keep the ash from clogging up the works.

Natural gas is the other significant fossil fuel source of electrical power in the United States, supplying about one-fifth of the nation's electricity. Natural gas plants use turbines to spin generators. The turbines are connected to pipelines that provide a constant supply of natural gas. Some plants use the natural gas to power the generator directly. Others use the natural gas to create steam, which spins the generator.

The United States government encourages power companies to build plants powered by natural gas because natural gas burns much more cleanly than coal and therefore does not create as much pollution. The U.S. Department of Energy predicts that 90 percent of new power plants built in the early 2000s will be powered by natural gas.

### Historical overview: Notable discoveries and the people who made them

Humans have been using fossil fuels for thousands of years, possibly as long ago as twenty thousand years. Oil sometimes seeps up through the ground, so it was easy for people to see it and experiment with it. The ancient Mesopotamians in what is now Iraq may have discovered a way to use oil about five thousand years ago. Historians believe that people first used petroleum as oil for lighting, dipping wood in it and setting it on fire as a torch. Ancient Greeks and Romans used coal as a fuel for heat and cooking. Ancient temples sometimes had eternal flames, which may have been powered by natural gas leaking up from the ground.

In the British Isles coal began to be used in the late thirteenth century, and it was the dominant fuel in London by 1600. Wood was abundant, so coal took time to become widely adopted. The first widespread use of fossil fuels occurred in the late 1700s, with the

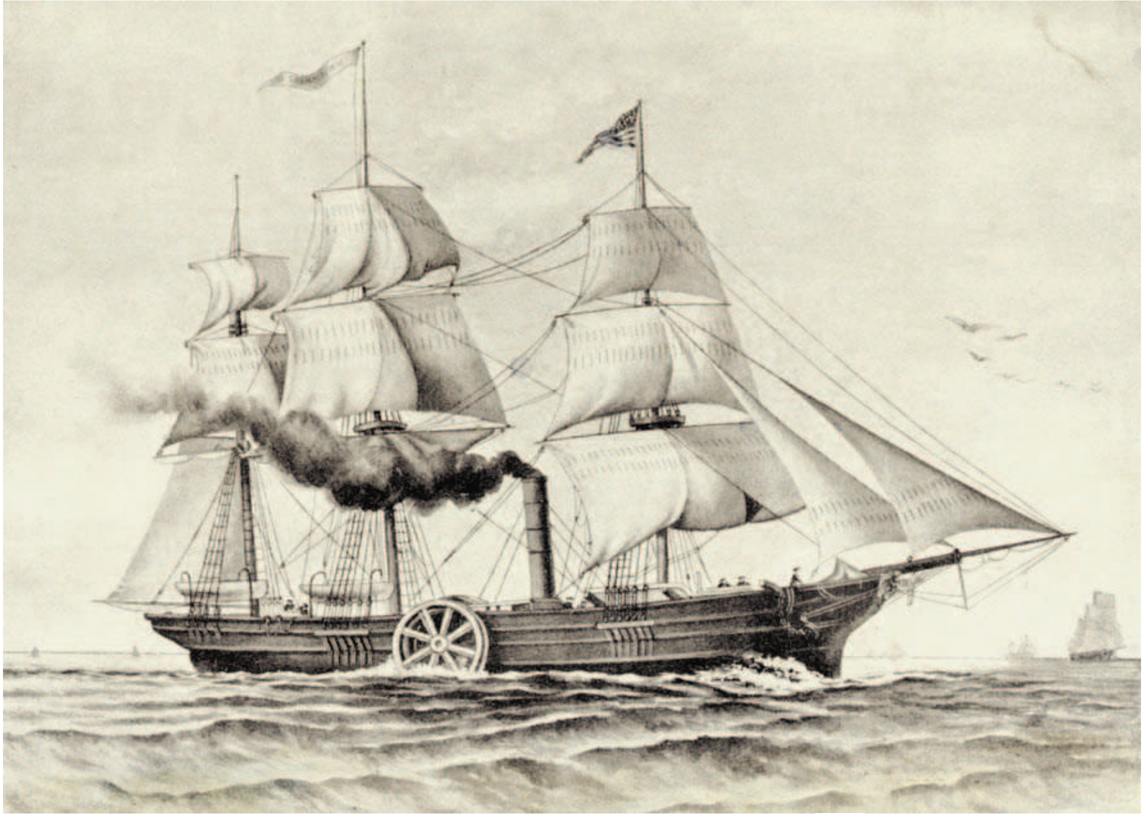


Illustration of the *Savannah*, the first steamship to cross the Atlantic Ocean. © *Bettman/Corbis.*

development of the steam engine and the start of the industrial revolution. James Watt (1736–1819) is usually credited as the inventor of the first commercially efficient steam engine in 1769, though his work was based on the inventions of others, particularly that of the Cornish engineer Thomas Newcomen (1664–1729), whose atmospheric steam engine was completed in 1711. The steam engine, powered by coal, made the industrial revolution possible. Steam engines could power trains, boats, and factories. The first coal-burning steam locomotive was built in Wales in 1804. In 1825 coal-powered trains became available for commercial use. Robert Fulton (1765–1815) invented the steam-powered riverboat in 1807, and riverboats became a popular way to travel up and down the Mississippi River in the United States. In 1819 a steamship crossed the Atlantic Ocean for the first time. By the mid-1800s people were regularly traveling between Europe and the United States on coal-powered steamships.

People began using natural gas to power lamps in 1785 in England. Natural gas lamps became common in the United States around 1816. The first natural gas well was built in Fredonia, New York, in 1821.

In the 1850s an American lawyer named George Bissell (1821–1884) investigated the possibility of using oil as lamp fuel. He thought he could find more oil if he drilled into the ground, so he hired Edwin Drake (1819–1880) to drill the first oil well. This well was completed in Titusville, Pennsylvania, in 1859. Drake used the oil to make kerosene, which people used in lamps and heaters. Gasoline was a by-product (one of the leftovers) of the process of making kerosene, but no one at the time had a real use for it. Other people began looking for oil, and they found it in places such as Indonesia, Texas, and the Middle East.

By the end of the nineteenth century many people were using light bulbs instead of kerosene lamps, so oil producers began adapting their product for other uses. The first gasoline-powered internal combustion engine was developed in 1886. The first mass-produced gasoline-powered car was the Oldsmobile, introduced in 1902. Henry Ford (1863–1947) introduced the Model T in 1908 and began producing his inexpensive cars on an assembly line. By 1920 there were twenty-three million cars in the world, and it turned out that gasoline was the most practical way to power them.

The Wright brothers, Orville (1871–1948) and Wilbur (1867–1912), flew their first successful airplane in 1903. They used petroleum as their fuel, and from that point on airplanes were powered by petroleum-based fuels. Diesel fuel gradually replaced coal as the dominant fuel for large ships. Diesel locomotives appeared around 1920 and had replaced steam engines by 1960.

Consumption of all fossil fuels increased greatly during the twentieth century. Petroleum was used to power automobiles, airplanes, ships, and electric plants. Coal heated homes, powered factories and trains, and generated electricity at power plants. Toward the end of the twentieth century the oil industry began to develop the potential of natural gas, and this fuel became useful in homes and businesses as well as in industry. Minor fossil fuels such as kerosene, propane, and butane were all widely used at the beginning of the twenty-first century. Perhaps the most notable transition from the twentieth to the twenty-first century is from stationary devices burning solid fuels to mobile sources using liquid fuels.

### Current and future technology

Fossil fuels supply a large percentage of the world's energy needs through a variety of technologies. Most automobiles and other vehicles use gasoline to power internal combustion engines, in which the burning that generates power takes place inside the engine. Coal or gasoline is burned to power factory equipment. Coal-fired plants generate much of the world's electricity. Almost every twenty-first century technology uses fossil fuels in some way.

Fossil fuel technology has changed. Scientists are constantly looking for technology that makes fossil fuels work more efficiently and reduces pollution. Fossil fuels are so common and considered so necessary that there is great incentive for engineers to improve methods of acquiring and using fossil fuels. Technology under development includes:

- Clean coal technology
- Vehicles powered by natural gas or substances other than gasoline
- Fuel cells that use small amounts of fossil fuel to make hydrogen
- Safer means of transporting fossil fuels
- Improved techniques for cleaning fossil fuels before, during, and after burning
- Improvements in extracting fossil fuels from the ground

### Benefits and drawbacks of fossil fuels

Most existing technology was designed for use with fossil fuels. Fossil fuel transport systems are already in place. Pipelines for oil and natural gas and trucks and ships for petroleum products move the fossil fuels where they are needed. And consumers can buy the fossil fuel products they use on practically every corner.

Yet, fossil fuels are non-renewable resources. Current supplies took a very long time to form under the Earth's crust. These supplies will be gone long before the Earth has a chance to replace them. Even now, getting fossil fuels is a major drawback to using them. Countries that do not have reserves of oil and natural gas must depend on those countries that do. And using fossil fuels contributes to air and water pollution.

### Environmental impact of fossil fuels

Fossil fuels cause or contribute to environmental problems such as the following:

- Damage to the landscape
- Air pollution
- Water pollution

- Oil spills
- Radioactivity (Coal contains the radioactive elements uranium and thorium, and most coal-fired plants emit more radiation than a nuclear power plant.)
- Health problems for workers and those nearby (Many fossil fuel byproducts can be harmful to humans: breathing toxic hydrocarbons, nitrogen oxides, and particulate matter can cause ailments such as chest pain, coughing, asthma, chronic bronchitis, decreased lung function, and cancer, and exposure to mercury can lead to nerve damage, birth defects, learning disabilities, and even death.)

Some experts believe the environmental problems are so serious that people need to find alternatives to fossil fuels even before all reserves are used up. Others believe that technological improvements will allow the use of fossil fuels for many years to come.

#### *Damage to the landscape*

Fossil fuels are found underground. There is no way to get them out without cutting into or removing the dirt on top of deposits. Strip mining for coal involves removing the dirt and rocks above a deposit of coal and digging out the coal beneath it. Miners sometimes remove the tops of mountains to remove the coal below. Mines below the Earth's surface can collapse, resulting in changes to the landscape on top of them.

Though drilling for oil and natural gas is not always as destructive as coal mining, it still involves machinery that can destroy animal habitats and pipelines that cut across the land for thousands of miles.

#### *Air pollution*

Air pollution results from driving cars and trucks, from burning coal and other fossil fuels to create electricity, from industry, from using gas-powered stoves and appliances, and from many other daily activities. As the number of drivers increases and average fuel efficiency declines due to a shift to lower mileage SUVs, air pollution increases. As the number of people using electricity increases, so does air pollution.

There are several types of air pollution:

- Particulate matter is tiny particles of burnt fossil fuels that float in the air. This kind of pollution is sometimes called black carbon pollution. Examples of coarse particulate matter include the smoke that comes from a diesel-powered

Aerial view of mountaintop removal and reclamation in the Indian Creek vicinity of Boone County, West Virginia. © *Library of Congress.*

truck or the soot that rises from a charcoal-burning grill. However, in addition to the visible black particulate matter there is the fine material (less than 2.5 microns) that creates large health problems.

- Smog is a mixture of air pollutants, both gases and particles, that create a haze near the ground. Sulfate particles, created when sulfur dioxide combines with other chemicals in the air, and ozone are the main causes of smog and haze in most of the United States.
- Ozone is a form of oxygen that contains three oxygen atoms per molecule. ($O_2$, the form of oxygen that humans need to survive, contains two oxygen atoms per molecule.) It is common in Earth's atmosphere, where it blocks much of the sun's ultraviolet radiation, preventing it from burning up most forms of life. Though it is beneficial and necessary in the atmosphere, ozone is also destructive and highly toxic to humans. Ozone forms spontaneously from the energy of sunlight in the air, but it can also form from other reactions, such as sparks from electrical motors or the use of high

### Where Does Air Pollution Come From?

According to the Environmental Protection Agency (EPA), mobile sources, such as cars, trucks, buses, trains, airplanes, and boats, represent the largest contributor to U.S. air toxics. In 1999 as much as 95 percent of the carbon monoxide in typical U.S. cities came from mobile sources, according to EPA studies. More than half of all nitrogen oxide air pollution in the United States came from on road and non-road vehicles. The rest came from industry, such as power plants and factories. But the EPA states that the majority of all hydrocarbons (53 percent) and particulate matter (72 percent) comes from non-mobile sources such as power plants and factories.

voltage electrical equipment such as televisions. Fossil fuel pollution contributes nitrogen oxides and other organic gases that can react to create ozone. Ozone forms close to the ground on light sunny days, especially in cities.

- Sulfur dioxide is a by-product of burning fossil fuels. It is one of the key ingredients of acid rain. The United States Environmental Protection Agency (EPA) considers the reduction of sulfur dioxide emissions a crucial part of the effort to clean up the nation's air. The United States has set national air quality standards, and state and local governments are required to meet them.
- Nitrogen oxides are gases that contain nitrogen and oxygen in different amounts. Most of them are colorless and odorless. Almost all nitrogen oxides are created by the burning of fossil fuels in motor vehicles, power plants, and industry. Nitrogen oxides react with sulfur dioxide to produce acid rain. They also contribute to the formation of ozone near the ground, and they form particulate matter that clouds vision and toxic chemicals that are dangerous to humans and animals. In addition, they harm water quality by overloading water with nutrients. Finally, they are believed to contribute to global warming.
- Carbon monoxide is one of the main sources of indoor air pollutants. It forms from the burning of fossil fuels in appliances such as kerosene and gas space heaters, gas water heaters, gas stoves and fireplaces, leaking chimneys and

### Accidental Death

Burning a charcoal grill or kerosene heater or running a car engine inside an enclosed space, such as a closed garage, can produce enough carbon monoxide to kill a person. Every year people die from inhaling concentrated carbon monoxide. Death comes easily and without warning because the victim often does not notice any symptoms; he or she simply gets sleepy from lack of oxygen, loses consciousness, and dies as carbon dioxide builds up in the blood.

furnaces, gasoline-powered generators, automobile exhaust in enclosed garages, and other sources. Carbon monoxide binds with the iron atoms in hemoglobin (the part of blood that carries oxygen) and prevents the blood from taking up enough oxygen to keep the brain running.

The United States and the individual states have passed various laws regulating air pollution. The Clean Air Act, passed in 1990, is one of the most important. It requires states to meet air quality standards, creates committees to handle pollution that crosses borders between states or from Mexico or Canada, and allows the EPA to enforce the law by fining polluters. It creates a program allowing polluting businesses to apply for and buy permits that let them release a certain amount of pollutants. Businesses can buy, sell, and trade these permits. They can receive credits if they release fewer emissions than they are allowed to produce.

One major difficulty with controlling air pollution is that some pollutants can travel thousands of miles from their sources. Certain types of air pollution in one state can originate from a coal-burning plant in another. For that reason, air pollution regulations must focus on large regions if they are to have any effect at all.

#### *Acid rain*

Acid rain is rain with small amounts of acid mixed into it. When sulfur dioxide and nitrogen oxides are released from burning fossil fuels, they mix with water and oxygen in the atmosphere and turn into acids. The acids in acid rain are not strong enough to dissolve a person, but they can contribute to environmental problems, such as the following:

### A HEPA Filter?

Particulate matter is air pollution in the form of particles suspended in the air. Of special concern to human health are fine particles (of less than 2.5 microns) that are easily inhaled and can cause irritation to the eyes, nose, and throat, and may get into the lungs and either be absorbed by the bloodstream or stay embedded in the lungs to cause more serious breathing problems. Particulate matter has even been linked to an increased risk of heart attack in people with heart disease. Breathing in the particles may cause shortness of breath and chest tightness. A HEPA (HEP-ah) filter cleans particulate matter from indoor air when it is used in vacuum cleaners or air conditioning and heating units. A HEPA filter makes indoor air healthier because it is a ‘‘high efficiency particulate arresting’’ filter.

- Polluting lakes and streams, which can kill fish, other animals, and aquatic plants and disrupt entire ecosystems
- Damaging trees at high elevations
- Deteriorating the stone, brick, metal, and paint used in everything from buildings and bridges to outdoor artworks and historical sculptures
- Damaging the paint on cars
- Impairing visibility by filling the air with tiny particles
- Causing health problems in humans when the toxins in the rainfall go into the fruits, vegetables, and animals that people eat.

The EPA has an Acid Rain Program that limits the amount of sulfur dioxide that power plants can produce, and the program has reduced emissions somewhat. Reducing emissions overall should contribute to eliminating acid rain.

#### *Global warming*

Most scientists believe that the use of fossil fuels has changed the world’s climate, and that this change is continuing. Burning fossil fuels releases gases called greenhouse gases, which include carbon dioxide, methane, and nitrous oxide. Greenhouse gases are good at trapping heat. When the sun’s radiation hits Earth, some of the heat

Smog shrouds the skyline of the city of Los Angeles in a view from the Hollywood Hills. The city is famous for pollution. © *Andrew Holbrooke/Corbis.*

is reflected back into space. When greenhouse gases get into the atmosphere, they act like the walls of a greenhouse, holding the heat in so that it cannot escape back to space. Ordinarily, this would be a good thing, because life on Earth depends on keeping some of the sun's heat on the surface. Since the industrial revolution, however, the amount of greenhouse gases in the atmosphere has increased. The amount of carbon dioxide has increased 30 percent; the amount of methane has increased 100 percent; and the amount of nitrous oxide has risen 15 percent. These gases make the atmosphere better at keeping heat in. As a result, Earth's temperature has risen and continues to rise.

### Kyoto Protocol

In 1997 many of the world's nations agreed to work together to reduce greenhouse gases and stop global warming. These nations signed an agreement in Kyoto, Japan, referred to as the Kyoto Protocol. The Kyoto Protocol sets targets for reducing emissions and deadlines for nations to meet those targets. The United States and Australia have not agreed to participate because the protocol does not place the same requirements on developing nations as it does on industrialized nations.

The increase in global temperatures can cause many problems. A possible effect is a rise in sea levels, which can change the shape of coastlines; cause changes in forests, crops, and water supplies; and harm the health of humans and animals. Fossil fuels account for 98 percent of carbon dioxide emissions, 24 percent of methane emissions, and 18 percent of nitrous oxide emissions.

***Oil spills***

When transporting petroleum, there is always the danger that the oil will leak out of its tank and contaminate the local environment. Many oil spills occur when a giant tanker ship crashes and the petroleum leaks out of the tank into the ocean. Spills can also happen when oil wells or pipelines break, or when tanker ships wash their giant tanks, rinsing the residue straight into the ocean.

When oil gets into the ocean, it quickly spreads over the surface of the water, forming an oil slick. The oil clumps into tar balls and an oil-water mixture called mousse. Seabirds and marine mammals get caught in the oil and die.

The 1989 wreck of the *Exxon Valdez* in Prince William Sound, Alaska, caused the worst oil spill that has so far occurred in North America. The ship hit and slid onto a coral reef. The accident allowed 38,800 tons of oil from the tanker to spread over 1,200 miles (1,930 kilometers) of shoreline, killing over one thousand sea otters and between 100,000 and 300,000 seabirds. At least 153 bald eagles also died from eating dead seabirds covered with oil. The cleanup cost nearly $3 billion, a large portion of that furnished by the United States government.

Almost 14,000 oil spills are reported each year in the United States. Usually, the owner of the oil or the tanker takes responsi-

## Build a Better Tanker

Transporting oil safely is a big concern for the oil industry. Modern tankers are much stronger than older ones, and they are built with double hulls. Double hull means there are two layers of metal between the oil and the ocean. Double-hulled tankers are much less likely to be torn open if they run into rocks or coral reefs.

bility for cleanup. Occasionally, local, state, and federal agencies must help. The EPA takes care of spills in inland waters, and the United States Coast Guard responds to spills in coastal waters and deepwater ports.

The long-term effects of oil spills are not known. Though it appears that it is possible to clean up most of the oil and that the local ecosystem can recover, it also seems that some of the effects of oil are very long-lasting. The Prince William Sound environment still had some problems in the early 2000s: many animal species affected by the spill had still not recovered to their pre-spill numbers, and some oil remained on the region's beaches.

### Economic impact of fossil fuels

Because they have been plentiful and are usually less expensive than other energy sources, fossil fuels supply nearly all of the world's energy. At the beginning of the twenty-first century the world economy is based on inexpensive fossil fuel. Almost all modes of transportation and industries require fossil fuels. Prices of consumer goods and services from food to airline tickets are partly determined by the cost of fuel. When the price of oil goes up, people who sell goods and services often must raise their prices because it costs more to make or deliver products.

As developing nations increase their use of automobiles, electricity, and other goods and services, their demands for fossil fuels increase. For example, oil consumption in China grew rapidly in the early twenty-first century. By 2003 China was consuming the second largest amount of oil in the world, behind the United States. China does not have sufficient fuel reserves to supply its own needs, so it must buy petroleum from other countries. Oil producers can raise their prices because they have several buyers competing to purchase their product.

Yet fossil fuels are still the cheapest source of power in the modern world. Alternative energy sources, such as solar power or hydrogen fuel cells, are much more expensive. Most people will not choose an expensive source of power when a cheap one is available, even if the cheap source contributes to pollution. For example, many coal-burning power plants still produce large amounts of pollution because the cost of controlling the pollution is deemed too expensive.

### Societal impact of fossil fuels

Modern life would be impossible without fossil fuels, and in many ways fossil fuels have benefited people. The fact that fossil fuels are everywhere means that it is nearly impossible to take any action without using them. In many houses turning on a light uses fossil fuels. Shopping, eating, going to school, and sleeping in a heated or air conditioned home require the burning of fossil fuels. Fossil fuels are an important global issue. Countries have clashed over the issue of oil.

Air and water pollution are also global issues. The pollutants that come from fossil fuels can spread from country to country. Developing nations, such as Thailand and China, have been rapidly increasing the number of cars owned and of fossil fuel-powered factories and power plants, which has resulted in an increase in air pollution. International groups that want to protect the environment must balance air and water quality with the desire of poorer nations to improve their economies. The less developed countries feel that the countries of Europe and the United States were allowed to use fossil fuels to build their economies, regardless of the environmental consequences, and that they too should be given that opportunity without being forced to worry about pollution.

### Issues, challenges, and obstacles in the use of fossil fuels

Fossil fuels are widely used and widely accepted. Nevertheless, there are ways to make fossil fuels less polluting, such as the use of clean coal technology and hybrid automobiles. These technologies have not yet become widespread, in part because they cost more than the methods that are currently used. As pollution increases and fossil fuels become harder to get, new methods of using fossil fuels will probably become more common.

## PETROLEUM

Petroleum is the most widely used fossil fuel, supplying about 40 percent of the world's energy. Petroleum is also called oil. One

### Is Petroleum Really a Fossil Fuel?

Some scientists in Russia and Ukraine believe that petroleum is not actually a fossil fuel but that it formed in Earth's crust from rocks and minerals rather than plants and animals. These scientists believe that the formation of oil requires higher pressure than the formation of coal and that there is not enough organic matter in Earth's deposits to explain the amount of petroleum available in large fields. Scientists in other countries disagree with this idea.

of the most important uses of petroleum is as fuel for motor vehicles. It can also be used to pave roads, to make other chemicals, and to moisturize skin.

Petroleum is a hydrocarbon, which means it is made up mostly of molecules that contain only carbon and hydrogen atoms. It also contains some oxygen, nitrogen, sulfur, and metal salts. The term *petroleum* encompasses several different kinds of liquid hydrocarbons. The main ones are oil, tar, and natural gas.

**Origins of petroleum**

The ingredients in petroleum include microscopic plants and bacteria that lived in the ocean millions of years ago. When they died, these plants and bacteria fell to the bottom of the ocean and mixed with the sand and mud there. This process continued for millions of years, and gradually the layers at the bottom were crushed by the layers above them. The mud became hotter, and the pressure and heat slowly transformed it. The minerals turned into a kind of stone called shale, or mudstone, and the organic matter turned into petroleum and natural gas.

Because they are not solid, petroleum and natural gas can move around. They seep into holes in undersea rocks such as limestone and sandstone, called reservoir rocks. These rocks are porous, meaning they have tiny holes in them that allow liquids and gases to pass through, and function as sponges. Because they are lighter than water, oil and gas migrate upward, although still trapped within Earth's crust. Sometimes the oil and gas end up in an area of rock that is not porous and is shaped in such a way that it can contain liquid and gas. This area becomes a reservoir, or geologic trap, that holds the petroleum and natural gas. Rock formations especially good at trapping hydrocarbons include anticlines, or layers of rock that bend downward; salt domes, or anticlines with a mass of rock salt at the core; and fault traps, or spaces between cracks in Earth's crust.

Within a trap, petroleum, natural gas, and water separate into layers, still within the porous reservoir rocks. Water is the heaviest and stays on the bottom. Petroleum sits on top of the water, and natural gas sits on top of the petroleum. Sometimes the natural gas and petroleum inside a trap find a path to the surface and seep out.

### Finding petroleum

Geologists are scientists who study the history of Earth and its life as recorded in rocks. When looking for oil they want to find underground geologic traps because these traps often contain petroleum that can be removed by drilling. Geologists use a variety of techniques to find oil traps. They use seismology (syze-MAH-luh-jee), sending shock waves through the rock and examining the waves that bounce back. Geologists also study the surface of the land, examining the shape of the ground and the kinds of rocks and soil present. These scientists use gravity meters and magnetometers to find changes in Earth's gravity or magnetic fields that indicate the presence of flowing oil. They use electronic "sniffers" to search for the smell of hydrocarbons. Finding oil is difficult. Scientists searching for oil have only about a ten percent success rate.

Petroleum is present all over the world, but large concentrations of it exist in only a few places. These accumulations are called fields, and they are the places where oil companies drill for oil. The largest fields in the world are in the Middle East, especially in Saudi Arabia, Qatar, and Kuwait, and in North Africa. There are also large fields in Indonesia, Nigeria, Mexico, Venezuela, Kazakhstan, and several U.S. states, including Alaska, California, Louisiana, and Texas.

### Extracting petroleum

Once an oil company finds oil in the ground, it has to get the oil out in order to sell it. First the company has to take care of legal matters, such as getting rights to the area it wants to drill. Once that is done, the company builds an oil well, or rig.

All oil rigs have the following basic elements:

- A derrick, which is a tall structure that supports the drill apparatus above ground

- A power source, such as a diesel engine, that powers electric generators
- A mechanical system, including a hoist and a turntable
- Drilling equipment, including drill pipe and drill bits
- Casing to line the drill hole and prevent it from collapsing
- A circulation system that pulls rock and mud out of the hole
- A system of valves to relieve pressure and prevent uncontrolled rushes of gas or oil to the surface

Some oil is located under the oceans. Oil drilling platforms are built on the water. These platforms are off the coast of Texas. © *Jay Dickman/ Corbis.*

As oil workers drill deeper, they add sections of pipe to the drill and add casings to the hole to keep it stable. They drill until they reach the geologic trap that contains the oil and gas. To get the oil out of reservoir rocks, workers pump in acid or a fluid containing substances to break down the rock and allow the oil to seep into the well. The workers then remove the rig and install a pump in its place. The pump pulls the oil out of the well. Once the oil has been removed from the ground, the oil company must transport the

### If Petroleum Formed in the Ocean, Why are Oil Wells on Land?

When petroleum was forming, much of the area that is now dry land was covered with water. The ocean has moved away since then, but the oil is still there. In addition, many oil wells are out in the ocean, not on land at all.

crude oil to a refinery. The most common means of transporting oil are tanker ships, tanker trucks, and pipelines.

#### Making petroleum useful

Crude oil arrives at the refinery with a great deal of water and salt mixed into it. The water and oil are mixed together in droplets forming an emulsion, which is something like what happens to a salad dressing made of oil and vinegar. The water and oil may eventually separate out into their layers, but this process can take a very long time in thick crude oil. To speed the process, oil refineries heat the crude oil to a temperature at which the water can move more easily. The water molecules then come together and leave the oil. The water also takes the salt out of the oil with it.

The refinery distills crude oil to sort it into its different forms. Crude oil has many different kinds of molecules, some much larger than others. The refinery sorts out these molecules so that molecules of the same size are all together. A refinery is shaped like a tower with trays stacked one above the other. Heating the crude oil makes the molecules turn into gases. These gases move up inside the refinery's tower. As they travel upward in the tower, the gases become colder. At certain temperatures, they become liquids again. The liquids drip back down and are caught in one of the trays. The higher the gas travels, the higher the tray it ends up in. The largest molecules stay at the bottom. The smallest molecules make it all the way to the top of the tower. The lighter molecules are turned into gasoline and other fuels. The heavier ones become engine lubricants, asphalt, wax, and other substances.

There is a much larger market for gasoline and other fuels than for the products made from heavier molecules, so refineries try to make as much gasoline as possible. They can sometimes break down larger molecules into smaller ones. They do this through a process called cracking, which uses either heat or chemical catalysts to break down the large molecules.

## The Oil Sands of Canada

Since the 1960s, investors and developers have been working to extract crude oil stored in the oil sands of Alberta, Canada. Some experts put the amount of proven oil reserves in the western Canadian oil sands at roughly 175 billion barrels. This would put it second only to Saudi Arabia (with 260 billion) in terms of proven oil reserves. Others believe that the amount of reserve oil in Alberta is much higher, possibly at 300 billion barrels, with more potentially buried deep underground.

Though people dreamed for decades of striking it rich by getting the oil out of Canada's sand, techniques are still in the early stages because of the difficulty of removing it. When compared to the relative ease of getting the oil that comes gushing out of oil fields in the Middle East and Texas, the existing process for turning oil sand into crude oil is difficult and expensive. It requires oversized trucks and shovels to dig out the sand and various machines to crush it, mix it with hot water, spin it to separate out the oil, and heat it to remove impurities. The expense concerned oil investors until political issues in the Middle East and other oil-producing nations and increasingly high demand in the early 2000s drove up oil prices to record levels, finally making oil removal from Alberta's sands profitable. With demand for crude oil on the world market growing, in particular to meet the needs of the United States and China, many of the residents and government officials of Alberta and Canada saw the potential for job creation and huge profits for the province and the rest of the country. In addition to making money by selling the oil, Canada could also potentially use the oil to negotiate with other countries on trade and political issues.

In the decades to come, Canada may become one of the biggest players in the fossil fuel economy, though the benefits may come at a high cost. The large amounts of natural gas and water used in the separation process create concerns for environmentalists. So does the excavation of thousands of tons of mud and sand, which creates large mining pits in Alberta's landscape. Though the oilmen who run Alberta's oil sand industry have promised to improve technology to clean up their greenhouse gas emissions and refill the mines and replant trees, groups like the Sierra Club of Canada have their doubts about whether technology will progress fast enough or trees grow quickly enough to make it worth the environmental damage. With little encouragement for conservation and the use of alternate energy sources by the worldwide community, demand for crude oil will most certainly transform Canada's economy and landscape as the oil sands become a valuable energy source for the world.

### Current and potential uses of petroleum

Petroleum has many uses. It can take on different consistencies depending on how much it is refined. About 90 percent of the

The Isla Oil Refinery in Curacao, Netherlands Antilles. © *2005 Kelly A. Quin.*

petroleum used in the United States is used as fuel for vehicles. Fuel types include:

- Motor gasoline used to power automobiles, light trucks, or pickup trucks that people drive as their daily transportation, boats, recreational vehicles, and farm equipment such as tractors
- Distillate fuel oil, including the diesel fuel used to power diesel engines in trucks, buses, trains, and some automobiles
- Heating oil to heat buildings and power industrial boilers
- LPGs (liquid petroleum gases), including propane and butane. Propane is used for heating and to power appliances. Butane is used as fuel and is blended with gasoline
- Jet fuel, which is a kerosene-based fuel that ignites at a higher temperature and freezes at a lower temperature than gasoline, making it safer to use in commercial airplanes
- Residual fuel oil used by utilities to generate electricity
- Kerosene used to heat homes and businesses and to light lamps

## Stopping the Knocking

The question of how to prevent engine knocking has occupied petroleum engineers for many years. In the mid-twentieth century, they added lead to gasoline to make it burn more efficiently. In 1979 leaded gasoline became illegal in the United States due to fears of lead poisoning in children. Since that time MTBE (methyl tertiary-butyl ether) has been added to gasoline in the United States to enhance octane. It has done a great job of reducing emissions from car engines, but it is not perfect. People are concerned that MTBE is dangerous when it gets into drinking water, and they want to find a substitute. Ethanol has been used in some cases, but it has drawbacks, too. As of the early 2000s, oil companies were still looking for the perfect fuel additive.

- Aviation gasoline, which is a high-octane gasoline used to fuel some aircraft
- Petroleum coke used as a low-ash solid fuel for power plants and industry

Petroleum has many other uses, including:

- Petrolatum, or petroleum jelly, used as a moisturizer and lubricant
- Paraffin wax used in candles, candy making, matches, polishes, and packaging
- Asphalt or tar used to pave roads or make roofs
- Solvents used in paints and inks
- Lubricating oils for engines and machines
- Petroleum feedstock used to make plastics, synthetic rubber, and chemicals

The United States uses over 250 billion gallons of oil every year. About one-half of that amount comes from domestic wells; the other half is imported.

### Benefits and drawbacks of petroleum

As compared to other fossil fuels, petroleum is easy to retrieve, refine, and use. It is fairly easy to transport and store. It is not prone to exploding spontaneously, so it is relatively safe to keep near homes. Petroleum burns easily, making it the ideal fuel for internal combustion engines. Petroleum has many applications in addition to fueling vehicles. These uses range from paving materials to skin moisturizers.

Using petroleum, however, has many drawbacks. It contributes to various types of environmental problems, including air and water pollution. There is only a limited supply of petroleum, which means that at some time in the future, the world's petroleum will be gone. When that happens, people will have to find another way of powering their vehicles, factories, and utilities.

### Impact of petroleum

Using petroleum as fuel contributes to many environmental problems. These include oil spills, which typically happen during the transportation of petroleum; the destruction done by drilling for oil; contamination from oil wells and pipelines; and air pollution. Drilling for oil, for instance, requires massive pieces of equipment and results in giant holes in the ground. Contamination happens when oil seeps into local soil and water. The people who live near oil wells and refineries sometimes suffer health problems as a result of exposure to petroleum.

When gasoline burns, it releases carbon dioxide and water into the atmosphere. It also produces carbon monoxide, nitrogen oxides, and unburned hydrocarbons, all of which can contribute to air pollution. Modern automobiles use catalytic converters to remove some of the pollutants from car emissions. Because of this improvement in car technology, automobiles in 2005 produced much less pollution than cars in 1970.

The economic impact of petroleum is enormous. The United States uses more than seventeen million barrels of oil daily and 250 billion gallons of oil a year. More than one-third of that petroleum powers cars and trucks. The country must import more than one-half of that amount from other countries. The United States has more oil reserves than it currently uses, but as of the early twenty-first century it was much less expensive to import oil than it was to extract reserves within the country. Foreign oil is becoming more expensive, however, especially as other countries increase their oil consumption. Some people support opening new U.S. sites to oil exploration and drilling partly because the oil industry can create so many good jobs.

A sudden change in oil prices can be disruptive to the United States and world economies. For example, oil prices rose steeply in

The Zueitina Oil Company's excess oil, water, and product waste dumping ground is outside the main oil pumping facilties in Libya. © *Benjamin Lowy/Corbis.*

the 1970s, creating an oil shock and inspiring car manufacturers to improve fuel economy. Oil prices were low and stable during the late 1980s and most of the 1990s. Rising prices in the early 2000s reflected increased demand for oil and other complicated economic factors.

**Issues, challenges, and obstacles in the use of petroleum**

There is a limited supply of petroleum on Earth. Some experts believe that oil production will peak by 2020 and that current oil reserves will run out by 2050, if not earlier. Other experts disagree, believing that there are enough oil reserves to provide for the world's energy needs throughout the twenty-first century. Many areas in the Middle East and Russia are still unexplored. Oil companies can now drill in much deeper parts of the ocean than they previously could; oil rigs in the Gulf of Mexico now drill into wells below 10,000 feet (3,048 meters) of water. Improved drilling technology such as drills that can twist and turn underground allows oil companies to reach petroleum deposits miles away from rigs.

## OPEC

The Middle East holds a great deal of the world's petroleum. Middle Eastern nations and a few others have formed an organization called the Organization of the Petroleum Exporting Countries, or OPEC (OH-peck), which coordinates the prices that the individual countries charge for oil. Most OPEC member countries are developing nations, which means they are working on making their countries more modern. Oil is extremely important for these countries because it brings in a huge amount of money. Furthermore, as long as petroleum is needed, the OPEC nations will have power over the rest of the world.

Pessimists argue that improved technology will only deplete oil reserves faster, especially as more of the world uses oil to power its vehicles and industry. Optimists believe that should not matter and that innovation will allow oil companies to keep furnishing the world with petroleum.

### NATURAL GAS

Along with coal and petroleum, natural gas is one of the three main fossil fuels in use in the early twenty-first century. People use natural gas for heating, electrical power, and other purposes. Natural gas produces much less pollution than petroleum, so some people believe it could be an ideal substitute for petroleum and coal in the future.

Natural gas is a gaseous hydrocarbon. It is colorless, odorless, and lighter than air. Natural gas is made up of 75 percent methane, 15 percent ethane, and small amounts of other hydrocarbons such as propane and butane.

The substance that oil companies sell as natural gas is almost pure methane, with the other gaseous components removed. When it burns, methane releases a large amount of energy, which makes it a useful fuel. Methane is sometimes called marsh gas because it forms in swamps as plants and animals decay underwater. Methane is naturally odorless, but gas companies add traces of smelly compounds to natural gas so that people will be able to smell gas leaks and avoid danger.


Oil wells at Midway-Sunset Oil Field in California. © *Lowell Georgia/Corbis.*

## Origins of natural gas

Natural gas formed from underwater plants and bacteria. These microscopic organisms fell to the bottom of the ocean when they died and over the course of millions of years were crushed and heated by the pressure of layers of sand, dirt, and other organic matter that accumulated on top of them. The mineral components of the undersea mud gradually turned into shale, and some of the

## Fuel Economy in Cars

The average fuel economy of cars sold in the United States has decreased steadily since 1985. That means that on average, a new car today uses more fuel for the same performance than an equivalent car built 20 years ago. Sport utility vehicles (SUVs) are partly to blame for this. The Clean Air Act required car manufacturers to build vehicles to certain specifications that limited pollution. Certain types of vehicles, such as trucks, did not have to meet the same standards as cars because they were larger and there were relatively few people driving them at the time. Because SUVs are classified as light trucks under the law, they do not have to have the same level of fuel economy that a passenger car has. Car manufacturers like SUVs because they are inexpensive to make and can be sold for relatively high prices. SUVs have also been fashionable among consumers. In 2005 a proposed reform of the government's Corporate Average Fuel Economy (CAFE) program for light trucks by the National Highway Traffic Safety Administration (NHTSA) required carmakers to make gradual changes to their designs to meet stricter fuel economy requirements for light trucks by 2011. The proposed plan was scheduled to go into effect in April 2006.

As gas prices rose and concerns about America's dependence on foreign oil began to concern Americans in the early 2000s, hybrid cars became fashionable. These cars were powered by a combination of gasoline and battery power and had considerably better mileage than gasoline-powered cars. In their first years only a few were available so they were hard to buy. Some critics complained that hybrid cars were too expensive and that they did not in fact provide the fuel economy that a small, light, efficient gasoline-powered car could.

organic components turned into natural gas. Natural gas can move around within porous reservoir rocks. It can also be trapped in underground reservoirs, or geologic traps. Natural gas is lighter than petroleum, so it usually sits on top of the petroleum in a reservoir. Natural gas sometimes seeps up through Earth's crust and appears on the surface.

### Finding and extracting natural gas

Natural gas is usually found with petroleum. When geologists (scientists who deal with the history of Earth and its life as recorded in rocks) search for underground oil, they find natural gas along with it. Sometimes there are pockets of natural gas in coal beds. Geologists occasionally find reservoirs that contain mostly or all natural gas with no oil. The largest reserves of natural gas in the United States are in Texas, Alaska, Oklahoma, Ohio, and

## Make Your Own Methane

Although most of the world's methane is very old, it is possible to make new methane through chemical reactions. The Sabatier process combines hydrogen and carbon dioxide with a nickel catalyst and high temperatures to synthesize methane and water. This method of producing methane could be used to generate fuel in outer space to power spacecraft. One common natural process also results in large amounts of methane: When cattle digest food, they produce methane that they emit into the atmosphere.

Pennsylvania. Some experts believe that there is enough natural gas in the Earth to last two hundred years, although much of this gas may be difficult to reach.

When they first began drilling for oil, people believed natural gas was an unpleasant by-product. They would burn the natural gas away before removing the oil from the ground. Now oil companies know that natural gas is a valuable commodity in its own right, and they extract it carefully. The process of drilling for natural gas is similar to that of drilling for petroleum. In many cases natural gas comes out of wells that have already been dug to extract oil. Oil companies also drill wells to extract natural gas by itself. There are three main kinds of natural gas wells:

- Gas wells, which are dug into a reservoir of relatively pure natural gas
- Oil wells, which are dug for extracting oil but also extract any natural gas that happens to be in the reservoir
- Condensate wells, which are dug into reservoirs that contain natural gas and a liquid hydrocarbon mixture called condensate but contain no crude oil

Natural gas that comes from oil wells is sometimes called associated gas. Natural gas from gas wells and condensate wells is called non-associated gas because it is extracted on its own and not as a by-product of oil drilling.

### Making natural gas useful

The natural gas that consumers use is almost pure methane. The natural gas that comes out of a well is not pure and may contain a mixture of hydrocarbons and gases, including methane, ethane, propane, and butane. It also may contain small amounts of oxygen, argon, and carbon dioxide, but methane is by far the largest component.

An oil or gas company processing natural gas separates the gases into individual components, dividing them into pure methane, pure propane, pure butane, and so on. The liquid forms of the non-methane gas components, such as propane and butane, are called natural gas liquids, or NGLs, and sometimes are called liquid petroleum gas, or LPG. All of these products can be sold individually, so it is cost-effective to separate them.

The first step in processing is to remove any oil mixed with the gas. Natural gas that comes out of an oil well is separated from petroleum at the well. Sometimes the gas is dissolved in the oil, like the carbonation in a soft drink, and through the force of gravity the gas bubbles come out of the oil. In other cases the oil workers use a separator that applies heat and pressure to the mixed oil and gas to make them separate. The workers must also remove any water from the natural gas, using heat, pressure, or chemicals. They then remove NGLs using similar techniques.

Once they have been removed from natural gas, NGLs must be separated from one another. This is done through a process called fractionation, which involves boiling the NGLs until each one has evaporated. A similar process is used to refine petroleum. The different NGLs have different boiling points. As the NGLs boil, the different hydrocarbons evaporate and can be captured.

Some natural gas comes out of the ground with large amounts of sulfur in it. It is called sour gas because the sulfur makes the gas smell like rotten eggs. The gas company must remove the sulfur before selling the gas because sulfur in significant amounts is poisonous for humans to breathe and because it corrodes metal. The companies can sell the sulfur for industrial uses once it is separated out.

Sometimes a processing plant turns natural gas into liquid before transporting it. Liquid natural gas is one six-hundredth the volume of natural gas in gas form. Liquefying it makes it possible to store and transport natural gas around the world.

Once it has been refined and liquefied, natural gas can be transported and sold. The most common way to transport natural gas is through pipelines, which crisscross the United States and many other countries. If the gas is not sold right away, the gas company must store it. Natural gas is usually stored underground in formations such as empty gas reservoirs; in aquifers, or underground rock formations that hold water; and in salt caverns.

### Current and potential uses of natural gas

People have known about natural gas for thousands of years. The eternal flames in ancient temples may have been fueled by natural gas. In the early nineteenth century people began using natural gas as a light source, but as soon as oil was discovered in the 1860s and electricity became widespread, people abandoned natural gas except for limited use in cooking and heating.

Even so, the natural gas industry built the first large natural gas pipeline in 1891 and a large network of pipelines in the 1920s. Gas companies built more pipelines between 1945 and 1970, which made it convenient to use natural gas for heating homes and for use in appliances.

Natural gas has become more appealing as a fuel in recent years. Some uses are:

- Powering heaters and air conditioners. Because so many homes and businesses use gas heat, natural gas consumption typically is much higher in the winter than in the summer.
- Running appliances such as water heaters, stoves, washers and dryers, fireplaces, and outdoor lights.
- Serving as an ingredient in plastics, fertilizer, antifreeze, and fabric.
- Producing methanol, butane, ethane, and propane, which can be used in industry and as fuel.
- Dehumidifying, or drying the air in, factories that make products that can be damaged by moisture.

Scientists are considering the use of natural gas in applications such as the following:

- Powering natural gas-fueled vehicles, which produce far fewer emissions than vehicles powered by gasoline.
- Powering fuel cells in which hydrogen is used to produce electricity with few emissions.
- Reburning, or adding natural gas to coal- or oil-fired boilers to reduce the emission of greenhouse gases.
- Cogeneration, a technology for generating electricity as it burns fuel, requiring less total fuel and producing fewer emissions.

- Combined cycle generation, a technology that captures the heat generated in producing electricity and uses it to create more electricity. Combined cycle generation units powered by natural gas are much more efficient than those powered by petroleum or coal.

Scientists are especially interested in technologies that combine natural gas with other fossil fuels to increase efficiency and reduce emissions. Natural gas is seen as a good source of fuel for the future, and as a result scientists are constantly inventing new ways to use it.

### Benefits of natural gas

Natural gas has advantages over petroleum and coal. It burns cleanly, producing no by-products except for carbon dioxide and water, so it does not cause the same degree of air pollution as the other fossil fuels. It does not produce the sludge that results from coal-burning emissions.

Natural gas can take the place of gasoline as a fuel for cars, trucks, and buses. Most natural gas vehicles are powered by compressed natural gas (CNG); the technology used to pump CNG into a car is almost identical to the process of fueling a gasoline-powered car. Some vehicles can use either gasoline or CNG. Natural gas cars have no trouble meeting environmental standards because of their low emissions. Natural gas is very safe; it does not pollute groundwater.

For many years natural gas has been cheaper than gasoline. Many cities have converted their buses, taxis, construction vehicles, garbage trucks, and public works vehicles to natural gas. These organizations are well suited to use natural gas as fuel because their vehicles do not travel long distances and can afford the cost of converting the vehicles in the first place.

### Drawbacks of natural gas

Natural gas historically was hard to transport and store, but modern technology has for the most part removed that difficulty. One reason natural gas is not a perfect substitute for petroleum is that supplies are limited. At current rates of use, all of the world's natural gas could be used up in forty to ninety years.

Natural gas vehicles have not become widespread because it is more expensive to convert gasoline vehicles for natural gas use; there are very few natural gas refueling stations; and the vehicles cannot travel long distances without refueling.

### Impact of natural gas

Natural gas is the cleanest fossil fuel. The burning of natural gas releases no ash and produces low levels of carbon dioxide, carbon monoxide, and other hydrocarbons and very small amounts of sulfur dioxide and nitrogen oxides. Vehicles powered by natural gas emit 90 percent less carbon monoxide and 25 percent less carbon dioxide than gasoline-powered vehicles.

Natural gas is becoming an increasingly common fuel for electrical power plants and in industry. Electrical power plants fueled by natural gas produce far fewer emissions than coal-powered plants. Burning natural gas does not contribute significantly to the formation of smog.

Natural gas does contribute to some environmental problems. Burning natural gas emits carbon dioxide, which is considered a greenhouse gas that contributes to global warming. On the other hand, natural gas produces 30 percent less carbon dioxide than burning petroleum and 45 percent less carbon dioxide than burning coal, so it is still preferable to either of those.

On an economic level, the cost of natural gas has dropped considerably. The development of LNG technology means that natural gas is easier and less expensive to store and to transport, and liquefaction techniques (turning gas into a liquid) improve every year. Petroleum engineers are constantly getting better at finding and extracting natural gas from the ground.

Natural gas may change the way people use power in their daily lives. In the twenty-first century natural gas is a fairly minor fuel compared with gasoline, but it has the potential to be much more important. If power plants switch to the use of natural gas during summer when demand for natural gas is lowest and smog is highest, they could emit fewer pollutants and improve air quality. Using natural gas instead of other fossil fuels could reduce acid rain and particulate emissions. As people become concerned about emissions and fuel economy, they may want vehicles powered by natural gas. The vehicles will then become more widely available, less expensive, and easier to refuel.

### Issues, challenges, and obstacles in the use of natural gas

Natural gas technology is not widespread. The fuel has many possible applications, but car manufacturers will have to decide that it is cost-effective for them to build natural gas vehicles before they do so on a large scale. Consumers will not buy natural gas vehicles until they are convinced that it will be convenient, safe, and inexpensive for them to buy natural gas as fuel. A final large issue is the supply of natural gas, which could run out in a few decades.

## COAL

Coal supplies about one-fourth of the world's energy needs. Coal is a solid hydrocarbon made primarily of carbon and hydrogen with small amounts of other elements such as sulfur and nitrogen. Coal looks like black rock, and it leaves black dust on things that it touches.

### Origins of coal

Millions of years ago Earth was covered with swamps full of giant trees and other plants. When they died, these trees fell into the swampy water and were gradually covered by other plants and soil. All living things, including plants and animals, are composed mainly of carbon. Over millions of years, the carbon in the swamp plants was compressed and heated. This caused it to rot, exactly the way fruit and vegetables rot if kept too long. This rotting produced methane gas, also known as swamp gas.

Over several thousand years, the weight of the upper layers compacted the lower layers into a substance called peat. Peat is the first step on the way to the formation of coal and other fuels. People can use peat as fuel simply by cutting chunks of it out of the ground and burning them. Ireland used to be covered with peat, which was the main source of fuel there for years. The Great Dismal Swamp in North Carolina and Virginia contains almost one billion tons of peat.

As the peat continued to be compacted by new layers of dead plants, it became hotter as it was being pushed closer to the heat inside the Earth. The heat and pressure gradually turned it into coal. Most of Earth's coal was formed during one of two periods: the Carboniferous (360 million–290 million years ago) or the Tertiary (65 million–1.6 million years ago).

### Finding coal

There are large reserves of coal all over the world. China has nearly one-half of the world's coal reserves and produces nearly one-fourth of the coal that is used every year. There are also large reserves of coal in North America, India, and central Asia. In the United States, most coal comes from mines in Montana, North Dakota, Wyoming, Alaska, Illinois, and Colorado. There are also coal deposits in the Appalachian area, especially in West Virginia and Pennsylvania.

### Getting coal out of the ground

Coal is extracted from the earth through mining techniques that vary depending on where the coal is located. If a coal seam (or deposit) is deep below the surface of the Earth, miners use subsurface mining. They dig vertical tunnels into the ground to reach the seam and then dig horizontal tunnels at the level of the seam. The miners ride elevators down to the seam, dig out the coal, and transport it back up to the surface. To prevent the earth from collapsing, miners leave pillars of coal standing to hold up the tunnel roof. Despite this precaution, coal mines sometimes collapse, killing miners trapped inside.

Surface mining, or strip mining, is a process of taking coal off the surface of the Earth without going underground. Miners use giant shovels to remove dirt, called overburden, from the coal seam and then use explosives to blast the coal out of the rock. Strip mining is much safer than subsurface mining, but it leaves huge scars on the land and can contribute to water pollution.

### Making coal useful

Coal comes out of the ground in chunks up to 3 or 4 feet (0.9–1.2 meters) across, and coal processors crush it into chunks about the size of a person's fist. These chunks of coal then go through a screen that separates out the smallest pieces. Coal plants sometimes clean coal by setting it, which washes out the heavier particles of stone. The plant may then dry the coal to make it lighter and help it burn better. Once processing is complete, coal is transported to buyers using trains, barges (flat cargo-carrying boats), and trucks.

Coal comes in several types, depending on how pure the carbon is, which also corresponds to how old the coal is. Coal is rated by heat value (how much heat it can produce when it burns). The purer the carbon is, the higher the heat value. Heat value is measured in British thermal units, or Btu, per pound. A Btu is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

- Anthracite (AN-thruh-syte) contains between 86 and 98 percent pure carbon and has a heat value of 13,500 to 15,600 Btu per pound.
- Bituminous (bye-TOO-muh-nuhs) coal contains between 60 and 86 percent pure carbon and has a heat value of 8,300 to 13,500 Btu per pound.
- Lignite contains between 46 and 60 percent pure carbon and has a heat value of 5,500 to 8,300 Btu per pound.

### Current and potential uses of coal

Coal became a popular fuel in England in the nineteenth century because England sits on top of huge coal deposits. Coal was more plentiful than wood, which meant it was less expensive. The availability of coal along with inventions such as the steam engine allowed England to become the first truly industrialized nation.

During the nineteenth century and in the early part of the twentieth century, many people had coal-burning stoves in their homes. This system of heating had many drawbacks. It was messy, and people had to make sure they did not run out of coal. By the late twentieth century coal was no longer a common fuel for heating homes. As individual homeowners used less coal, industry used more.

Between 1940 and 1980 the amount of coal used by electrical power plants doubled every year. Coal also powers factories that make paper, iron, steel, ceramics, and cement. At the beginning of the twenty-first century over one-half of the electrical power plants in the United States were powered by coal.

### Benefits and drawbacks of coal

Coal burns hotter and more efficiently than wood, and in many places it is more readily available. There is a great deal of coal in the world, so supplies are not likely to run out in the near future.

One of the drawbacks of using coal is that it has to be dug out. All methods of mining coal have problems associated with them. Coal is also very dirty. Coal dust coats anything it falls on, from buildings to people. Gases released by burning coal are big contributors to air pollution.

### Environmental impact of coal

Coal is not environmentally friendly. It produces large amounts of pollution, which may contribute to acid rain and global warming. Mining it is often damaging to the environment, and transporting it is destructive as well. Most coal is moved around on trains, which are powered by pollution-causing diesel fuel.

#### *Air pollution*

The difficulty with burning coal is that it rarely produces only carbon dioxide, water, and energy. If the temperature is not high enough or if not enough oxygen is available to keep the fire burning high, the coal is not completely burned. When that hap-

## Eternal Coal Fires

Sometimes the coal inside a mine will catch on fire by accident. It can be nearly impossible to put out this kind of fire; drilling into the mine only adds oxygen to fuel the flames. A coal deposit in Tajikistan has supposedly been burning underground since 330 BCE when Alexander the Great visited the area. A network of coal mines in Centralia, Pennsylvania, caught fire in 1962 and is still burning. Someone had burned trash in an abandoned coal pit, and the coal vein ignited. The town had to be evacuated in the 1980s. Hundreds of coal mines are burning in the United States, but many more are burning in China and India, where mining development is proceeding too rapidly to control. In addition, coal mining produces tailings (coal mining wastes) that are put in large piles above ground; the tailings can also catch fire and burn for decades.

pens, the coal releases other substances into the air. These substances include:

- Carbon monoxide, which is toxic to humans and animals
- Soot, which is pure carbon dust and can turn buildings, trees, and animals black (The English invented glass-covered bookcases in the 1800s so their books would not get covered with soot.)
- Sulfur dioxide, sulfur trioxide, and nitrogen oxides, which become part of acid rain
- Lead, arsenic, barium, and other dangerous compounds that are in coal ash, which can float in the air or stay where the coal was burned and cause people to become ill

As mentioned, electrical power plants produce 67 percent of the United States sulfur dioxide emissions, 40 percent of carbon dioxide emissions, 25 percent of nitrogen oxide emissions, and 34 percent of mercury emissions. Coal-fired power plants account for over 95 percent of all these emissions.

New power plants may be less polluting than older ones, but most power plants operating in the United States as of 2005 still used older technology. Under the Clean Air Act older plants were prevented from expanding, in the hope that they would gradually close down and be replaced by modern facilities. The Clear Skies program enacted in 2003 by President George W. Bush removed this requirement, allowing older plants to keep operating and to expand their operations if they chose to do so.

Regardless of what developed countries of the twenty-first century do about emissions, China and other developing nations are using outdated technology that releases huge amounts of pollution. As the developing nations move towards resembling the developed world technologically, vast amounts of pollution travel around the world and end up in countries elsewhere.

### *Coal mining*

Surface coal mining can leave huge holes in the land and even destroy entire mountains. Water that flows over the mine site can flush pollutants into streams and rivers. Underground coal mining leaves behind tunnels in the ground, which can collapse suddenly. In the old days of mining, abandoned surface mines would turn into forbidding deserts, full of old rusted equipment.

Modern coal mining is very different, at least in the industrialized world. Due to several decades of pressure from consumers and environmental groups and new environmental laws, twenty-first century coal mining companies are much more careful about restoring the landscape after they take the coal from it. Miners save the topsoil and store local plants in greenhouses. Mining companies hire biologists, botanists (scientists who study plants), and fisheries experts to restore the environment as it was before mining began. Before laws required it, no mining company spent the money to avoid environmental harm.

## Economic impact of coal

Coal started the industrial revolution in Europe in the late eighteenth century. Without coal, there would have been no factories, no steel, no trains, no steamships, and no electric lights. In the early twenty-first century coal is still a huge business. Coal mines bring in a great deal of money. In areas that have large coal deposits, most of the local population may be employed by the coal industry. The closing of a coal mine can harm a community by putting many townspeople out of work.

## Societal impact of coal

Coal mining was one of the first industries to attract the attention of socially conscious lawmakers, who passed laws protecting workers. Coal mining was also one of the first industries in which workers organized, leading to the development of trade unions. Although mining techniques in the United States are much better than they were in the nineteenth century, coal miners still face more daily risks than most workers. Some health problems are much more common in coal miners than in other groups of people. Aside from the danger of being killed in a mine collapse, coal miners are at risk of life-threatening lung diseases. People who live in coal mining regions depend on the coal industry for their income and do not want to see coal mining disappear. At the same time, they would like to see coal mining become safer and less destructive.

### Issues, challenges, and obstacles in the use of coal

The demand for coal is expected to triple in the twenty-first century. Coal is the only fossil fuel that is likely to be in large supply in the year 2100, so people may become even more dependent on it. The U.S. Congress has encouraged coal producers to clean up coal technology since 1970. Scientists are trying to invent ways to use coal for fuel without causing pollution. These methods are called clean coal technologies and include the following:

- Coal gasification, by which coal is turned into gas that can be used for fuel, leaving the dangerous solid components in the mine
- Coal liquefaction, by which coal is turned into a petroleum-like liquid that can be used to power motor vehicles
- Coal pulverization, by which coal is broken into tiny particles before it is burned
- Use of hydrosizers, which are machines that use water to extract (take out or remove) the usable coal from mining waste to increase the amount of coal that can be retrieved from a mine
- Use of scrubbers and other devices to clean coal before, during, and after combustion to reduce the amount of pollution released into the atmosphere
- Use of bacteria to separate pollutants from organic components in coal so that the sulfur and other pollutants can be removed before burning
- Fluidized bed technology, which burns coal at a lower temperature or adds elements to the furnaces in coal plants to remove pollutants before they burn

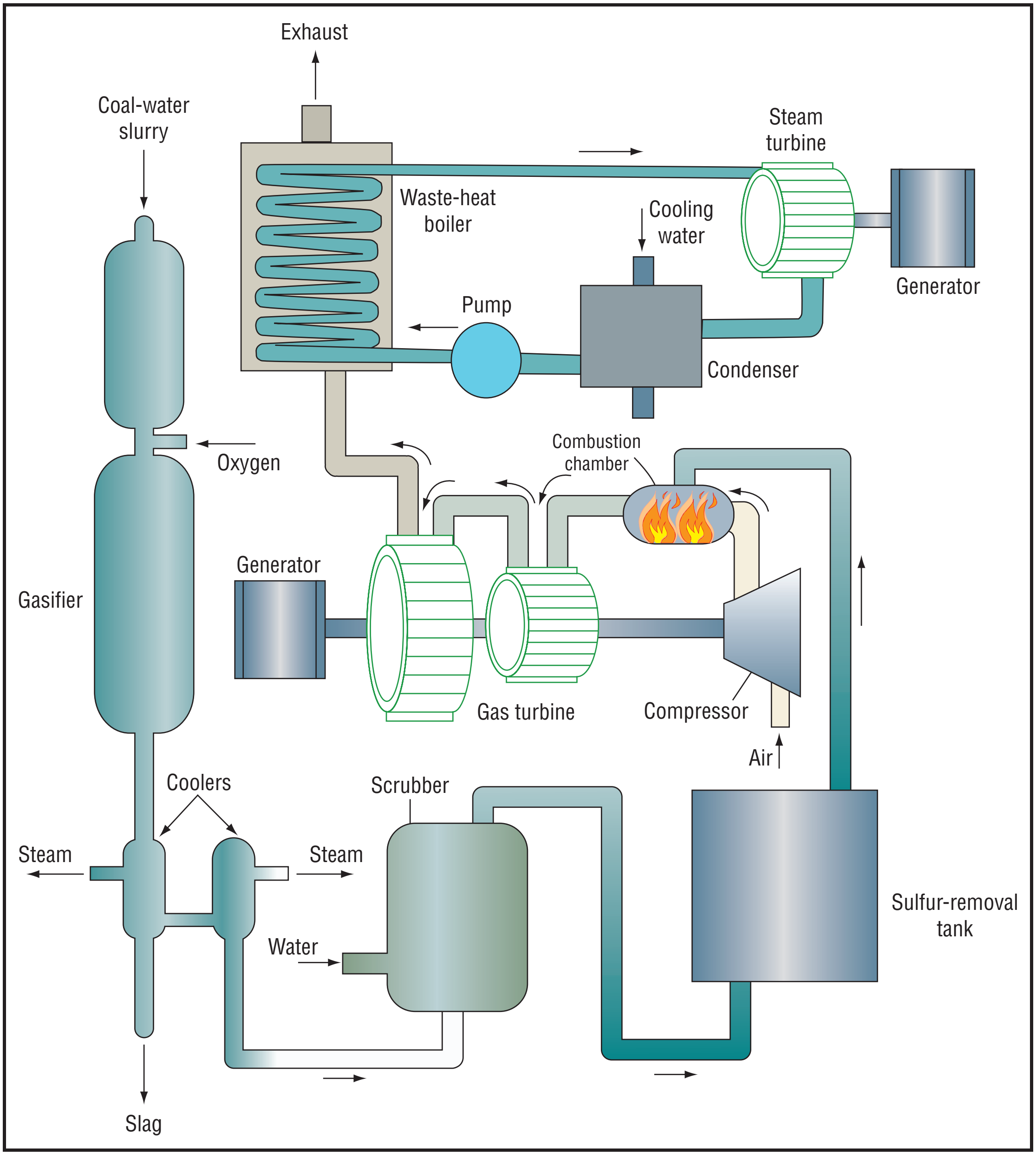



Illustration showing coal gasification, with the elements that are used to give power to the electric generators. © *Thomson Gale.*

## COAL GASIFICATION

Coal gasification is a process that converts coal to a gas that can be used as fuel. The main advantage of gasification is that it can remove pollutants from coal before the coal is burned, so the harmful substances are not released into the air. Coal gasification is a clean coal technology.

Coal gasification is done in stages. The first step is to crush and dry the coal. The crushed coal is placed in a boiler, where it is heated with air and steam. This heat causes chemical reactions that release a mix of gases that can then be used as fuel. The solid waste, or ash, remains in the boiler, where it can be collected and thrown away. Dangerous gases such as carbon dioxide and sulfur dioxide are removed in scrubbers like the ones in smokestacks at coal plants.

Gasification has been around for at least 100 years. It was widely piped and used as a fuel in Britain and many other European countries by 1900. Although it was used in other countries, in the United States it wasn't utilized during the first half of the century because petroleum and natural gas were inexpensive and plentiful. In the 1970s utility companies began considering gasification as a way to obey stricter environmental laws. Many people hope that coal gasification will be a valuable technology in the twenty-first century.

### Current and potential uses of coal gasification

Coal gasification produces the following kinds of gases that can be used as fuel:

- Methane, which can be used as a substitute for natural gas
- Chemical synthesis gas consisting of carbon monoxide and hydrogen, which is used in the chemical industry to produce other chemicals, such as ammonia and methyl alcohol
- Medium-Btu gas, which is also made of carbon monoxide and hydrogen and used by utilities and industrial plants

### Benefits and drawbacks of coal gasification

Plants and factories that run on coal gasification technology have much lower emissions than traditional coal-burning plants, and their solid wastes are not hazardous. The waste products themselves can be useful. The sulfur dioxide scrubbers produce pure sulfur that can be used in other processes, and some scientists believe the ash can be used to build roads and buildings. Some people believe it may even be possible to use sewage or hazardous wastes to power the coal gasification boilers.

The greatest problem with coal gasification is cost. Using coal gasification technology to provide power to an industrial plant costs three times as much as using natural gas. Supporters of the technology hope that researchers will develop ways to make gasification less expensive. Coal gasification requires vast amounts of water, which creates a problem. For gasification to be cost-effective, the plants must be built near coal mines so that the coal does not have to travel far, and most coal mines in the United States are in western states, where water is limited and expensive.

### Impact of coal gasification

On an environmental level, gasification has the potential to make coal a much less polluting fossil fuel. It will not have any impact on the environmental destruction caused by coal mining itself. However, coal mining is now much less destructive than it used to be.

Economically, coal gasification is much less efficient than burning coal directly; 30 to 40 percent of coal's energy is lost during the process of converting it to gas. Gasification would hardly be worth the cost of production if it were not for the environmental benefits it offers.

### Issues, challenges, and obstacles in the use of coal gasification

Scientists in Europe and the United States have been working to improve coal gasification techniques. They have been experimenting with using chemicals called catalysts to release the gases from coal. Using catalysts would allow gasification to occur at a lower temperature, which would make the process less expensive. Some scientists believe that the answer is to carry out gasification inside coal mines. Miners could pipe up the useful gases and leave the solid wastes underground. This idea is attractive because a large portion of coal reserves are nearly impossible to remove by the usual methods, and underground gasification would make those reserves available.

## LIQUEFIED PETROLEUM GAS: PROPANE AND BUTANE

Liquefied petroleum gas, or LPG, is petroleum gas that can easily be turned into a liquid at ordinary temperatures simply through the application of pressure. The main types of LPG are propane and butane. Propane is the most common LPG and is usually what people mean when they refer to LPGs. Propane and butane are both colorless, flammable gases that belong to the category of hydrocarbons called paraffins or alkanes. Unprocessed natural gas contains both propane and butane, which are removed during the purifying process. Petroleum refining also creates LPGs.

The first step in processing LPG is to remove any oil that might be mixed with the gas. Sometimes the natural gas is dissolved in oil, and the gas bubbles will come out of the oil through the force of gravity. In other cases oil workers use a separator that applies heat and pressure to the mixed oil and gas to make them separate.

Once the methane has been removed from the natural gas, the workers separate the remaining components, which include propane, butane, and ethane in a liquid form. The process is called fractionation, which basically involves boiling until each one of the gases has evaporated. The different gases have different boiling points. As each different boiling point is reached, the gases evaporate and can be captured separately. Because LPGs are naturally odorless, oil companies often add a substance called ethanethiol (eth-THAN-ee-thee-all) to it so people can smell the gas if it leaks. Ethanethiol smells like rotten eggs.

Oil companies usually store large amounts of LPGs in underground salt domes and pressurized empty mines near gas production facilities and pipeline hubs. These reservoirs are tied directly to pipelines so the LPGs can be delivered rapidly. LPG merchants store the gas in large pressurized above-ground tanks. Consumers then store LPGs in smaller above-ground tanks at their homes or businesses.

Most LPGs in the United States are transported through a network of about 70,000 miles (113,000 kilometers) of pipelines. Most of these pipelines are concentrated along the Gulf Coast and in the Midwest. The Midwest also receives LPGs from two pipelines running from Canada. The east coast of the United States has only two pipelines serving the area. LPGs can be delivered by trucks, trains, barges, and ocean tankers. The United States imports about ten percent of its total LPG supply from other countries, including Saudi Arabia, Algeria, Venezuela, Norway, and the United Kingdom.

### Current and potential uses of LPG

LPGs are useful as substitutes for natural gas for purposes such as powering stoves, furnaces, and water heaters. LPGs, often sold as or called propane, can be used in many ways, including:

- As a fuel for internal combustion engines, such as the ones in cars and buses

- To power home appliances, such as hot water heaters, heat pumps, space heaters, fireplaces, stoves, and clothes dryers
- As a fuel for devices such as forklifts
- For industrial purposes such as soldering, cutting, heat treating, and space heating
- To power campers and recreational vehicles
- As a solvent and refrigerant in the petroleum industry
- As a propellant in aerosol sprays, replacing CFCs (chlorofluorocarbons)
- For agricultural purposes such as weed control, crop drying, and as fuel for irrigation pumps and farm equipment

Butane by itself is used in cigarette lighters and portable stoves, such as the stoves people take camping. Petroleum refineries leave some butane in gasoline to make it easier to start engines since butane ignites quickly.

Ethane, which is another kind of LPG, is used as a starting material in the production of ethylene and acetylene, which are used as fuel in welding. It is possible to power automobiles and other vehicles with LPG. Some people have converted their cars to burn LPG instead of gasoline.

Homeowners and private consumers use about 45 percent of the LPGs sold in the United States. Most of this LPG, that is, propane for heat and other home purposes, is used during the winter. The petrochemical industry uses about 38 percent of the LPGs in the manufacture of plastics. Farms and factories use another seven percent each. Farms use the most LPGs in the fall, but factories use a steady amount year-round. Transportation accounts for only three percent.

### Benefits of LPG

LPG is a good fuel for internal combustion engines. LPG is no more dangerous than gasoline when contained in a fuel tank. Because LPG becomes liquid easily, it is possible to put it in pressurized tanks for storage and transport. People can keep tanks of LPG in their yards, and tanker trucks can deliver it to rural areas that are not served by natural gas companies.

Propane is an excellent fuel for automobiles and is becoming one of the most popular alternative fuels. Propane vehicles produce between 30 and 90 percent less carbon monoxide and 50 percent fewer smog-producing pollutants than gasoline-powered vehicles. In the early 2000s there were about 350,000 propane-powered vehicles in the United States and about four million in the world. These vehicles include cars, vans, pickup trucks, buses, and delivery trucks. The U.S. Department of Energy has encouraged consumers to consider using propane-powered vehicles.

In many ways propane is superior to electricity and to other fuels. It does not produce nearly as much pollution as gasoline or coal. Propane furnaces are more efficient at heating and release fewer air pollutants than heaters powered by electricity or fuel oil. Propane fireplaces are cheaper and less polluting than wood-burning fireplaces, and they can be turned on and off with a switch. Many professional cooks prefer propane stoves to electric stoves because they produce heat instantly and are easier to control. Moreover, propane appliances will still work during power outages, unlike electric appliances.

### Drawbacks of LPG

LPG is more expensive to produce than gasoline. It is not widely available, so it can be difficult to refuel a car that runs on LPG, although in the early 2000s this situation was improving. It can be difficult to find an LPG-powered vehicle because not many are made. Propane-powered vehicles usually have a slightly lower driving range than gasoline-powered vehicles because the energy content of propane is lower than that of gasoline.

LPG is highly explosive. It is important to maintain propane appliances in good condition and have them inspected regularly. Consumers should find out where gas lines run under their yards so they can avoid striking them with shovels or other hard metal objects. Anyone who smells a propane leak should immediately evacuate the building and call the fire department. No one should flip light switches, turn on other electrical appliances, or use the telephone if near a propane leak.

### Impact of LPG

LPG emissions of nitrogen oxides, carbon monoxide, hydrocarbons, and particulate matter are very low. LPG releases almost no emissions through evaporation, as gasoline and diesel fuel do. Engines that run on LPG are quieter than those that run on gasoline. LPGs do not cause carbon to accumulate inside machinery.

Economically, because propane and LPGs are produced as a by-product of natural gas and petroleum refining, their prices are directly tied to petroleum and natural gas prices. Prices for LPGs fluctuate (go up and down) according to seasonal demand. They are usually most expensive in winter, when people are using them for heat. Prices also vary by distance from source, so that consumers who live far away from sources of LPGs often pay more for them than consumers who live close by. Automobile manufacturers do not build LPG-burning cars because LPG is more expensive than gasoline.

On a societal level, LPG is invaluable to people in rural areas because it is a source of power that can be transported to areas not otherwise served by natural gas and electricity.

### Issues, challenges, and obstacles in the use of LPG

Since LPG comes from the production of petroleum and natural gas, when those supplies run out, so will LPG. At the beginning of the twenty-first century many organizations are trying to encourage consumers to use more propane and LPGs as fuel for their homes or vehicles, and interest in LPGs has increased somewhat as people become concerned about the environment. In order for more people to use LPGs as fuel for transportation, companies will have to make it easier to refuel the vehicles and less expensive to buy them.

## METHANOL

Methanol is a kind of alcohol that can be used as fuel. It is also called methyl alcohol and is used primarily in industry and in racecars. Some people hope it can be used to power fuel cells.

Methanol is a clear, colorless liquid with a distinctive odor. Methanol used to be called wood alcohol because people made it by burning wood and condensing the vapors that emerged. The ancient Egyptians created methanol in this way and used it to embalm mummies. Robert Boyle (1627–1691) isolated methanol in the 1660s, and Pierre Eugène Marcelin Berthelot synthesized it in about 1860. In the twenty-first century methanol usually is produced from natural gas. It may be possible to use coal or wood to produce methanol in order to avoid using natural gas resources.

### Current and potential uses of methanol

Methanol has several uses. Chemists use it to manufacture plastics and formaldehyde, which is used to preserve organic matter. It is useful as a solvent and as antifreeze. Methanol also can be used to power fuel cells, such as those in cellular telephones or laptop computers, and to manufacture the fuel additive MTBE (methyl tertiary-butyl ether).

### Do Not Drink the Methanol

The alcohol people drink in beer, wine, and whiskey is ethyl alcohol, or ethanol. Methanol, although it is a type of alcohol, is not the sort of thing anyone would want to drink. Drinking even a small amount can cause blindness. Drinking a larger amount can kill a person.

Automakers have experimented with using methanol as a fuel for cars, either alone or mixed with gasoline. A mix of 85 percent methanol and 15 percent unleaded regular gasoline (called M85) emits only half the pollutants of gasoline alone. Between 1978 and 1996 several automobile manufacturers made demonstration vehicles that could use both M85 and regular gasoline. Two companies offered these fuel-flexible vehicles for sale to consumers in 1995 and 1996. Methanol is a popular fuel for race cars largely because methanol fires can be put out with water, which makes it safer than gasoline.

#### Benefits and drawbacks of methanol

When used as an automobile fuel, methanol produces fewer emissions and has better performance than gasoline. It is also less flammable. Methanol can be made from a variety of substances, including natural gas, coal, and wood. Use of methanol could reduce dependence on petroleum. Methanol can easily be made into hydrogen so it has potential as a fuel source for hydrogen fuel cells.

However, methanol has several drawbacks as a fuel. The flame produced by burning methanol is colorless and almost invisible, which makes it dangerous for people working near it. Methanol vapors are poisonous and can burn skin. People who handle methanol without adequate protection can absorb it through their skin or lungs and quickly become ill, because methanol is highly poisonous.

Methanol is also more expensive to produce than gasoline, which makes methanol-gasoline mixes more expensive than plain gasoline. Anyone who owns a methanol-powered vehicle has a hard time finding a place to refuel. Automobile manufacturers stopped making methanol-powered vehicles in 1998, switching their attention to ethanol instead.

#### Impact of methanol

Methanol produces fewer greenhouse gases than gasoline. Vehicles powered with mixed gasoline and methanol emit just one-half the smog-forming pollutants that a comparable gasoline-powered vehicle emits. The formaldehyde it produces when it burns, however, is quite poisonous.

Many industries use methanol in their daily business. Because most methanol is made from natural gas, changes in natural gas prices affect methanol prices. Some factories that produce methanol stop production if natural gas prices go too high, a practice that can cause methanol shortages.

#### Issues, challenges, and obstacles in the use of methanol

Many people believe methanol has potential as a fuel. Federal and state governments have passed laws encouraging the development of alternative fuels such as methanol. The California Energy Commission has encouraged car manufacturers to experiment with methanol since 1978. Twenty-five years of experimenting did little to increase public support for using methanol as a fuel. As of 2005 most car manufacturers had abandoned methanol research.

Japanese cellular telephone manufacturers have been developing fuel cells powered by methanol. They hope that by 2007 people will be able to provide hours of power for their cellular telephones by squirting drops of methanol into them. The main drawback to this technology is the need to carry flammable methanol in public places, such as on airplanes. Researchers hope that this technology will have a wider application in the near future.

### METHYL TERTIARY-BUTYL ETHER

Methyl tertiary-butyl ether, or MTBE, is a substance added to gasoline to make it burn more completely and produce fewer polluting emissions. It has been added to gasoline in the United States since the late 1970s. In the 1990s communities discovered that MTBE was getting into their water supplies, which led to a movement to eliminate MTBE use.

MTBE is a chemical compound made of methanol and isobutylene. At room temperature, MTBE is a colorless liquid that dissolves easily in water. It is volatile (or unstable) and flammable. It has a strong odor, and small amounts of it can make water taste bad. MTBE is an oxygenate, which is a substance that raises the oxygen content of another substance. MTBE is used to raise the oxygen content of gasoline.

#### Current and potential uses of MTBE

MTBE, used as a fuel additive, increases the octane level of gasoline and reduces emissions of carbon monoxide and pollutants that form ozone. The U.S. Clean Air Act was passed in 1963 and updated in 1970 and 1990, requiring people in certain areas to use oxygenated gasoline. MTBE is one of the least expensive oxygenates, so most oil companies chose it as a fuel additive. Gasoline with oxygenates added to it is sometimes called reformulated gasoline, or RFG. At the end of the twentieth century about 30 percent of the gasoline sold in the United States was RFG, and MTBE was the oxygenate most commonly mixed into it. MTBE is the primary oxygenate because it is relatively inexpensive.

### Benefits and drawbacks of MTBE

MTBE blends easily with gasoline, and it can be shipped through existing pipelines. Gasoline with MTBE mixed into it burns more cleanly than plain gasoline, reducing tailpipe emissions. This has resulted in an improvement in air quality. The U.S. Environmental Protection Agency estimated that the addition of MTBE to gasoline reduces toxic chemical emissions by twenty-four million tons a year and smog-forming pollutants by 105 million tons.

MTBE dissolves easily in water, which can pose a hazard. When gasoline tanks or pipelines leak above or below the ground, the MTBE can dissolve in groundwater and travel to water supplies. Urban runoff, rain, motorboats and jet skis, and car accidents can all result in gasoline and MTBE getting into groundwater. Gasoline tends to stick to soil so it does not travel very far when it is spilled, but MTBE moves freely with water and can easily contaminate water supplies. It does not break down in the environment, so it can stay in groundwater for years.

Some people fear that MTBE causes health problems. Research animals exposed to large amounts of MTBE have developed cancer and other health problems. So far researchers do not believe that MTBE in gasoline poses any major health risks to humans. Researchers do, however, believe MTBE may cause cancer in people who drink water contaminated with large amounts of it.

### Impact of MTBE

The use of MTBE in gasoline has improved air quality in the United States since 1995. But MTBE has gotten into the groundwater in some areas. This happens easily when gasoline leaks out of storage containers or is spilled during transport. Rain can carry MTBE into shallow groundwater, and it can then get into deeper water supplies. MTBE can make water undrinkable. Some states have set limits on the amount of MTBE allowed in drinking water. Most public water systems must monitor their water supplies for the presence of MTBE.

Although MTBE can spread through the ground and water very easily, it does not break down easily. Getting MTBE out of water is difficult, so once it has polluted a water source, MTBE can be very hard to clean up. In 1996 the city of Santa Monica, California, found that two wells supplying the city's water were contaminated with MTBE and that levels of MTBE were increasing. After discovering more areas contaminated with MTBE, the state issued an order requiring that MTBE be removed from all California gasoline by the end of 2003.

On an economic level, MTBE is one of the least expensive and most convenient fuel additives. A huge amount of MTBE is produced in the United States. In 1999 more than two hundred thousand barrels were produced every day. Production of MTBE is very profitable, but cleaning MTBE out of the U.S. water supply is very expensive. MTBE has caused a number of lawsuits over cleanups that have cost both cities and oil companies huge amounts of money.

#### Issues, challenges, and obstacles in the use of MTBE

Many U.S. states have decided that the risks associated with MTBE are too great. Following California's lead, many states have called for MTBE to be phased out completely by 2014. A proposed $2 billion may be spent between 2005 and 2013 to help MTBE manufacturers switch their operations to some other substance.

## CONCLUSION

In the early 2000s most of the world is utterly dependent on fossil fuels for its energy needs. A number of nations are deeply concerned about this dependence because the use of fossil fuels contributes to air pollution and sometimes leads to strife between nations, and because the supply of some types of fossil fuel is likely to run out in the not-too-distant future. Many governments have begun looking for ways to end their dependence on oil, by exploring alternative sources of energy and developing systems of public transportation.

## For More Information

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# Bioenergy

## INTRODUCTION: WHAT IS BIOENERGY?

Bioenergy is renewable energy produced by living things like plant matter or by the waste that living creatures produce, such as manure. These living things and their waste products are called biomass. Biomass is organic matter (which comes from living things), just like fossil fuels (coal, oil, or natural gas, which are formed in the earth from plant and/or animal remains), but it is much more recently created and is renewable on a time scale that is useful to humans. Fossil fuels take millions of years to form. During this time they accumulate large amounts of carbon, which is returned to the atmosphere during burning. Plants grow continuously, animals constantly produce manure, and people throw away waste material all the time. Using these items for fuel does not deplete them because they are always being made.

For this reason, many experts believe that bioenergy will be a major source of power in the future. Besides being renewable, many kinds of bioenergy are considered less polluting than fossil fuels. They can be used as direct substitutes for fossil fuels, powering diesel or gasoline engines, heating buildings, and producing electricity. They can be made and used locally, which can make individual areas more self-sufficient and less reliant on foreign suppliers for energy. Bioenergy is created by using biofuels. Biofuels are made from sources of biomass including wood, plant matter, and other waste products. These sources can then be turned into biofuels. There are three types of biofuels: solid, liquid, and gas.

## Words to Know

**Anaerobic** Without air; in the absence of air or oxygen.

**Biodiesel** Diesel fuel made from vegetable oil.

**Bioenergy** Energy produced through the combustion of organic materials that are constantly being created, such as plants.

**Biofuel** A fuel made from organic materials that are constantly being created.

**Biomass** Organic materials that are constantly being created, such as plants.

**Distiller's grain** Grain left over from the process of distilling ethanol, which can be used as inexpensive high-protein animal feed.

**Feedstock** A substance used as a raw material in the creation of another substance.

**Flexible fuel vehicle (FFV)** A vehicle that can run on a variety of fuel types without modification of the engine.

**Infrastructure** The framework that is necessary to the functioning of a structure; for example, roads and power lines form part of the infrastructure of a city.

### Types of bioenergy

Biofuels come in all three forms of matter: solid, liquid, and gas. Solid biofuels are solid pieces of organic matter that release their energy through burning. Solid biofuels include the following:

- Animal waste (dung or manure)
- Bagasse (plant waste left after a product like juice or sugar has been removed)
- Charcoal
- Garbage
- Straw, dried plants, and the shells of grains
- Wood

Liquid biofuel is any kind of liquid derived from matter that has recently been alive and that can be used as fuel. Types include the following:

- Biodiesel, which is diesel fuel made of vegetable oils and animal fats instead of petroleum.
- Vegetable oil fuel, including straight vegetable oil, or SVO, and waste vegetable oil, or WVO.
- Ethanol and other alcohol fuels, which are made from corn, grain, and other plant matter and can be mixed with or substituted for gasoline.
- New fuels, such as P-Series fuels, which combine ethanol, natural gas traces or leftovers, and a substance made from garbage.

## Whale Oil

Whale oil was an important liquid biofuel in the eighteenth and nineteenth centuries. Whalers traveled the world's oceans searching for right whales and sperm whales in order to kill them and remove the oil from their bodies. This oil was used to light lamps and to make candles, cosmetics, and drugs. People still hunted whales in the twentieth century, and new uses were developed for whale oil. However, synthetics and fossil fuels replaced whale oil for almost all purposes by the mid-twentieth century. They were cheaper and more plentiful, especially as whales were hunted to near extinction and became more difficult to find and catch. Most of the world's countries in the twenty-first century have declared whaling, and the taking of whale oil, illegal.

Biofuel can also come in the form of a gas, or biogas, particularly that is emitted (given off) by decaying plants, animals, and manure. This gas is largely methane, which is the main component of the fuel natural gas. Most methane used in 2005 comes from fossil fuels, but scientists are currently researching ways to collect methane from decaying garbage. Scientists are also investigating the possibility of using biofuels to generate hydrogen, which could then be used in fuel cells. Gasification of solid biofuels (transforming their energy into natural gas) is also a possibility.

### Historical overview: Notable discoveries and the people who made them

People began experimenting with bioenergy in motors in the mid-1800s. In 1853 scientists used a chemical process with vegetable oil that created biodiesel. Rudolf Diesel (1858–1913), inventor of the diesel engine, gave a speech in 1912 in which he suggested that vegetable oil fuels were destined to become as important as petroleum and coal. However, diesel engine manufacturers in the 1920s geared their engines to run on thicker petrodiesel (diesel made from fossil fuels) because it was cheaper than biodiesel at the time. As a result, manufacturers ignored vegetable oil fuels for most of the twentieth century. Nevertheless, a few people used biodiesel and vegetable oil fuels throughout the 1900s.

A view of ethanol storage tanks that are being constructed on the northern side of the port of Santos, Brazil, September 3, 2004. Brazil is the world's largest producer and exporter of sugar and ethanol. © *Paulo Whitaker/Reuters/Corbis.*

Ethanol, too, generated interest in the early 1900s. Henry Ford (1863–1947) believed ethanol made from grain would be a valuable fuel. No one used much ethanol, however, until the oil embargo of 1973 led to an oil crisis. Convinced that the world was running out of oil, some people decided to use ethanol instead of gasoline. The movement was small in the United States and focused mainly in corn-growing states, but it became a big business in Brazil, which had ample sugarcane to use in making ethanol. Ethanol-burning automobiles were popular in Brazil until the late 1980s, when oil prices came down and sugar prices went up.

In the late 1900s, as people grew increasingly concerned about the limited supply of fossil fuels and the pollution caused by burning them, scientists and consumers once again turned their attention to bioenergy. In the 1990s France began producing

### The 1973 Oil Crisis

On October 17, 1973, the nations that belonged to the Organization of Petroleum Exporting Countries, better known as OPEC (OH-pek), announced that they would no longer sell petroleum to nations that had supported Israel in its fight with Egypt. These nations included most of Western Europe and the United States. Oil suddenly cost four times more than it had the month before. Gasoline appeared to be in short supply, and nations began limiting people's access to fuel. The government of the United States realized how dependent it was on Middle Eastern oil and responded by increasing efforts at U.S. oil exploration and extraction. The crisis spurred a new interest in fuel economy and alternate sources of energy. The national speed limit was reduced to 55 miles per hour, Daylight Savings Time was lengthened to save electricity, and the Department of Energy was created.

biodiesel fuel locally, using rapeseed oil to make the fuel. By the end of the twentieth century a large number of French vehicle manufacturers were producing vehicles intended to use some biodiesel in their fuel mixes. Increasing numbers of ethanol fuel plants were being built in the early 2000s. Biofuels may become big business in the twenty-first century as the supply of fossil fuels dwindles and the price of fossil fuels goes up. Biofuels such as biodiesel are increasingly part of European union legislation, so there is much pressure to develop and use them.

## How bioenergy works

Biofuels work by burning either directly (such as putting wood logs on a fire) or indirectly as through an engine. They are similar to fossil fuels, which also release their energy when they burn. Biofuels are the alternative fuels most similar to fossil fuels. In many cases they function as direct replacements of, or supplements to, fossil fuels.

### *The internal combustion engine*

Gasoline is the main fuel used in automobiles, which are powered by internal combustion engines. The basic principles of internal combustion have not changed in over one hundred years. They are the same whether the fuel is petroleum-based or biofuel. An internal combustion engine burns a fuel to power pistons, which make the engine turn. An engine contains several cylinders (most cars have between four and eight) that make the whole engine move.

One complete cycle of a four-stroke engine will turn the crankshaft twice. The crankshaft is a shaft connected to a crank that turns and moves the pistons in an engine up and down. A car engine's cylinders can fire hundreds of times in a minute, turning the crankshaft, which transmits its energy into turning the car's wheels. The more air and fuel that can get into a cylinder, the more powerful the engine will be. An engine using methanol is a bit different than one using petroleum or propane, but the concept is similar.

#### *Stoves, campfires, and grills*

The simplest technology using solid biofuels is a fire, such as a campfire, which consists of a pile of sticks, logs, or animal dung set on fire. There are many ways to arrange the pile of sticks, logs, or dung for safety and efficiency of burning, but basically the construction of a fire is simple and does not require the addition of complex equipment. Charcoal is often the preferred fuel because some of the other fuels give off smoke that can be harmful to the environment.

There are also devices that make it easier for people to use fires for heat or cooking. Grills placed on top of a fire, or devices that can hold a fire in a bowl with a grill on top of that, make it easy to cook food. Woodstoves come in a variety of styles. Some woodstoves make it possible to heat a large house with a small fire. Others contain both stove tops and ovens for cooking flexibility.

#### *Gas pipes*

Gaseous fuels travel through pipes from the place where they are produced to the place where they burn. In London in the 1800s, pipes delivered biogas from the sewers to street lamps. In 2005 some dairy farmers collect biogas from fermenting tanks of manure and run it to their appliances through pipes. The biogas can be lit at the pipe's end, powering a light, a stove, or another appliance.

### Current and future technology

Biofuels are already widely used in many parts of the world. Germany, Britain, France and Brazil all use biofuels in different ways. Biodiesel and ethanol are increasingly common. Scientists are working to develop new technologies that can take advantage of currently inaccessible sources of bioenergy.

Vegetable oil was one of the first fuels used in internal combustion engines. Today most vegetable oil is consumed in the form of biodiesel, which functions almost exactly like diesel made from petroleum, called petrodiesel. Vegetable oil, either new or used, can be used for fuel by itself in diesel engines, though the engines must be modified for this to work well. In the twenty-first century large companies are taking more of an interest in biodiesel; commercially prepared biodiesel is becoming more widely available, either straight or mixed with petrodiesel.

Ethanol, which is the same alcohol used in alcoholic beverages, has a long history of use as a fuel. Other alcohols, such as methanol, can also be used as fuel. Ethanol is easy to make from corn, grain, sugarcane, or other plant material. Ethanol can be mixed with gasoline to power internal combustion engines. Normal cars can use small amounts of ethanol in their fuel. Flexible fuel vehicles (FFVs) can use fuel that is nearly all ethanol. (Few vehicles in the early twenty-first century can use straight ethanol with no gasoline in it.) In some parts of the world, ethanol is routinely mixed in fuel, reducing the use of fossil fuels.

Scientists are also working to develop new types of fuels. P-Series fuel is a fuel that is made from a combination of ethanol, the leftovers from natural gas processing, and a substance made from garbage. It works in flexible fuel vehicles and appears to be a stable substitute for gasoline. Whether these fules are pollutants or not has not been concluded. Some scientists believe that they are non-polluting, but others believe that they give off significant nitrogen oxide emissions.

### Benefits and drawbacks

Biofuels appear likely to furnish at least some of the world's energy needs. There are many good reasons to use biofuels:

- They are environmentally much cleaner than fossil fuels, producing less air pollution and consuming materials that would otherwise be considered garbage.
- They are renewable; the supply of biofuels is less likely to run out, while the supply of fossil fuels probably will.
- They can be made locally using local materials.
- They can be flexible, easily mixed with other fuels.
- They can be cheaper than fossil fuels and will certainly become less expensive as the price of fossil fuel rises.


Singer Willie Nelson poses with a pump for Biodiesel fuel. Nelson, along with his business partners, are marketing a brand of clean-burning biodiesel fuel. The fuel is made from vegetable oils, mainly soybeans, or from animal fats, that can be used without modification to diesel engines. *AP Images.*

- Ethanol and biodiesel are better for car engines than fossil fuels. They can be used as additives to improve performance even if they are not the main fuel source.

But biofuels are not without some disadvantages:

- To make large amounts of biofuels would require cultivating more land than is currently farmed. This could be a very large problem to try to overcome.
- Some kinds of biofuels require modifications to vehicle engines.

### Flexible Fuel Vehicles

Flexible fuel vehicles, or FFVs, are vehicles that can run on various kinds of fuels, such as ethanol-gasoline blends, methanol, gasoline, P-Series fuels, or combinations of those, without having to be physically modified. The engine contains sensors that identify the type of fuel and adjust the timing of the spark plugs and fuel injectors to provide the optimum combustion.

In 2005 some common FFVs included the Ford Explorer, the GM Yukon, and the Mercedes-Benz C320. The owner's manual of the car states if the vehicle is indeed an FFV. Most FFVs are in the sport utility vehicle or light truck category. Sedans that are FFVs are usually made specifically to be fleet vehicles, one of many identical cars owned and used by a large company or organization.

- Making biodiesel at home or processing vegetable oil for home use is messy and inconvenient.
- Biofuels are not widely available.
- Some biofuels still require the use of fossil fuels; for example, most vehicles must have some gasoline mixed into ethanol to work and cannot run on ethanol alone.

#### Environmental impacts

Bioenergy is less polluting than fossil fuel–produced energy in respect to carbon dioxide. Biofuels contain carbon that only recently was in Earth's atmosphere, so the carbon dioxide released through burning them does not add to total carbon dioxide in the air. Fossil fuels, however, contain carbon that was removed from the atmosphere millions of years ago, and they emit large amounts of extra carbon dioxide when they burn. Replacing some fossil fuels with biofuels may help ease global warming, lessen air pollution, and clean the world's air.

Bioenergy, however, may be a contributor of formaldehyde to urban air. Biodiesel fuels are potentially high emitters of nitrogen oxides, which are a major component of smog. People with respiratory illnesses and small children are most affected by these air pollutants.

Biofuels are renewable. They come from plants and other currently growing organic material, so it is possible to generate new ones constantly. This makes them more environmentally

The power from this power plant is generated from the methane of the manure of the cattle grazing in the foreground. *©Charles O'Rear/Corbis.*

appealing than fossil fuels, which are, for all practical purposes, not renewable and are even in the process of being depleted.

Biofuels can use waste for feedstocks (starting materials). For example, waste vegetable oil from fast food restaurants or potato chip factories can be turned into biodiesel. This prevents the waste material from being disposed of in a landfill.

On the other hand, biofuels require large amounts of land to be cultivated and harvested. This can cause major environmental problems, such as habitat destruction and fertilizer runoff. Farmers use large amounts of fossil fuels to grow crops such as corn, which decreases the value of the energy made from those crops. In some cases, producing biofuels such as ethanol actually uses more energy than the ethanol yields.

## Economic impacts

In the early 2000s production of biofuels increased very rapidly. In the United States production of ethanol rose 30 percent each year between 2000 and 2005. During the same period Germany's production of biodiesel increased by 40 to 50 percent annually. France planned to triple its output of ethanol and biodiesel between 2005 and 2007, while Britain built two major biodiesel plants during the first few years of the century. As of 2005 China had built the world's largest ethanol plant and intended to build another just like it. A Canadian company planned to build a plant to make ethanol out of straw.

The reason for this increase was simple. Biofuels had previously been more expensive than fossil fuels, making them uneconomical during most of the twentieth century. Some people had supported biofuels all along because they wanted the world to use fuels that they believed were not as damaging to the environment as fossil fuels, and they persuaded governments to back them. But in the early 2000s it became clear that biofuels also made good economic sense. The price of fossil fuels went up, making biofuels comparatively cheaper. Depending on location, biofuels even became cheaper in real terms, that is, without governmental supports.

For individual consumers, biofuels can be more or less expensive than fossil fuels depending on how they are used. People who make their own biodiesel using free waste vegetable oil from restaurants spend very little money on fuel, though they do spend a certain amount of time in the pursuit of energy. Wood heat can be less expensive than electrical or gas heat. In the past, purchasing biofuels was usually more expensive than purchasing fossil fuel equivalents. That is changing in the twenty-first century, and more people are finding that biofuels make economic sense.

## Societal impacts

One of the biggest impacts that biofuels can have on society is increased self-sufficiency for areas and individuals that use them. Individual consumers and most nations do not have fossil fuels


A Cambodian villager stands in front of her gas stove powered by a biological gas digester. It converts human and animal manure into an enviornmentally friendly fuel. *AP Images.*

readily available. People and countries must buy their oil, gas, or coal from large companies that drill and process them. Consumers are vulnerable to changes in the price or supply of oil. Using biofuels allows people or nations to make their own fuel on the spot. This is especially useful to developing nations that have a large need for energy but do not have much money to buy fossil fuels.

### Barriers to implementation and acceptance

Few people used biofuels during the twentieth century because fossil fuels were readily available and inexpensive. By the early twenty-first century biofuels were becoming more attractive to large companies, which suddenly saw biodiesel and ethanol as potential sources of profit. Oil and gas companies still have little interest in pursuing sources of bioenergy, and their influence on national and state governments could prevent biofuels from being used in public transportation fleets.

Most people still know little about biofuels and so do not seek them out. Biofuels are not readily available in many places, so it is difficult for people to use them. Few people want to go to the trouble of making their own biodiesel or modifying their car engines to run on vegetable oil. As biofuels become more commercially available and user-friendly, consumers are likely to adopt them in increasing numbers.

## SOLID BIOMASS

Solid biomass was the first fuel humans ever used. Prehistoric humans used wood and animal dung to make their first fires, over which they cooked food and kept themselves warm. Ever since, solid biomass has played an important role in human energy needs.

Biomass energy is energy derived from solid organic matter other than fossil fuels. This can include charcoal, wood, straw, hulls of grains, animal manure, and bagasse (solids left over from the processing of sugarcane or fruit). The fuel can be used directly as for fire or used to power other devices such as electrical generators.

Solid biomass fuel can be used as it is found, but it often benefits from some processing to make it drier or denser than it is in nature. For example, the process of making charcoal transforms wood into a dry substance that is nearly pure carbon. Removing impurities can also improve efficiency.

Whether solid biomass is renewable or not depends entirely on how rapidly it is used. Wood met human energy needs for millennia, but once a forest is completely cut down, it becomes useless until the trees grow back, if they do.

### Current uses of solid biomass

Solid biomass is still widely used around the world. Most developed nations have moved away from using solid fuels for their day-to-day energy needs, favoring more efficient and readily available fossil fuels, but in much of the world wood for the fire is still a daily necessity. People in developed countries still use solid biomass as a source of fuel for some purposes.

#### *Animal waste*

Animal feces, also called manure or dung, is an important source of fuel around the world. Manure contains large amounts of carbon and nutrients that can be used as fertilizer, but it also contains ample plant fiber that will burn. Dried dung is widely used as fuel for fires in areas where there are many animals. People use dung from cattle, buffalo, horses, llamas, kangaroos, and other

## The Problem with Poop

Manure is a big problem for anyone who raises large numbers of farm animals such as cattle. A herd of cattle produces a tremendous amount of manure. Modern farmers gather the manure from barns or pastures and collect it in large heaps. Manure, like any pile of organic matter, gets hot as it decomposes. It can get so hot that it catches on fire, which results in a dangerous situation and very stinky smoke. Piles of poop also breed flies, which can spread disease. Though manure has many uses, on large farms it quickly becomes too much of a good thing. That is why scientists are investigating uses for manure such as the production of biogas.

creatures. Biomass sources such as garbage and manure can be allowed to decay to produce methane, or natural gas.

### *Bagasse*

Bagasse is the solid material left behind after removing a product from its source, such as juice from oranges or grapes and the sugar from sugarcane. About 30 percent of the sugarcane is left over after processing, and this solid fibrous material has long been used as fuel. In the earliest days of sugarcane processing, the bagasse was used as fuel for the sugar mill; in some cases, the processors would not extract as much sugar as they could from the bagasse so that they would have more bagasse left over to burn.

Bagasse is now an important source of fuel in Brazil. Brazil expanded its sugar industry in the 1970s to make sugar to produce ethanol. The ethanol plants use bagasse to power their machinery. Brazilian sugar growers sell excess bagasse to other industries, such as juice and vegetable oil factories, which burn it instead of fuel oil. This saves the nation several million dollars a year in oil import costs.

### *Charcoal*

Charcoal is a black combustible material made by removing the water and volatile substances from wood or other organic materials. It consists almost entirely of carbon, usually between 85 and 98 percent. The main reason to make wood into charcoal is to make it burn hotter and more efficiently. Wood contains a great deal of water, which cools the fire; volatile compounds such as


Two bagasse-burning Trankil Sugar Mill steam locomotives, numbers 3 and 4, in operation in Java, Indonesia. The bales on the back of the locomotives are pressed bagasse fuel from sugar cane waste. © *Colin Garratt; Milepost 92/Corbis.*

methane and hydrogen; and tars. To make charcoal, wood is buried to prevent oxygen from reaching it and allowing it to catch fire and then baked at a moderate heat for many hours. The impurities burn off in smoky clouds. Commercial charcoal manufacturers add borax to bind (hold together) the charcoal, nitrate to help it catch fire, and lime to color the ashes white.

Most twenty-first century Americans use charcoal only on outdoor grills, but charcoal has a long history of use. Bronze Age Europeans five thousand years ago used charcoal to melt metals. Blacksmiths used charcoal because it produced more heat than wood, important for heating metal. Charcoal was fuel in glassmaking and cooking. Artists use charcoal to create soft gray or black lines that blend easily. Charcoal is an ingredient in gunpowder. Charcoal in the metallurgy industry (metal industry) has now largely been replaced by fossil fuels such as coke and anthracite coal.

### *Compost*

Compost is organic material that has decomposed and turned into humus (material that results from partially decomposed plant and animal matter). It is added to soil as fertilizer and to improve the soil's structure. Plant matter that falls to the ground, such as leaves from trees, naturally decomposes and becomes part of the soil. Composting is the practice of consolidating this matter and controlling the conditions under which it decomposes, which speeds up the decomposition greatly. A compost bin or pile can contain dried leaves, green plant matter, table scraps such as vegetable skins, animal manure, and even paper. The mix needs water and oxygen to decompose properly. Microbes and insects such as ants break down the organic matter and turn it into a substance that looks very much like dirt. Though a simple trash heap will eventually produce usable compost over many months, a skilled composter will use techniques that make the pile grow very hot, killing seeds and germs and producing usable compost in just a few weeks.

Compost is not itself an energy source, but it can be a valuable replacement for fertilizers made with fossil fuels like natural gas. Farmland enriched with compost is more fertile than uncomposted land because the nutrients from the compost become part of the soil. Organic gardeners use compost to recycle yard and table waste and to make their soil richer. About one-third of landfill space is occupied by yard waste and table scraps. Putting yard waste and table scraps into compost saves landfill space by turning those materials into dirt.

### *Garbage*

Garbage is usually seen as a problem—as waste material that must be dumped somewhere, but preferably not close to anyone's home. Some scientists, however, have been experimenting with ways to turn garbage into fuels or useful substances. Some types of garbage can be converted into biogas, which can be used as fuel. Garbage is also a component of P-Series fuel.

### *Straw, dried plants, and shells of grains*

There is some possibility that dried plant matter could be used to manufacture ethanol. Making ethanol from this kind of cellulose (cellular material in plants) is more difficult than making it from sugarcane or grain. Straw and hulls do not contain as much sugar, and it is more difficult to remove the sugar from them, but it is possible. These dried substances can also be made into compost or converted into biogas. They are usually not the best fuels for fires because they burn quickly and cannot produce long-lasting heat.

## Ancient Central Heating: The Hypocaust

The ancient Romans used wood to create central heating for their homes. They used a system called a hypocaust. A hypocaust was a structure of tunnels under the floor of a building leading up into ducts in the walls of rooms. People would light a fire in the hypocaust, and the warm air would flow through the tunnels and air ducts, heating the building. This system was also used in public baths to heat floors, rooms, and water. A hypocaust was not a practical solution for most people because it required several slaves to feed the fires and remove ashes, and it could only be implemented in buildings made of stone or brick.

### *Wood*

Wood is perhaps the oldest solid biomass fuel. For most of human existence people have burned wood for heat and cooking. In many parts of the world wood is still the primary or the only available source of power. In the United States, wood is still a common source of heat in colder climates where it is plentiful. Some homes have wood stoves that burn wood to heat the house. Others have boilers outside the house that pipe heat into the home. Wood had a brief resurgence in popularity after the 1973 oil crisis.

The residues of wood and other forms of biomass can be used as a source of gaseous fuel. For example, wood residue inside a reactor vessel can be heated to make it break down and produce gas. This gaseous fuel can be burned on the spot as fuel for a turbine or other device.

### Benefits and drawbacks of solid biomass

Solid biomass is renewable, at least as long as plants keep growing and are not harvested faster than they can replace themselves. Solid biomass is flexible; a stove that can burn wood can probably also burn charcoal, dung, or other solid matter, though the results may be different. It can be used for simple purposes such as heating a home directly or complex ones such as generating electricity.

Yet solid biomass is only renewable as long as it is not consumed faster than it can be replaced. Solid biomass fuels have much lower energy content than fossil fuels, which means that people using them must acquire large quantities of them to do the same jobs that much smaller quantities of fossil fuels can achieve. Coal, for example, burns much hotter than wood and lasts longer. Anyone using solid biomass for home heating and energy must have access and transportation for large quantities of fuel and must be able to store it until it is needed, such as in a woodpile.

Preparing solid biomass fuels can take a great deal of work. Wood is heavy to move and must be cut into small pieces to fit into stoves or fireplaces. Dung must be collected and carried to wherever it will be burned, and bagasse takes up a great deal of space. A fire fed by solid biomass fuels must be fed regularly or it will go out. Fireplaces and stoves fill with ashes that must be removed from time to time. Ventilation can be a problem, because these fuels all produce smoke. In addition, smoke from woodstoves can be very high in carcinogenic substances.

### Environmental impact of solid biomass

Burning wood does not contribute to greenhouse gases because burning wood releases no more carbon dioxide than can be consumed by growing trees. Modern heating stoves are designed to emit few greenhouse gases. Burning wood does produce ash, but ash can be used as fertilizer or in soap making. Bagasse likewise produces few greenhouse gases. However, burning any renewable biomass fuel causes smoke that can seriously cloud the air in the immediate area. Sugarcane cutters often burn cane fields before cutting down the sugarcane. The resulting smoke can linger in nearby towns for weeks. Animal dung causes especially bad air pollution; the World Health Organization estimates that 1.5 million people have died of inhaling air polluted by burning dung.

### Issues, challenges, and obstacles of solid biomass

Deforestation (the destruction of forests) is a growing problem around the world. Without enough trees to provide wood, solid biomass fuel will not be a practical source of energy. Tree farming has largely solved this problem in the developed world, but in places where solid biomass fuel is still the main fuel source, lack of trees is a serious problem.

Woodstoves experienced a surge of popularity in the 1970s, after the oil crisis of 1973. Since then other sources of fuel have once again grown in popularity. Solid biomass fuels do not contain as much energy per weight as fossil fuels, so they are not the focus of most research into future energy sources. Wood, charcoal, bagasse, and other solids will probably still be used in the future but only for small-scale purposes such as home heating and cooking. Though biomass fuels have the potential to be a valuable source of energy in some places, such as Brazil's bagasse electricity industry, in most areas they do not seem to be practical sources of large-scale power.

## BIODIESEL

Biodeisel is diesel fuel made from renewable sources of carbon such as used vegetable oil or animal fats used in cooking. In diesel engines it can be used as a direct substitute for petrodiesel fuel made from petroleum.

Biodiesel is a clear amber liquid. Its consistency is similar to that of petrodiesel. Biodiesel can be used on its own in a diesel engine or mixed with petrodiesel. Some people mix small amounts of biodiesel into gasoline to decrease its air-polluting qualities.

Biodiesel is usually made out of the vegetable oil that is most readily available in a particular area. In France most commercial biodiesel is made from rapeseed oil. Other kinds of oil used to make biodiesel include palm, mustard, Jatropha, and soybean.

In the United States, soybeans make up the biggest source of biodiesel fuel because they are widely grown. Soybeans are not a particularly good source of biodiesel, but soybean growers have been able to expand the market for soybean-based biodiesel. Rapeseed, mustard, and Jatropha all produce two or three times as much oil as soybeans. Palm oil is an excellent source of oil to make biodiesel, and there has been some research into growing algae to use in making the fuel. Scientists are working on developing crops that produce larger amounts of oil for use in making biodiesel.

Biodiesel users sometimes refer to biodiesel or biodiesel blends by the letter B followed by a number indicating the percentage of biodiesel in the mix. For example, B20 is petrodiesel that contains 20 percent biodiesel. B100 is pure biodiesel.

### Vegetable oil into diesel fuel

It is possible to run a diesel vehicle on plain vegetable oil from the grocery store. The first diesel engine ran on straight peanut oil. In diesel engines, however, unprocessed vegetable oil is not very good for the engine because it eventually clogs the filters. In order to keep running the vehicle on vegetable oil, the owner must modify the engine; this is generally true even if the owner mixes the vegetable oil with petrodiesel or kerosene. If the vegetable oil is transformed into biodiesel, however, it becomes so similar to petrodiesel that it can be used in an unmodified diesel engine with no ill effects.

Biodiesel can be made from either new or used vegetable oil or from animal fat. Vegetable oil is the most common feedstock. Waste oil is more difficult to process into biodiesel than virgin oil because it must first be filtered to remove impurities. On the other hand, it is cheaper, often free, and is a good way of recycling a product that otherwise would be thrown away.

### How biodiesel is made

Making biodiesel involves joining the fatty acids of the vegetable oil or animal fat into long chains of triglycerides in a process called transesterification. This process converts the oil into long chains of mono-alkyl esters and glycerin. To transform the fats into biodiesel, a processor mixes an alcohol with a lye catalyst (something which causes a chemical reaction faster or at a different rate than it normally would) and then combines the mixture with warm oil. The most common alcohol used in this process is methanol, or methyl alcohol, but ethanol will work as well. The fatty acids float to the top of the mix and are siphoned off as biodiesel, while the glycerin stays at the bottom of the mixing vessel. The biodiesel must then be washed to remove any contaminants that could damage an engine.

Many people make their own biodiesel at home. There are many recipes available, easily found on the Internet. Though biodiesel fans claim that whipping up a weekly batch is no problem, the procedure involves a certain amount of trouble, mess, and danger.

### Current use of biodiesel

Biodiesel will work in any diesel engine, with no modifications necessary. This means it can be used as a substitute for petrodiesel fuel. It can be mixed into petrodiesel to reduce emissions, improve engine performance, and clean engine parts.

For many years the only people using biodiesel were enthusiastic environmentalists who made their own biodiesel at home, but that has changed. Commercial suppliers have been making biodiesel and selling it to the public for several years. Biodiesel is widely used in Europe and Asia. France is the world's largest producer of biodiesel. All petrodiesel fuel sold in France contains at least 5 percent biodiesel. In Germany over 1,500 filling stations sell biodiesel, which is less expensive than petrodiesel. The European Union, of which

France and Germany are members, passed legislation to require all member states to mix biodiesel into their petrodiesel. Public transportation fleets are often the first vehicles to adopt the use of biodiesel or biodiesel-petrodiesel blends as their standard fuel.

In the early 2000s biodiesel is becoming more common in the United States. Several states have passed laws requiring biodiesel to be mixed into diesel fuel. Over five hundred commercial fleets use biodiesel. Users include the United States Postal Service, the United States Marine Corps, the National Aeronautics and Space Administration (NASA), the United States Department of Agriculture, numerous state departments of transportation, and the San Francisco International Airport.

The use of biodiesel is increasing rapidly worldwide. In 1998, for instance, 380,000 gallons of commercially manufactured biodiesel were sold in the United States. That amount increased to thirty million gallons in 2004. Biodiesel production is fast becoming a viable economic opportunity and is attracting investors and inventors.

### Benefits and drawbacks of biodiesel

Biodiesel has many benefits. It is very easy to substitute for petrodiesel. Employees do not need special training to use it and no equipment needs to be modified. Unlike petrodiesel, biodiesel will not catch fire or explode. It is not poisonous to humans. It is completely biodegradable (capable of being broken down into harmless products). It is environmentally much cleaner than petrodiesel.

In addition, bodiesel is an excellent engine cleaner. It will remove dirt and residue left in a tank and fuel system by petrodiesel. Biodiesel can be added to ultra-low-sulfur petrodiesel to improve its lubricity (ability to reduce friction or rubbing). It makes the diesel fuel flow more smoothly and prevents the accumulation of contaminants within the engine and fuel system.

One reason many people make their own biodiesel is that they take pride in being independent of oil companies and being able to create their own fuel. Many of them save a great deal of money as well, but for many the feeling of independence and environmental virtue is the real attraction.

One major problem with biodiesel is that it is not widely available. France, Germany, and other European countries have many filling stations that sell it, but biodiesel is rare in the United States. For this reason, many people make their own, which itself presents problems. Making biodiesel is time-consuming and can be dangerous. Waste oil must be filtered before it can be used. The chemicals used to make biodiesel are poisonous to humans. Anyone making biodiesel must purchase safety equipment, including gloves, aprons, and respirators, and must have access to a secure work area that children and animals cannot enter.

Another drawback is that biodiesel can be more expensive than petrodiesel, depending on its ingredients. Purchasing new vegetable oil can be expensive, and biodiesel users must often purchase other ingredients and equipment to make the fuel. Converting a diesel engine to run on SVO (straight vegetable oil) can cost money.

Also, biodiesel is not as effective as petrodiesel in cold weather. Both kinds of diesel fuel get cloudy and full of small wax crystals that can clog fuel filters, but biodiesel is more sensitive to this problem than petrodiesel. When biodiesel gets cold enough, it turns into a solid and will not flow at all. Biodiesel made from virgin oil stays fluid at lower temperatures than biodiesel made from waste oil. Most biodiesel users find that they have difficulty with their fuel when temperatures fall below freezing. Some people get around this problem by adding 30 percent petrodiesel to their biodiesel. Others add anti-gel agents to winterize the fuel. Some people worry that biodiesel will decay rubber parts within the fuel system. This can happen, but rubber parts have been uncommon since the 1980s and are easily replaced in any case.

### Environmental impact of biodiesel

Biodiesel is much better for the environment than petrodiesel. It is completely biodegradable and non-toxic. It poses no threats to human health. It does not emit the pollutants produced by fossil fuels, which makes it very appealing for areas trying to improve air quality. It does not emit the black smoke that petrodiesel does. It is safe to store and transport. Its flash point (the temperature at which it will catch fire) is over 257°F (125°C), as opposed to 136°F (58°C) for petrodiesel, so it is harder to start a fire with biodiesel.

Making biodiesel is a good way to recycle waste oil that would otherwise end up in a landfill. Though there is a large amount of waste vegetable oil (WVO) produced daily, it is nowhere near the amount of diesel fuel used every day. Likewise, waste animal fat is not nearly plentiful enough to meet major energy needs. Some WVO is already converted into other products, such as soap. Nevertheless, a large amount of WVO and animal fats currently end up in landfills and could profitably be converted to biodiesel.


Students heading to their school bus, which runs on biodiesel fuel, Wednesday, Sept. 7, 2005, in Morgantown, West Virginia. *AP Images.*

**Economic impact of biodiesel**

Biodiesel can function as a substitute for petrodiesel, so economic costs depend partly on what a person or company would be spending on petrodiesel. Nations that use a great deal of biodiesel do not have to purchase petrodiesel from foreign suppliers, which can mean a tremendous savings. The cost of biodiesel to individual consumers varies depending on where they are and how they get it. In Europe biodiesel is widely available and in many places is less expensive than petrodiesel. In the United Kingdom, taxes on biodiesel are lower than those on petrodiesel. Biodiesel is still more expensive than petrodiesel in the United States, but use is increasing and the price is dropping as a result. Several states are considering laws that would require all petrodiesel to include a portion of biodiesel. There are tax credits available to businesses that use biodiesel.

The first users of biodiesel made their own, and this practice is still popular. People who make their own biodiesel using freely donated waste vegetable oil claim to be able to run their vehicles on just a few dollars a month. Integrating biodiesel into an existing petrodiesel infrastructure is not expensive because very few things need to be changed. The equipment is the same, and no training is necessary. Because biodiesel is better for engines than petrodiesel, using biodiesel can make an engine last longer and break down less often. Making biodiesel commercially is becoming more profitable as more people purchase it. Thus, producers are taking a much greater interest in making biodiesel for sale as it becomes more profitable.

### Issues, challenges, and obstacles of biodiesel

Biodiesel is growing in popularity. In 2006 it is far past the experimental stage and is in the process of being accepted as a mainstream fuel. But public officials and consumers are sometimes resistant to change for various reasons. Public transportation fleets must often coordinate their fuels so that they all use the same ones, which can make it difficult to introduce new fuels. Politicians make promises to various industries, which can also hamper efforts to introduce biofuels.

## VEGETABLE OIL FUELS

It is possible to power a diesel engine on plain vegetable oil. This usually requires the engine's owner to modify it slightly. There are two main types of vegetable oil fuels. Straight vegetable oil, or SVO, is exactly what it seems: vegetable oil, just like the kind available in the grocery store. In fact, many people buy vegetable oil from the grocery store to use as fuel. SVO will work in a diesel engine, though for best results the engine needs to be modified. The second type is waste vegetable oil, or WVO, which is oil that has already been used for cooking and can no longer be used for that purpose. Fast food establishments and potato chip factories produce huge amounts of WVO. This oil can be collected, purified, and used as SVO fuel. Waste vegetable oil can also be used as animal feed.

Both SVO and WVO can be used just as they are in engines modified to use them. They can also be mixed with diesel fuel or kerosene to combine the benefits of biofuels with the advantages of fossil fuel. Or they can also be converted to biodiesel.

### Current use of vegetable oil fuels

Vegetable oils are mainly used in diesel engines. If the vegetable oil is not converted into biodiesel, which can be used in an ordinary diesel engine, the engine must be modified to get the best results.

SVO can run an engine on its own. So can WVO, which functions just like SVO once it has been cleaned. There are two main


Gasohol 95 is a gasoline extender made from a mixture of gasoline and ethanol. Thailand, whose daily consumption of ethanol is about 66,045 gallons (250,000 liters), plans to raise its daily consumption 12-fold by 2006, which would reach 10 percent of its daily demand for gasoline. *© Chaiwat Subprasom/ Reuters/Corbis.*

ways to convert an engine to run on SVO. One way is to use a single tank fitted with different filters, temperature controls, injectors, injector pumps, glow plugs, and a fuel pre-heater. Some single-tank systems can run on SVO, biodiesel, or regular petrodiesel. Other vehicles use a two-tank system; one tank holds petrodiesel or biodiesel, and the other contains SVO. The vehicle uses the tank holding diesel to start and warm the SVO and then switches to the SVO to provide power. Using SVO without modifying the engine will gradually result in clogged injectors.

It is possible to use SVO in a diesel engine without modifying it. This is not a practical long-term practice, however. The filters and fuel injectors gradually get clogged up and can cause engine failure.

Some people mix vegetable oil into diesel fuel or kerosene. These blends can contain various proportions of vegetable oil to petrodiesel, mixed according to personal preference and what is available. Though mixed fuel can work in an ordinary diesel engine, the best results come from using a two-tank system such as the one that can be used with SVO.

People who use biofuels often see mixes as a poor compromise. The engine still must be modified as if it were running on SVO, and the user is still consuming fossil fuels and emitting pollutants. On the other hand, mixing SVO with petrodiesel or kerosene offers some advantages over straight SVO. It avoids some pollution caused by burning straight fossil fuel, and the engine starts better in cold weather than when it's powered by either biodiesel or SVO.

### Benefits and drawbacks of vegetable oil fuels

Using vegetable oil for fuel has many benefits. It is environmentally clean. If WVO is used, it prevents that oil from ending up in a landfill. It is not a fossil fuel, so its use can make regions more self-sufficient and less dependent on foreign sources of oil. People who use SVO as fuel tend to be independent experimenters; they especially enjoy the sense of freedom they get from using fuel that they can acquire themselves.

But using SVO or WVO in engines requires modifying them, which is inconvenient and expensive. SVO is not a direct substitute for diesel, unlike biodiesel, and cannot be used alternately with petrodiesel. Even though using SVO does not require the user to make biodiesel, it still must be prepared before it is burned; WVO especially must be cleaned of all food particles.

Liquid biofuels have a higher viscosity (a level of stickiness) than diesel fuel. This means they do not flow as well in the engine, especially at cold temperatures. Below about 40° Fahrenheit (4.5° Celsius), vegetable oil can solidify, making it useless.

One side effect of using cooking oil in diesel engines is that the exhaust fumes smell like cooking food. Most people do not consider this a major drawback, especially because diesel exhaust fumes also have an odor.

### Environmental impact of vegetable oil fuels

SVO is a very clean fuel. SVO mixed with diesel or kerosene is not as clean and still releases the emissions of fossil fuels. Yet it does reduce somewhat the amount of fossil fuels consumed and burned.

In the year 2000 the United States produced over 11 billion liters of waste vegetable oil, most of it from deep fryers in potato chip factories and fast food restaurants. This oil is usually thrown away. Using WVO for fuel is an excellent way of getting rid of

After collecting about 100 gallons of used vegetable oil from San Francisco restaurants, Ben Jordan pours it into a 250 gallon holding tank. He uses it in a 1981 Volkswagon truck converted to run on the waste vegetable oil. © *Mike Kepka/San Francisco Chronicle/Corbis.*

waste oil and avoiding the consumption of fossil fuels. On the other hand, vegetable oil must come from plants, and these plants must be grown. Substituting vegetable oil for fossil fuels will require as much land as possible to be devoted to growing crops that can produce it.

**Economic impact of vegetable oil fuels**

The economics of using vegetable oil for fuel depend somewhat on whether the oil fuel is new or used. Purchasing new vegetable oil can potentially cost more than purchasing diesel fuel. However, in many cases WVO is free for the taking. Factories and restaurants must pay to dispose of their WVO in the garbage. Therefore, they are often willing to donate it to anyone who wants to collect it. Some enterprising individuals retrieve WVO from local shops and use it in their vehicles, either straight or converted to biodiesel. These people can run their cars for as little as $8 a month, much less than the cost of fueling a gasoline- or diesel-powered vehicle. Even purchasing WVO is inexpensive; in 2003 it sold for about 40 cents a gallon.

### Do Not Steal that Oil!

Even though WVO is often freely donated to people who ask for it, it is a bad idea to take WVO directly from a dumpster without asking first. The WVO usually belongs to the company that owns the dumpster, and anyone who takes oil out of it without permission can be charged with stealing. The best approach is to ask individual restaurant owners if they would mind pouring their used oil back into the containers it came in and putting it out for collection by people who want it for fuel. Oil fuel hobbyists claim that Asian restaurants are often a good source of oil because they have the best quality WVO. Hamburger restaurants often have the worst quality WVO. Biodiesel hobbyists also emphasize the importance of maintaining a good relationship with the restaurants that supply them with WVO.

#### Issues, challenges, and obstacles of vegetable oil fuels

SVO, WVO, and animal fats are popular substances for experimentation. There are many people who would love to be able to run their vehicles and equipment on unmodified cooking oils. As fossil fuels grow more expensive, more commercial enterprises have taken an interest in alternative fuels. Most of this interest, however, seems to be focused on biodiesel, not on SVO. Biodiesel is a much more practical alternative to petrodiesel than SVO because it does not force people to change their vehicles. For that reason, SVO as a fuel by itself is a less likely alternative fuel than biodiesel.

## BIOGAS

Biogas is a mixture of gases produced by the fermentation of waste material in anaerobic (without air) conditions. Biogas technology is also called "anaerobic digestion technology." The gases include methane, carbon dioxide, and trace gases such as ammonia, nitrogen, hydrogen, sulfur dioxide, and hydrogen sulfide. Generally the methane content is between 60 and 70 percent. Methane works like natural gas drilled from the ground as a fossil fuel, but unlike natural gas, biogas is renewable. Many people think biogas is an ideal form of energy because it turns waste material into a source of power that produces few pollutants.

Biogas develops in nature all the time. The distinctive smell of swamps is caused by marsh gas, or methane and other gases that develop when vegetation that settles to the bottoms of wetlands is anaerobically digested by bacteria. The manure of cattle in particular contains a great deal of biogas produced by bacteria living in their intestines. These bacteria digest the cellulose in the plant matter that the cattle eat and release methane and carbon dioxide. To collect biogas from manure, a processor collects the manure in a closed tank called a digester. The bacteria digest the cellulose through anaerobic digestion and release methane and other gases into the tank. The biogas can then be collected or piped to wherever it is needed. Biogas can also be made from garbage in landfills or from sewage. Scientists have been developing many different techniques of capturing and using biogas.

### Current uses of biogas

Because biogas contains so much methane, it can be used to power appliances that run on natural gas. In many parts of the world biogas is used as a substitute for natural gas, either to run appliances and vehicles or as a source of electricity. A digester on a large dairy farm can produce between four and six million cubic feet of biogas annually, resulting in 124,000 to 198,000 kilowatt-hours of electricity.

Biogas is commonly used in rural areas where there is a ready supply of manure or garbage. In the Netherlands and Denmark biogas is a common source of power. In the United States some dairy farms have begun using biogas systems as a way of managing their increasing manure supplies. In Canada, landfill gas is a major source of energy for electricity generation.

### Benefits and drawbacks of biogas

Biogas offers many benefits. It is a good way to get rid of waste materials. The energy it produces is powerful and clean. It does not pollute groundwater or air. Methane can power appliances and vehicles and can be used to generate electricity. Biogas is also quite safe. Homemade biogas does not present any risk of explosion because the gas accumulates slowly and dissipates (goes away) quickly if it leaks instead of pooling on the ground as gasoline does.

But biogas has only one-half the heating value of natural gas. There is not much biogas infrastructure available, so the use of biogas is limited. In addition, using biogas requires the installation of expensive new equipment.


A researcher checks a sealed pot of methane in an electrical generator. The system breaks down organic wastes to create gases which then power an eco-friendly fuel cell generator. One ton of organic waste is enough to generate 580 kilowatts of power, or the equivalent of an average household's electricity consumption over two months. © *Reuters/ Corbis.*

**Impact of biogas**

Biogas appears to offer many environmental benefits. It uses waste materials that would otherwise take up space in landfills or pollute the landscape to generate fuel. The fuel it creates is far less polluting than most fossil fuels. When methane burns, it produces carbon dioxide and water, so it does not cause the same degree of air pollution as fossil fuels. It does not produce the sludge that results from coal-burning emissions. Burning methane releases no ash and only small amounts of sulfur dioxide or nitrogen oxides and does not contribute to the formation of smog. Methane and carbon dioxide, the main components of biogas, are themselves pollutants, but burning the biogas prevents these pollutants from being released into the atmosphere.

On an economic level, biogas technology can save individual producers a great deal of money on power costs. For example, a dairy farm that implements biogas technology can save thousands of dollars every year on electricity, heating, and manure pit maintenance. On the other hand, installing the technology is very expensive; it can take several years to earn back the investment. Maintenance costs are also a factor. Some estimates predict that it would take a dairy farm more than five years to earn back the investment in a biogas operation, which is too long for most businesses to find financially acceptable.

### Issues, challenges, and obstacles of biogas

Biogas technology is still being developed. It is difficult to persuade people to invest a great deal of money in equipment to collect and use biogas when they already have good equipment that uses fossil fuels. Few people know about biogas so there is not yet great demand for biogas appliances. China has used biogas from sewage fairly widely in the mid-twentieth century, on cooperative farms. There were successes, but the appliances have been difficult to maintain.

## ETHANOL AND OTHER ALCOHOL FUELS

It is possible to use alcohol to power engines, either by itself or mixed with gasoline or other fuels. Ethanol is the most common of the alcohols that can be used to power engines. Ethanol is also known as ethyl alcohol and is the same kind of alcohol found in alcoholic beverages. It is clear and looks like water. but it is not the only one.

Methanol, or methyl alcohol, and butanol can also be used as fuel. Methanol is an alcohol made from fermentation of cellulose or from fossil fuels, particularly methane. It is used mainly as a fuel for race cars. Butanol is an alcohol made from fermenting plants. It can also be used as a fuel for internal combustion engines. Propanol is another kind of alcohol fuel. Methanol, butanol, and propanol all have the disadvantage of being toxic to humans and highly volatile (explosive). Ethanol is also volatile and toxic, but the toxicity level is lower, and so is considered more acceptable. Regardless of which one is used, alcohol combined with gasoline results in a fuel called gasohol.


An employee of Toshiba Corporation adds methanol liquid into the company developed prototype direct methanol fuel cell (DMFC) powered HDD-based digital audio player. The HDD player can run for approximately 60 hours on a single 10ml charge of pure methanol. *©Issei Kato/Reuters/Corbis.*

Blends of gasoline and alcohol are often identified by abbreviations that combine the letter E with a number indicating the percentage of ethanol in the blend. For example, E10 contains 10 percent ethanol, E5 contains 5 percent ethanol, and E7 contains 7 percent ethanol.

### How to make ethanol

Ethanol can be made from a large number of organic materials, including corn, wheat, grass, sugarcane, seaweed, cellulose left over from making paper, and nearly any other source of carbon. It can also be made from leftover petroleum feedstocks.

To make ethanol, a producer grinds up the feedstock, such as corn. This exposes the starch in the plant material. The ground-up corn is mixed with water and enzymes and heated to convert the starch to sugar. The producer adds yeast to the mix to help the sugars ferment into ethanol. The alcohol is then removed by a process called distillation: The producer boils the mixture so that

## Do Not Drink the Ethanol

Humans long ago figured out how to make ethyl alcohol. It is fairly easy to do; any source of sugar will create the fermentation that results in drinkable alcohol. Ethanol producers, however, ruin their liquid for human consumption. First they add benzene to the ethanol to remove any water that might be lingering in it, which would impair its ability to function as a fuel. Drinking ethanol with benzene in it can damage the liver. Before the ethanol is sold, the producer ‘‘denatures’’ it by adding some poisonous substance to it. A popular choice for this poison is methanol, also known as methyl alcohol or wood alcohol, which is terribly toxic to humans.

the alcohol evaporates and then catches the alcohol in a container and cools it back into a liquid.

Sugarcane is the best source of ethanol because it naturally contains the sugars that ferment into alcohol. Scientists are working on better methods of making ethanol from cheaper biomass materials, such as wood and straw. It is harder to make ethanol from these substances because they do not release their sugars as easily as corn or sugarcane.

### Current uses of ethanol and other alcohol fuels

Ethanol and other alcohols can be used to power motor vehicles instead of gasoline. In almost all cases the ethanol is mixed with gasoline. Gasoline-powered vehicles have no difficulty using gasoline that contains small amounts of ethanol. Generally this mix must contain at least 10 percent ethanol to qualify as gasohol. Gasohol is widely available in Denmark, Brazil, and the American Midwest. The state of Minnesota requires all gasoline sold there to contain at least 10 percent ethanol.

Increasing numbers of light trucks are sold as flexible fuel vehicles, capable of burning a variety of fuels, including mixes of gasoline and ethanol and other alternative fuels such as P-Series fuels. Vehicles that can run on pure ethanol are rare and require special engineering to function, which is why fuels for FFVs usually contain at least some gasoline.

One common ethanol blend is called E85, which contains 15 percent gasoline and 85 percent ethanol. Producers add this small amount of gasoline to the ethanol to make the vehicle start better in cold weather. E85 is generally priced at about the same level as gasoline.

Many scientists also hope that ethanol can be an important source of fuel for fuel cells in the future. Ethanol and methanol can both be used as fuels in fuel cells, though ethanol is a less efficient source than methanol. Fuel cells would use the energy stored and released by hydrogen.

Ethanol also has many other uses. It has a low melting point, so it can be added to liquids as an antifreeze. In addition, it can be added to gasoline as an anti-knocking agent. It can also be a safe replacement for MBTE, a fuel additive that has been found to present environmental problems.

### Benefits and drawbacks of ethanol

Because ethanol can be made from so many different substances, it can be made nearly anywhere from nearly any raw material. Most ethanol is made from corn and sugarcane, but scientists have been investigating other sorts of biomass as a source of ethanol. Cellulose from grass or hay, cardboard, paper, farm wastes, and other waste products could potentially produce much more energy per source than is currently possible, with the side benefit of using up organic waste matter that would otherwise be thrown into landfills.

Ethanol is less flammable than gasoline and thus may be less of a fire hazard. When it does catch on fire, however, its flame and smoke are very hard to see, which presents another set of risks. Ethanol and other alcohol fuels dissolve in water, so water will put out alcohol fires, unlike gasoline fires, which require special fire extinguishers.

Ethanol will dissolve rubber and plastic, so pure ethanol cannot be used in unmodified gasoline engines. Also, ethanol's octane rating is higher than gasoline, which can require modifications to spark timing, carburetor jets, and starting systems. Gasohol does not present the same problems and can be used in ordinary vehicles without modification.

### Environmental impact of ethanol

The environmental implications of making and using ethanol are the source of much debate. While burning ethanol has many environmental advantages over gasoline, particularly in reduced air pollution, the production of ethanol can be decidedly un-green.

Ethanol does not emit the same greenhouse gases that gasoline does. When it burns, it emits only carbon monoxide and water. Air quality improves quickly when ethanol replaces gasoline. Minnesota, which requires all its gasoline to contain 10 percent ethanol, has met Environmental Protection Agency (EPA) carbon monoxide targets partly because the ethanol has reduced the amount of gasoline burned.

Ethanol has the potential to reduce garbage in landfills. If ethanol can be made from waste paper or wood, that would supply a use for what has historically been a big source of trash. On the other hand, the process of creating ethanol from waste cellulose itself creates waste products that cannot be used.

Ethanol production does come with some environmental problems, however. Many experts contend that ethanol made from corn is actually worse for the environment than fossil fuels. This is because it can take more energy to raise the corn and make ethanol than the resulting ethanol can itself provide. Commercial farms use vast amounts of fossil fuels in planting, harvesting, and fertilizing their crops and making ethanol. In the United States the corn ethanol industry has been heavily subsidized (supported) by the government, which makes it inexpensive to manufacture ethanol from corn crops. If, however, the industry uses more energy to make ethanol than ethanol can provide, then ethanol is in fact not a workable alternative to gasoline.

### Economic impact of ethanol

For states that produce corn, ethanol adds a great deal of value to local corn crops. For example, in Minnesota about 14 percent of the corn crop is made into ethanol. Exporting ethanol instead of raw corn doubles the value of the corn. Many midwestern states have subsidized ethanol production from corn since the 1970s, when Middle Eastern nations instituted an oil embargo in 1973. The U.S. federal government has guaranteed loans to build ethanol plants and since 1978 has made gasohol exempt from (free of) certain taxes.

For individual consumers, the cost of running a vehicle on gasohol is about the same as running it on gasoline, though that varies widely with the price of oil. As oil prices rose in the early 2000s, ethanol became comparatively cheaper. During this time, as it became apparent that biofuels were becoming widely accepted, production of ethanol increased very rapidly around the world. Ethanol appeared poised to become a giant and lucrative (money-making) industry.

### Issues, challenges, and obstacles of ethanol

In areas where it is easy to make ethanol, such as Brazil, with its ample water and warm climate that makes it easy to grow sugarcane, ethanol is an entirely viable fuel. The nation powers its ethanol plants by burning bagasse, the sugarcane solids, which can generate enough power to have some left over. Hydroelectric power is also a good way of making ethanol without using fossil fuels.

The main source of debate about ethanol is whether or not making and using ethanol is actually more efficient than using straight fossil fuels. The problem is that producing ethanol consumes a great deal of energy. First, a farmer must grow the grain or sugarcane that provides the source of most ethanol, which takes up agricultural land and consumes water and fertilizers, many of them made from fossil fuels. The process of making and transporting ethanol consumes energy. Natural gas is a commonly used fuel in the distillation process, and it is itself a fossil fuel. Critics of ethanol have long insisted that making ethanol from corn costs more energy than the resulting ethanol can produce.

Critics also claim that corn-growing states in the United States have been emphasizing the importance of corn-based ethanol to get subsidies from the federal government that are far out of proportion to ethanol's value to the economy. Corn growers have exerted a great deal of political power, and agricultural states have used ample influence in national politics. Critics fear that ethanol producers will persuade the government to invest in their industry despite the fact that it may not have real environmental benefits.

## P-SERIES FUELS

P-Series fuels are a new type of renewable fuel that use up an extremely common and little-valued resource: garbage. P-Series fuel is a blend of 35 percent natural gas liquids, 45 percent ethanol, and 20 percent methyltetrahydrofuan (MeTHF). The natural gas liquid is a substance called pentanes-plus, a liquid left over from the processing of natural gas, with butane added in winter months. MeTHF is made from biomass such as waste paper, food wastes, agricultural waste, or yard waste, and serves as a co-solvent (substance that turns another into liquid). The fuel is a colorless clear blend with octane between 89 and 93, the same octane as gasoline. It can be formulated for winter or summer use. It can be used alone or mixed with gasoline in a flexible fuel vehicle (FFV).

P-Series fuel was developed in the 1990s by Princeton University thermonuclear physicist Stephen Paul. He wanted to create a substitute for gasoline and thought that using garbage as fuel could work. He gave the fuel its name in honor of Princeton University. Paul and fellow investors have bought a sludge plant in New Jersey that they intend to use to make enough P-Series fuel to power about fifteen thousand vehicles.

#### Current uses of P-Series fuels

P-Series fuels are not currently widely used. They are still quite new, and no car manufacturer has yet produced a "P-Series-specific" FFV. If consumers begin buying these fuels, however, they could be a good substitute for gasoline.

#### Benefits and drawbacks of P-Series fuels

Using P-Series fuels has several benefits. It decreases the amount of petroleum used to power vehicles. It makes use of waste that would otherwise have to be placed in a landfill, incinerated, or transported to some other location. P-Series fuels are easy to use. Fueling an FFV with P-Series fuel is identical to fueling a vehicle with gasoline. There is no need to monitor fuels because gasoline and P-Series fuels will work mixed together, so a car owner can fuel up at ordinary gas stations or at P-Series pumps without thinking about which is which. This is especially useful when traveling to areas where P-Series fuels are unavailable.

But P-Series fuels cannot be used in vehicles designed to burn gasoline only. FFVs designed to burn methanol or ethanol can burn it, but ordinary cars cannot. P-Series fuels are slightly more efficient than gasoline, but in practice, mileage for vehicles using P-Series fuels is about 10 percent less per gallon than those using gasoline.

#### Environmental impact of P-Series fuels

The feedstock used to make MeTHF is chemically digested by the process of making it; as a result, the raw material is completely consumed and no emissions enter the air. Burning P-Series fuels in vehicles releases many fewer emissions than burning fossil fuels. In fact, P-Series fuels were added to the list of alternative fuels under the U.S. Energy Policy Act in 1999.

#### Economic impact of P-Series fuels

In 2003 P-Series fuels cost about $1.49 per gallon, which was then slightly lower than gasoline. Because P-Series fuels provide slightly less power than gasoline, the resulting operating cost is about the same for a P-Series-powered car and a gasoline-powered car. It is possible that as fossil fuels become more expensive, P-Series fuels will seem less expensive.

Manufacturers of P-Series fuels usually buy their natural gas liquids and ethanol in bulk from companies that produce those products. MeTHF is made by hydrolysis; the process basically involves mixing garbage with some acid and heat and agitating (mixing) it until it turns into liquid. The feedstock, or raw material, for MeTHF actually has a negative cost, because it is made from materials that would otherwise cost a city money to dispose of. As a result, it is fairly easy for a P-Series plant to recoup (get back) its investments and become profitable. Small P-Series plants are viable because it is not very expensive for them to operate. This makes it possible for many small P-Series plants to be distributed throughout a geographic area. This distribution would have the added advantage of preventing any one location from becoming the region's dumping ground.

#### Issues, challenges, and obstacles of P-Series fuels

P-Series fuels are still very new and appear to be unproven. Producers of the fuel have a hard time finding investment capital for their enterprises because banks or companies investing in the project want to be sure they can collect a return on their money. The developer of the fuel insists that it burns cleanly and that it will in fact be inexpensive to make. Without a provable record, however, it is difficult to persuade investors that this is true.

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# Geothermal Energy

## INTRODUCTION: WHAT IS GEOTHERMAL ENERGY?

Geothermal energy is energy created by the heat of the Earth. Under the Earth's crust lies a layer of thick, hot rock with occasional pockets of water. This water sometimes seeps up to the surface in the form of hot springs. Even where the water does not travel naturally to the Earth's surface, it is sometimes possible to reach it by drilling. This hot water can be used as a virtually free source of energy, either directly as hot water, steam, or heat or as a means of generating power. Geothermal energy is nonpolluting, inexpensive, and in most cases renewable, which makes it a promising source of power for the future.

The word *geothermal* comes from two Latin words, *geo,* meaning "earth," and *thermal,* meaning "heat." So the word *geothermal* means "heat from the earth." In most cases, the geothermal resource that people want is water that has been trapped within the Earth, where it becomes very hot.

### Types of geothermal energy

There are two main types of geothermal energy. The energy can be used directly, as heat or hot water, or it can be a means of generating electricity.

Naturally hot water has been recognized as a resource for thousands of years. People have used hot springs for bathing, for medical treatments, and as heating for their buildings. The hot water can also be used in agriculture, aquaculture, industry, and other applications.

Geothermal power can also generate electricity. Geothermally generated electricity is becoming increasingly important. In 1999 over 8,000 megawatts of electricity were produced by about 250

## Words to Know

**Aquaculture** The formal cultivation of fish or other aquatic life forms.

**Balneology** The science of baths, especially for therapeutic use.

**Core** The center, innermost layer of the Earth.

**Crust** The outermost layer of the Earth.

**Geothermal reservoir** A pocket of hot water contained within the Earth's mantle.

**Lava** Molten rock contained within the Earth that emerges from cracks in the Earth's crust, such as volcanoes.

**Magma** Liquid rock within the mantle.

**Mantle** The middle layer of the Earth between the inner core and the outer crust.

**Turbine** A device that uses the movement of a liquid or gas to spin a machine that produces electricity.

geothermal power plants around the world, located in twenty-two different countries. Most of these power plants are located in developing nations. However, that same year the United States produced nearly 3,000 megawatts of geothermal electricity, more than twice the amount of power generated by wind and solar power. Ten percent of the electricity in Nevada and 6 percent of the electricity in Utah came from geothermal power plants.

### Historical overview: notable discoveries and the people who made them

Knowledge of geothermal energy is very old. Ancient Chinese and Japanese people bathed in hot springs and used the water for cooking. Ancient Romans used the water from hot springs as a medicine for skin diseases, and the buildings in ancient Pompeii were heated with hot water that ran under them. Native Americans settled near hot springs more than 10,000 years ago. During the Middle Ages in Europe people traveled to towns in Germany and France that had built spas, or health resorts, around natural hot springs.

#### *Discoveries of the 1800s*

During the 1800s European settlers moved westward across the North American continent. They noted the existence of hot springs and settled near them. In 1807 John Colter (1774–1813) is believed to have found hot springs in what is now Yellowstone National Park. That same year the city of Hot Springs, Arkansas, was founded. By 1830 Asa Thompson of Hot Springs was selling visitors the right to sit in a wooden tub fed by a hot spring; the price was $1 per person. The hot springs area in Arkansas was declared a national park in 1921.

Bath, England, with its natural hot springs, is the site of an elaborate Roman public bath built in the first century C.E. © *Bob Krist/ Corbis.*

In 1847 William Bell Elliot, a member of John Fremont's California survey group, found a valley full of steaming hot springs that he described as resembling the gates of hell. He named the area "the Geysers" (though it did not actually contain geysers). The region was located north of San Francisco. Within five years the area had been developed into a resort spa that was visited by famous people such as the author Mark Twain and the presidents Theodore Roosevelt and Ulysses S. Grant. Ten years later Sam Brannan built a $500,000 resort southeast of the Geysers called

## Hot Springs Baths

The ancient Greeks and Romans knew of a number of natural hot springs, many of them located near volcanoes. The oldest known hot springs bath still in existence is located in Merano, Italy. People are believed to have used it five thousand years ago. Bath, England, has long been famous for its natural hot springs. The waters at Bath are about 120°F (48°C) and contain numerous minerals, including calcium and magnesium. Ancient Celts are believed to have bathed in the springs as early as 800 BCE (before the common era). The Romans built bath houses around the springs nearly two thousand years ago; the town became a major tourist resort starting around the time of Queen Elizabeth I (1533–1603), who went there often to bathe.

Germany is full of natural hot springs, many of which long ago became the sites of baths. Ancient Romans built baths on these springs. Like Bath in England, Germany's bath towns became extremely popular with the rich in the nineteenth century. Towns such as Bad Cannstatt and Baden-Baden grew rich from their well-to-do visitors who came to bathe, be massaged, drink the waters, and indulge themselves in other entertainments. These baths are still popular today and have been supplemented with modern healing treatments such as shiatsu massage and with trendy shopping facilities. Japanese baths are likewise famous around the world. Hot springs resorts, called *onsen*, attract millions of visitors who come to soak in the waters. The waters often contain particular minerals that are said to have specific effects on physical and mental health. Some baths have facilities for drinking the water or inhaling the steam.

Calistoga, which resembled European resorts with racetracks, bathhouses, a hotel, and a skating pavilion.

Americans began experimenting with large-scale geothermal heating in 1864, with the construction of the Hot Lake Hotel in La Grande, Oregon. In 1892 the city of Boise, Idaho, built a geothermal district heating system that piped hot water from a geothermal reservoir to the buildings in town.

People bathing in Blue Lagoon near Grindavik, Iceland © *Hans Strand/ Corbis.*

***Beginning of geothermal electricity***

The first geothermal electrical power plant was built in Larderello, in Tuscany, Italy, in 1904. Larderello is a geologically active area that was used in Roman times as a hot springs resort. This made it ideal as a site for experimenting with geothermal energy. The first plant lit up five light bulbs, using the steam that came from cracks in the ground. In 1911 a larger plant opened in the area, and it was the only geothermal power plant in the world until after World War II. The plant at Lardarello was destroyed during World War II, but it was quickly rebuilt. Engineers from New Zealand and other countries went to visit the Larderello plant to learn how it was built and also noted the enthusiasm that the Italian engineers had for their plant. Lardarello's plant still produces enough power for one million households in Italy, nearly ten percent of the total geothermal power produced in the world.

In 1921 John D. Grant drilled a well at the Geysers with the hope of using its steam to generate electricity. The next year he built the first geothermal power plant in the United States. His

## Hot Springs Monkeys

Humans are not the only creatures to have noticed and taken advantage of natural hot springs. Japanese macaques, also known as snow monkeys, are large monkeys that live in northern Japan. The Japanese winter is cold and snowy, but the macaques have learned a trick that helps them keep warm: They sit in natural hot springs that come up from the ground. The monkeys got so enthusiastic about hot springs that the prefecture (governmental district) of Nagano decided to build them their own hot springs and feeding stations to keep them away from human hot tubs and spas.

power plant generated enough power to power the lights at the Geysers resort. However, geothermal power at the time cost more than other sources of power to produce, so this effort was soon abandoned.

Through the 1920s people continued to drill experimental wells in Oregon and California, hoping to take advantage of the heat within the Earth. In 1927 the Pioneer Development Company drilled some wells in Imperial Valley, California. In 1930 gardeners in Boise, Idaho, opened the first geothermally heated commercial greenhouse, using the water from a 1,000-foot (305-meter) well. That year Charlie Lieb of Klamath Falls, Oregon, built the first downhole heat exchanger, which he used to heat his home. In 1940 the Moana neighborhood of Reno, Nevada, began using geothermal heat for residential heating. Eight years later the first groundwater heat pumps went into use in Ohio and Oregon.

The first flashed steam geothermal power plants, which depressurized hot water to produce steam, were built in the late 1940s. In 1960 the United States' first large-scale geothermal power plant began operation, at the same site and with the same name (the Geysers) as the earlier spa. Its first turbine produced 11 megawatts of net power. As of the early 2000s the Geysers was the largest geothermal plant in the world.

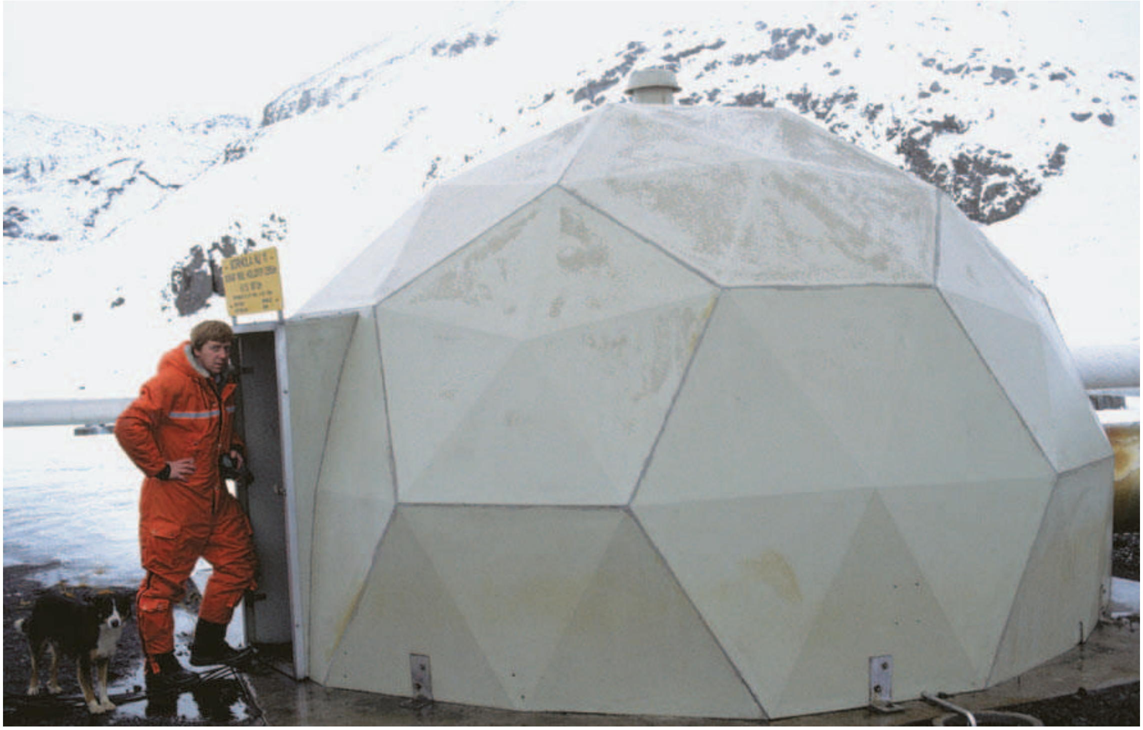
### *Governmental encouragement*

In the 1970s the United States and other nations created several agencies and passed laws to encourage the development of geothermal energy. In 1970 the United States passed the Geothermal Steam Act, which gave the Secretary of the Interior the authority to use public lands for environmentally sound geothermal exploration and development. The Geothermal Resources Council was formed to make it easier to develop geothermal resources worldwide. The Geothermal Energy Association, founded in 1972, was created by several companies around the world to develop geothermal electricity generation and direct heat technology. The 1974 Geothermal Energy Research, Development and Demonstration Act instituted a geothermal loan guaranty program, which gave investment security to companies attempting to create technologies to use geothermal energy. In 1975 the Geo-Heat Center was formed at the Oregon Institute of Technology; the institute began using runoff from its geothermal heating system to heat water used to raise freshwater prawns.

The first geothermal food processing and crop drying plant was opened in Brady Hot Springs, Nevada, in 1978. It received $3.5 million from the Geothermal Loan Guaranty Program. That year the United States Department of Energy opened a facility in Fenton Hill, New Mexico, to test "hot dry rock" energy generation, a process in which water is pumped into an area of hot rock, becomes superheated, and then is pumped back to the surface so that the heat can be siphoned off. This facility managed to generate some electricity two years later.

Between 1979 and 1982 the Department of Energy sponsored development of a geothermal electrical power plant in Imperial Valley, California, as well as research into direct uses of geothermal energy for heating and agriculture. The first flashed steam plant in the United States was built in Brawley, California, in 1980. In 1981 a binary power plant was built in California's Imperial Valley. The plant was so successful that Ormat, the company that built it, paid off its loan within one year. By 1984 there were geothermal power plants in Hawaii, Nevada, and in the Salton Sea in California.

In 1989 the first hybrid geothermal power plant opened in Pleasant Bayou, Louisiana. It used both geothermal heat and methane to create electricity. During the 1990s several geothermal power plants went into operation in the Pacific Northwest, Nevada, and Hawaii. In 1994 the United States Department of Energy created two programs to increase the use of geothermal power generation and heat pumps in an effort to reduce greenhouse gas emissions.



A geodesic dome at the geothermal power plant in Nesjavellir, Iceland. The plant sends heated water to the city of Reykjavik. © *Roger Ressmeyer/Corbis.*

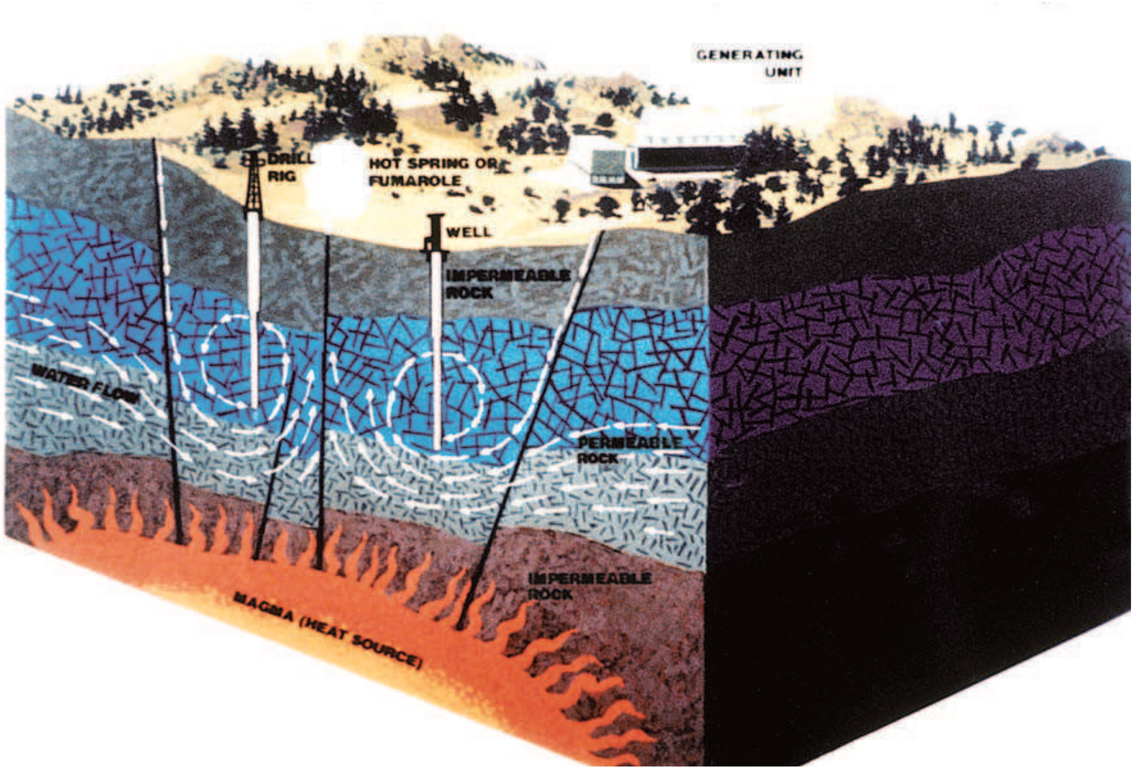
In 2000 the U.S. Department of Energy created its GeoPowering the West initiative, which funded twenty-one partnerships with private companies to develop geothermal energy in the western United States. Several groups in the western states spent the early 2000s working to identify barriers to geothermal development and to create ways to make geothermal energy more commonly used.

## How geothermal energy works

Geothermal energy uses the heat of the Earth to produce electricity and heat. This form of power works because the inside of the Earth is much hotter than the surface.

### *The structure of the Earth*

The Earth consists of several layers of matter. The outer layer, called the crust, is the surface where people live and plants grow. It is composed of aluminum, silicon, oxygen, iron, and other minerals. Below the crust is a layer called the mantle, a thick layer of rock and oxides that comprises about 82 percent of the Earth's total volume. It is made up mostly of




Cutaway drawing of the Earth, showing source of geothermal energy. *U.S. Department of Energy, Washington D.C.*

peridotite, a kind of rock containing iron, magnesium, oxygen, and silicon. The mantle is mostly solid but can also flow like a liquid when it is under pressure. The top layer of the mantle consists of hot liquid rock called magma. The crust floats on top of this liquid rock.

At the center of the Earth is the core, a chunk of extremely hot iron and nickel. The core itself consists of two layers, the outer core, which is liquid, and the inner core, which is solid because of the tremendous pressure it experiences. The center of the core is about 4,000 miles (6,400 kilometers) from the surface of the Earth.

### *Water heated underground*

The Earth's temperature increases about 41.7°F (5.4°C) for every 328 feet (about 100 meters) traveling from the surface to the core. About 10,000 feet (3,048 meters) below the surface, temperatures are hot enough to boil water. The inner core may be over 9,000°F (4,982°C). This heat constantly travels upward toward the surface, heating the mantle, which carries heat toward the crust. Similar to the curved pieces of peeled skin from an orange, Earth's outermost layers are cut and fractured into pieces or sections called plates. Like the inner and outer sides of an orange peel, these plates have distinct sections, an inner side and an outer crust. Each plate (also called a lithospheric plate) moves over a hotter, denser—but in many ways more fluid-like (molten)—region of Earth's interior termed the asthenosphere (a portion of Earth's mantle). The visible continents such as North and South America are actually an outer crust of the lithospheric plates upon which they ride, shifting slowly over time as a result of forces, including differences in temperature, which help move or drive the plates. The theory that describes this motion is perhaps the most important in all of geology (the study of Earth's structure) and is called plate tectonics (the theory of plate structure and movements). Although plates move very slowly (in many cases, just inches per year) they are, of course, very heavy and so their rubbing, sliding, slipping, collisions, and bending causes earthquakes.

Where the edges of plates overlap, volcanoes may form. Depending on the materials that compose them, one plate may drive under another (subduction) or both plates may drive skyward to form mountain chains. Hot magma from Earth's molten inner layers (or from pieces of plate being destroyed during subduction) can carve tunnels, chambers, and channels in the plate and crust and so allow hot magma to reach the surface of the plate (even if it is under the ocean). When magma reaches the surface and flows from a volcano it becomes known as lava. Volcanoes can also form over areas in plates away from the edges (especially thinner areas of plates under the oceans) called "hot spots" where molten material from Earth's mantle pushes upward.

The rock underground is full of cracks and small pockets, and these can fill with water. Water that gets trapped in underground caves will get very hot, even hotter than boiling temperature, but it cannot boil because there is no place for steam to escape into the air. This water sometimes finds its way to the surface in the form of hot springs. Most of the hot water stays underground in pockets called geothermal reservoirs.

### *Making use of geothermal energy*

There are several ways to make use of geothermal energy. The most basic is simply to use the water as hot water when it comes out of the ground. The water can be channeled to different places as heat, for heating homes, or for cooking.

A fumarole bubbles at a Pacific Gas and Electric Company geothermal power plant in California. © *Roger Ressmeyer/Corbis.*

Engineers can drill down into the ground to reach geothermal reservoirs and then use the hot water, steam, or heat to power generators to make electricity. Scientists have developed techniques to find geothermal water. When they find reservoirs, they drill production wells down into them. The hot water or steam travels up the well to the surface, where it can be collected and harnessed for various uses.

### *The Ring of Fire and other hot spots*

The Pacific Ocean is one of the most geologically active areas in the world. The land that borders the Pacific is sometimes known as the Ring of Fire because of the volcanic activity that occurs there. New Zealand, Japan, the Philippines, Hawaii, Alaska, California, and other places in the area experience a great deal of tectonic shifting, as pieces of the Earth's crust move around and crash into one another. All of these areas also have active volcanoes.

There are active volcanoes in many other places. Iceland has so much volcanic activity that it derives much of its power from

### Geysers, Hot Springs, Mudpots, and Fumaroles

Magma heats water trapped or flowing underground. Hot springs are places where hot water rises up from the Earth on a regular basis. Geysers are explosive hot springs where hot water periodically shoots out of a hole in the ground. Fumaroles are openings near volcanoes that emit steam and sulfurous gases. They can look like holes or cracks in the ground and may stay in the same spot for centuries or come and go within weeks. Mudpots are fumaroles or hot springs that form in areas with small amounts of water. The water bubbles up to the surface and creates a crater filled with boiling mud.

geothermal sources. Kenya, Turkey, Italy, and Zambia all have enough geothermal energy to make profitable use of it. Because of the nature of current geothermal technology, these geologically active areas are also the main sites of geothermal power.

## Current and future technology

Geothermal energy technologies are used in the generation of electricity and in direct uses of the hot water. There is room for development of new technologies in both categories.

### *Geothermal power plants*

One of the most important uses of geothermal energy is to generate electricity. In geothermal power plants, hot water drawn from geothermal reservoirs through production wells spins turbine generators, which produce electricity. The used water is injected back into the reservoir through another well called an injection well. This water gets hot again and helps maintain the pressure within the reservoir. If all the water were removed and not replenished, the reservoir would eventually cool off and run out of water, making it useless. Groundwater must be very hot in order to generate electricity. Water colder than 250°F (121°C) is currently not usable for power.

There are three main types of geothermal power plants.

- Flashed power plants have reservoirs with water between 300 and 700°F (148 and 371°C). This water comes up from the well and is flashed (turned quickly) into steam, which powers a turbine.
- Binary power plants have reservoirs with water between 250 and 360°F (121 and 182°C), which is not quite hot enough


Sulfur extraction from Geysers geothermal steam power plant operations, Sonoma County, California. *©Gerald & Buff Corsi/Visuals Unlimited. Reproduced by permission.*

to generate enough steam to power a turbine. These plants use the heat from the water to heat another liquid with a lower boiling temperature, called a binary liquid. The binary liquid boils and produces steam to spin a turbine.

- Dry steam power plants have reservoirs that produce steam but not water. The steam is piped directly into the plant, where it spins a turbine.

There are also hybrid power plants that combine geothermal heat with other sources of energy, such as methane. All types of geothermal power plant have no emissions and can produce a large amount of power. Geothermal power is especially appealing because it is possible to have power plants of almost any size, from tiny 100 kilowatt plants to much larger 100 megawatt plants that are connected to national power grids. They can operate twenty-four hours a day every day of the year, but they can also vary operation according to demand.

### *Direct uses of geothermal energy*

Hot water is useful in and of itself. Some common uses of geothermal water include:

- Using hot springs for bathing. This is called balneology.
- Growing plants in winter greenhouses.
- Heating the ground in which outdoor crops are growing to prevent it from freezing.
- Growing fish and shellfish for commercial purposes.
- In industry, such as pasteurizing milk or washing wool.
- Heating buildings or cities through underground channels. Reykjavik, Iceland, has the world's largest geothermal district heating system.
- Piping water under streets and sidewalks to keep them from freezing.
- Geothermal heat pumps that use the heat from just a few feet below the Earth's surface instead of heat from geothermal reservoirs. These can heat or cool homes anywhere, not just in areas with geothermic activity.

Every use of geothermal water as hot water saves energy. Heating water takes a great deal of power, and every gallon that does not have to be heated can save oil, coal, wood, or other heating fuels.

Direct uses of geothermal energy provide about 10,000 thermal megawatts of energy in thirty-five countries around the world. This does not include the use of geothermal waters for bathing by individuals who have not developed the resources for commercial use. In the United States in the late 1990s there were eighteen district heating systems, twenty-eight fish farms, thirty-eight greenhouse establishments, twelve factories, and more than two hundred spas using geothermal waters.

### *Developing technology*

Scientists are working to create technology that will make geothermal energy more accessible to people everywhere, not just to those living in areas with shallow geothermal reservoirs. The entire planet has heat beneath its surface, but not all places have hot water. Deeper drilling techniques could make more areas of heat and steam accessible. Scientists would love to take advantage of the heat from magma in the mantle, but there is not yet a workable technology to do this.

Engineers are working to develop technology that would make hot dry rocks (HDR) 3 to 6 miles (5 to 10 kilometers) below the surface usable for power. Techniques include piping water down to the hot rock to create steam. Teams in the United Kingdom, Australia, France, Switzerland, and Germany are working on HDR technology as of the early 2000s. It remains to be seen if they can devise a method of producing power that is worth its cost.

## Benefits of geothermal energy

There are many benefits to using geothermal power. It is clean and nonpolluting. It does not require the consumption of fossil fuels, so it reduces dependence on foreign or domestic oil, and it reduces harmful emissions from burning these fuels. Geothermal plants do not destroy large tracts of land. They are efficient: A geothermal plant usually can produce more power than a fossil fuel-burning plant of the same size.

Geothermal plants are also very reliable. Because they do not depend on external fuel sources, they can run twenty-four hours a day, every day of the year. This is not always possible with power plants that burn coal or oil, which must be transported from distant locations. Geothermal plants are not vulnerable to weather, natural disasters, strikes, political disturbances, or other events that can disrupt fuel supplies.

Geothermal plants, on many levels, are flexible. It is possible to build them of modular components and to add or adapt components as the need arises. This is usually not possible with fossil fuel-burning plants. Geothermal power plants are especially valuable in areas with small power grids or in cases where a power grid is in the process of expanding. Flexible geothermal plants can provide backup power while the rest of the grid is installed.

Geothermal energy is generally sustainable and renewable. The Earth generates heat constantly. Rainfall and snowmelt continuously replenish reservoirs, and returning used water to the underground reservoir maintains its pressure and heat so that the reservoir can be used for an indefinite period of time.

### Drawbacks of geothermal energy

The major limitation of geothermal power is that it can only be implemented in areas where there is a ready supply of hot water underground. This limits its use to geologically active areas such as California, Iceland, Japan and the rest of the Pacific Rim, and other areas with a thin crust, an active mantle, and pockets of subterranean hot water.

Only the hottest water can be used to generate electricity. Some places have naturally heated groundwater that is not hot enough to produce the steam needed to turn turbines. That water is still usable for other purposes but not as a workable power source.

It is possible to deplete a reservoir. If a geothermal reservoir runs out of water or grows too cool, it ceases to be useful, though this depletion can take decades or even centuries. For this reason some experts claim that geothermal energy is not actually a renewable resource.

In the early 2000s there are few areas with enough readily accessible geothermal water to produce electricity at a price that can compete with other sources of power. This may change as technology improves and other geothermal sources become usable or as the price of fossil fuels increases.

### Environmental impact of geothermal energy

Like solar power and wind power, geothermal energy is clean. Geothermal power plants do not have to burn fuels so they do not produce emissions of greenhouse gases or other pollutants, which means they do not contribute to smog or global warming. They do emit very small amounts of carbon dioxide, about four percent of the amount emitted by burning fossil fuels. Binary plants produce no emissions at all. Areas that have geothermal power plants tend to have much better air quality than those with fossil fuel-burning power plants.

A geothermal power plant can be small compared to other types of power plants, so it is not as disruptive to the landscape. It can be built right next to its geothermal well. There is no need to build dams, dig mines, cut down trees, or dispose of wastes, which are necessary with other common forms of power. It is actually possible to build geothermal power plants in the middle of farmland or forests without damaging the surrounding plants and animals.

Even in areas where geothermal energy is not powerful enough to create electricity, people can still make use of local hot water for heating and bathing. This means they do not have to use electricity from other sources to heat their water, which can help save money and fuel.

There are some minor environmental drawbacks to using geothermal resources. Geothermal reservoirs sometimes contain hydrogen sulfide gas, which smells like rotten eggs and can be toxic at high concentrations. Geothermal power plants use scrubbers to remove this gas from emissions. Geothermal water also contains a high concentration of minerals, so geothermal wells must contain several layers of pipe and casings to prevent geothermal water from mixing with ordinary groundwater. Because geothermal power plants re-inject their used geothermal water back into the underground reservoir, in most cases the geothermal water never gets near groundwater and cannot harm aquatic plants and animals.

The areas around geothermal power plants experience increased activity, such as small earthquakes, and there is a danger of landslides. Federal laws in the United States prohibit the construction of geothermal power plants in national parks, such as Yellowstone. However, the environmental problems associated with using geothermal energy are generally far less serious than those caused by using fossil fuels.

### Economic impact of geothermal energy

Geothermal power is produced locally, in the same area in which it is used. This means that states or nations do not have to pay other countries for fuel, as most countries do with fossil fuels. All economic benefits from a geothermal power plant remain in the area that produces the energy.

Using geothermal water saves money on other fuels, either to create electricity or to heat water. In the late 1990s, worldwide use of geothermal energy saved the equivalent of 830 million gallons of oil or 4.4 million tons of coal. This amount could be increased considerably if the use of geothermal energy were expanded.

### Societal impact of geothermal energy

Much of the world's geothermal energy is used by developing nations that cannot afford to use fossil fuels for power and that may not have other sources of energy. Thailand, Indonesia, the Philippines, and the Azores have all been making use of geothermally generated electricity since the late 1980s or early 1990s.

Geothermal energy is a good, nonpolluting way for developing nations to build their infrastructures without destroying the landscape or polluting their air and water. The power produced by geothermal energy can raise standards of living in remote areas that are too far from other power sources. Because the energy is inexpensive, nations may be able to use the energy generated during off-peak hours for regional development projects, such as pumping water for irrigation. Local communities can be in complete control of their source of power, making them less dependent on their own government or foreign aid.

Many developing nations have created energy policies that emphasize using local resources for power, encouraging local private investment in energy, and expanding power into rural areas. Geothermal energy is very compatible with these goals because it can be locally run, and the resulting power used by the local community.

### Barriers to implementation or acceptance

Many areas have geothermal potential that has not been tapped. During the twentieth century fossil fuels were a cheap and established source of power, and few areas have any incentive to spend the money to build geothermal power plants. People have not yet become aware of the many potential uses of geothermal water, so they are not taking full advantage of it. For example, in some areas naturally hot water is used for purposes that ordinary water could fulfill, such as irrigation of crops and municipal water supplies.

Many nations, both developing and advanced, have conducted initial investigations into their own geothermal potential. They have identified numerous geothermal reservoirs that could be used directly or converted into electricity, but they have not pursued the deep drilling needed both to confirm the reservoirs' potential and to exploit them. Geothermal energy does require large capital investments in its initial stages, and this investment comes with some risk. This initial investment deters (holds back) many governments and companies, as does the fact that it can take several years to achieve a return on the investment of building a geothermal power plant. Fossil fuel power plants earn back their investments much more quickly. It is also known, however, that geothermal power plants have long-term economic benefits, including low operating costs and long-term profits.

One major difficulty with developing geothermal power is access to land. Because geothermal power plants can only be built on or near geothermal reservoirs, power companies must be able to buy or lease this land.

In the early 2000s, most cities and buildings have been designed around fossil fuels and other more traditional sources of energy. Oil, gas, and coal companies do not want to see fossil fueled power plants closed because that would cause them to lose customers. Utilities do not want to have to rebuild existing power plants to convert them to geothermal power because that would be very expensive. In many countries the government grants monopolies to utility companies that make it possible for those companies to provide power at all times regardless of price fluctuations, but also make it impossible for alternative energy suppliers to compete in an open market.

## AGRICULTURAL APPLICATIONS

Geothermal water is very useful in agriculture. Agricultural applications make direct use of geothermal water, using it to heat and water plants, to warm greenhouses, or to dry crops.

In agriculture, geothermal water is used mainly as a source of heat and moisture. Irrigation pipes can bring hot water to cold ground, making it possible to grow crops that would otherwise die. It can also be piped into greenhouses to keep them warm and to maintain humidity. As with most other uses of geothermal energy, geothermal agriculture is only practical in areas that have geothermal resources. It is possible in agriculture, however, to use geothermal water that is much too cold for power generation or even home heating. Only a few nations have thus far made much use of geothermal heat for agricultural purposes. They include the United States, Kenya, Greece, Guatemala, Israel, and Mexico.

### Current uses of geothermal energy in agriculture

The main agricultural uses of geothermal water include heating and watering open fields, warming and humidifying greenhouses, and drying crops.

#### *Open field agriculture*

Geothermal water can be used to keep the soil in open fields at a steady warm temperature. Farmers run irrigation pipes under the soil to provide both water and heat to the crops. Cool-weather root crops and rapidly growing trees grow faster and more abundantly if the soil temperature is kept at about 70 °F (21 °C). Using geothermal water for irrigation extends the growing season and keeps plants from being damaged by low air temperatures.

Geothermal water can also sterilize soil to kill pests, fungus, and diseases that can harm crops. Sterilization requires very hot water so that the steam can be applied directly to the soil. The farmers either heat the soil from pipes underneath it, or they apply the steam above the soil and cover it with a plastic sheet to keep the heat inside.

#### *Greenhouses*

Greenhouses are buildings with clear plastic or glass walls and ceilings that trap solar heat to create a controlled atmosphere for growing plants. Greenhouses often benefit from another source of heat during the winter months. Heating greenhouses with geothermal water helps maintain a constant temperature, resulting in a more reliable crop and faster-growing plants. The water in the pipes can be released into the air inside the greenhouse, raising humidity if necessary.

There are several techniques used to heat greenhouses with geothermal water. These include plastic tubes, finned pipes, finned coils, soil heaters, or unit heaters. These parts can be combined according to water temperature and the preferences of the grower and the plants. For example, a grower producing roses would want to create a heating system with good air circulation and low humidity. A grower producing tropical plants could adjust the system to create high humidity and high soil temperatures. Chinese shiitake mushroom growers in Fujian province use geothermal heat in a greenhouse to speed production time.

Two large greenhouses at the La Carrindanga Project in Bahia Blanca, Argentina, have been using geothermal pipes to heat their facilities. These greenhouses have sliding glass side panels that can open and close to regulate humidity and heat, and misting systems to water plants and maintain moisture in the air. The geothermal water runs through pipes buried just beneath the surface of the soil, where the heat from the water easily reaches plant roots. Boxes containing dirt and seeds can sit on top of these pipes so that they receive heat from below. The beds grow vegetables, flowers, and indoor and outdoor plants from seeds and cuttings. Bahia Blanca has an unreliable climate and is not a very good location for outdoor agriculture, but its geothermally heated greenhouses are very productive and reliable.

Hot water from below the ground is piped into the greenhouses, which are used for growing tomatoes. Steam is rising from the warm waters. *Martin Bond/Photo Researchers, Inc.*

### *Drying crops*

The heat from geothermal water can also be used to dry crops and timber. For example, since the mid-1980s the Broadlands Lucerne Company in New Zealand has been using geothermal steam to dry alfalfa.

### Benefits and drawbacks of agricultural applications

Geothermally heated greenhouses are especially useful in marginal areas where the climate is unreliable. They make plant and vegetable production more efficient, and they reduce the time it takes seeds to germinate and grow to maturity. In addition, they make it possible to grow crops in the off-season, when such plants ordinarily would not grow and when they can be sold for higher prices. Farmers can grow plants under denser and more controlled conditions. They lose fewer plants and can make more precise commitments to buyers for future deliveries of crops.

However, geothermal water is not available everywhere. Not every farming operation can make use of geothermal resources because either there are none in the region or they are too difficult to reach. Installing equipment to pipe geothermal water into a farm can be expensive and time-consuming.

### Impact of agricultural applications

Using geothermal water to enhance agriculture causes few environmental problems. It does not pollute the land because only water is emitted, although if the water is contaminated with heavy metals, such as mercury, this could cause a public health concern. The use of geothermal water could potentially result in farms being constructed in areas that would otherwise not be suitable for agriculture, which could destroy natural landscape and animal habitat.

Economically, using geothermal water in agriculture can be quite inexpensive. If geothermal wells already exist, then the farmers need invest only in steel or plastic pipes to transport the steam or hot water to the field, greenhouse, or drying facility. In many places the hot water is quite shallow and inexpensive to reach.

Despite this comparative lack of expense, even this level of equipment is too expensive for many individuals and businesses. There are many regions that have geothermal resources that could be used for agriculture that have not yet been able to take advantage of them. For example, the Oserian Development Company on the shores of Lake Naivasha, Kenya, grows flowers for market. It has considered using hot water from the Olkaria Geothermal field to sterilize the soil. As of the early 2000s this plan had not been implemented because of the cost.

## AQUACULTURAL APPLICATIONS

Aquaculture is the raising of fish and other aquatic animals in a controlled environment—basically, it is the farming of fish, shellfish, and other freshwater or marine (saltwater) creatures. Using geothermal water in aquaculture helps keep water temperatures consistent, which increases survival rates and makes the creatures grow faster.

Low-temperature geothermal resources that are not hot enough to produce electricity are very useful to fish farmers. Animals grown in water of the proper temperature grow faster and larger than those in cold water or water with fluctuating temperatures. They are also more resistant to disease and die less frequently.

Fish farmers with access to geothermal water can use it to regulate the temperatures of their fish ponds. Though the mechanism to accomplish this can be complicated, basically what happens is that the fish farmer opens valves to allow geothermal water to flow into the fish ponds until they reach the desired temperature. The valves are then closed to prevent the water from getting too hot. The mechanism is similar to adding hot water to a bathtub to bring the temperature to the desired level.

Water flow can be adjusted throughout the year to account for air temperatures. Most ponds contain some mechanism to circulate the water and keep it all at an even temperature. Aquaculture operations usually have several ponds, which are kept small enough to be heated or cooled easily.

### Current uses of aquacultural applications

Geothermal water has played a role in aquaculture for more than thirty years. In the 1970s the Oregon Institute of Technology began using runoff from the school's geothermal heating system to heat water used to raise freshwater prawns. In Arizona, fish farmers use geothermal waters between 80 and 105 °F (26 and 41 °C) to raise bass, catfish, and tilapia. The Salton Sea and Imperial Valley areas in southern California are home to about fifteen aquaculture operations. These fish farms produce about ten million pounds of fish every year, mostly catfish, striped bass, and tilapia, which are almost all sold in California.

People in other nations have also taken advantage of geothermal water for aquaculture. There are geothermal eel farms in Slovakia. Geothermal fisheries in Iceland grow arctic char, salmon, abalone, and other fish and shellfish. China has over 500 acres of geothermal fish farms, while Japanese fish farms grow eels and alligators. There are also fish farms in France, Greece, Israel, Korea, and New Zealand.

The main species raised in geothermal waters are catfish, bass, trout, tilapia, sturgeon, giant freshwater prawns, alligators, snails, coral, and tropical fish. The warmth of geothermal water makes it possible to raise tropical marine (saltwater) species in cold, landlocked places such as Idaho.

Some creatures have a range of temperatures in which they thrive. For example, catfish and shrimp grow at about 50 percent of optimum rate at temperatures between 68 and 79 °F (20 and 26 °C) and grow fastest at about 90 °F (32 °C), but they decline at temperatures higher than that. Trout thrive at around 60 °F (15.5 °C) but dislike lower or higher temperatures.

Scientists are investigating using geothermal aquaculture to grow plants that humans and animals could eat. Possible crops include kelp, duckweed, algae, and water hyacinth. As of the early 2000s, the technology was not yet good enough to allow economically worthwhile harvesting and processing.

### Benefits and drawbacks of aquacultural applications

Like other direct uses of geothermal water, aquaculture allows an area to make use of groundwater that may not be hot enough to generate electricity but is still hot enough to be useful as hot water. Arizona, for example, has a great deal of geothermal water that is under 300 °F (149 °C), which cannot generate electricity but is very useful in aquaculture.

The fish grown in geothermal fisheries are healthier and stronger than fish grown in unheated fish ponds. Fish farmers can regulate temperature throughout the year to make sure the fish grow to a consistent size year-round.

However, fish farmers must be careful to regulate water temperature. The water in and near the pipes bringing in the hot groundwater can get very hot, creating pockets that are too hot for fish. For aquaculture to work well, there must be a source of cool water in addition to the hot water. Some geothermal fisheries collect geothermal water in holding ponds and let it cool in order to regulate pond temperatures. If the water does not circulate evenly there can also be cold spots. This can make the fish crowd into areas where the temperature is at the right level. The hot pipes also can be dangerous to human workers who must wade into the pools for repairs, feeding, and harvesting.

### Impact of aquacultural applications

For the most part, using hot groundwater to heat fish ponds is good for the environment. A farm that uses geothermal water is not burning fossil fuels or other sources of heat to regulate water temperature and is therefore not emitting pollutants. Many geothermal aquaculture operations use water that has already been used by geothermal power plants or heating systems. The water has lost most of its heat but is still hot enough to raise the temperature of the fish ponds, so it can be put to a second use before disposal.

Aquaculture itself has both good and bad aspects for the environment. It takes pressure off wild fisheries, many of which have

Geothermal power plant well in Dixie Valley near Fallon, Nevada. © *Inga Spence/ Visuals Unlimited. Reproduced by permission.*

been severely overfished. In some areas, however, it contributes to water pollution.

Economically, using geothermal energy to heat water for aquaculture can have many benefits. Places that use water that has already been used for heating or electricity generation can heat their fish ponds essentially for no cost. They can also enjoy the economic benefit of selling the fish or prawns that they produce. Fish grown in geothermally heated water grow faster than fish in unheated water, so some fish farmers can grow extra fish crops for sale. Heated water makes it possible to grow fish in winter when it ordinarily would not be possible. Selling tropical fish for the pet store market can be quite profitable. Developing nations can export their fish produce for good prices, bringing foreign capital into the country.

## GEOTHERMAL POWER PLANTS

One very promising use of geothermal power is the generation of electricity. Areas with hot geothermal reservoirs can use this heat and steam to create electricity without having to spend money for fuel and without polluting the atmosphere or ground.

All types of geothermal power plants use geothermal steam to turn a turbine. The turbine is attached to a generator that creates the electricity. The electricity is then fed into a grid, which is attached to individual users. There are three main types of geothermal power plant: binary, dry steam, and flashed steam. There are also hybrid power plants that combine geothermal energy with other energy sources. The type of plant built in a given area depends on what sort of geothermal resource is available, either steam or liquid and either high or low temperature.

#### Binary power plants

Binary power plants use a two-step process to extract power from geothermal water that is not quite hot enough to spin a turbine by itself. The hot water is pumped up through the ground and passed through a heat exchanger that contains a fluid with a much lower boiling point than water. The heat from the geothermal water causes this “binary” fluid to flash into vapor. That vapor spins the turbine, which powers the generator. The geothermal water is injected back into the reservoir. The binary fluid stays inside the tank, where it is used over and over again. Nothing is released into the atmosphere.

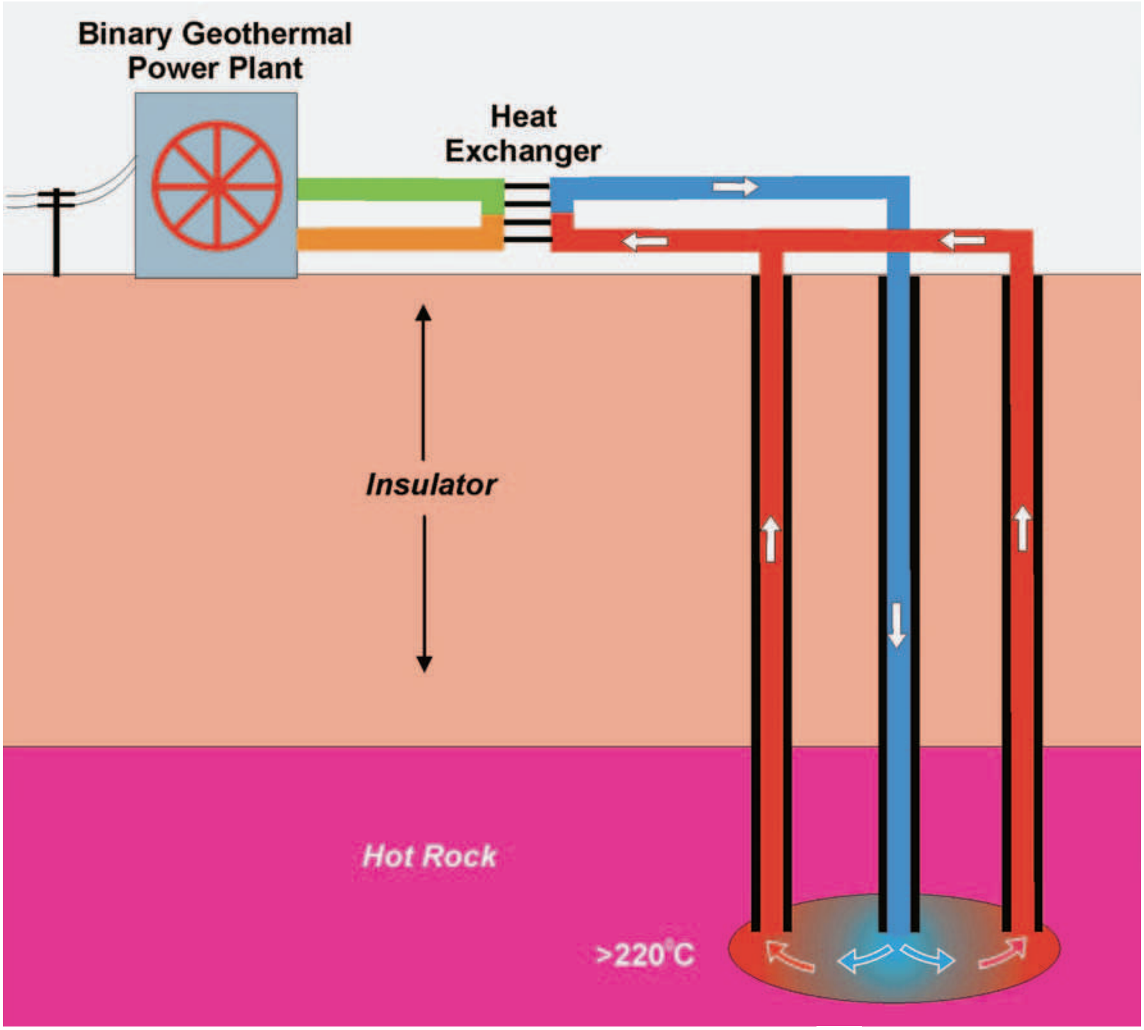
Many areas have geothermal reservoirs with water that is below 400°F (204°C). Moderate-temperature geothermal water is much more common than high-temperature water. The United States Department of Energy predicts that most geothermal power plants built in the future will be binary power plants that can take advantage of this slightly cooler water.

#### Dry steam plants

Dry steam plants use the steam that comes up from a geothermal reservoir to power turbines that power generators. The liquid and steam is then injected back into the reservoir to regain its heat and maintain the reservoir’s pressure. Dry steam was the first technology used to build geothermal power plants. The plant built in Lardarello, Italy, in 1904 used dry steam technology. The Geysers in northern California uses dry steam to produce power. Dry steam is still the largest source of geothermal power in the world.

#### Flashed steam plants

Flashed steam plants are the most common type of geothermal power plant. These plants use geothermal water that is over 360°F (182°C). The fluid is pumped up at high pressure and then sprayed into a tank that is at lower pressure than the water. This causes the geothermal water to “flash,” or turn into steam instantly. The steam




A graphic illustration shows a geothermal technology Australian companies are developing to generate electricity from the heat of ancient rocks buried deep below the red sands of the Australian outback. Spurred by high commodity prices and a drive to reduce Australia's reliance on coal, several

spins a turbine, which powers a generator. Fluid left in the first tank is then pumped into another tank to be flashed again. After the water has been used, it is injected back into the reservoir to regain its heat.

**Hybrid power plants**

Some areas do not have enough geothermal energy to run a full power plant. These places can be ideal sites for hybrid power plants that combine different types of power generation. They can combine different types of geothermal energy generation or combine geothermal energy with other energy sources, even fossil fuels.

### Benefits and drawbacks of geothermal power plants

Geothermal power plants are usually built with modular designs, which makes them very flexible. It is easy to start with a small plant and then add additional units if the demand for electricity increases. Geothermal plants can also use some of their water, either freshly pumped or after being used for electricity, for other direct purposes, such as heating or aquaculture.

However, not every location can use geothermal power. Geothermal power plants must be located near a geothermal reservoir that has water of at least 250°F (121°C) and preferably 300°F (148°C). Not all reservoirs have water this hot. An ideal geothermal reservoir is hot with low mineral content, has shallow aquifers nearby to make it easy to re-inject used water, is on private land in order to make it easier to get permits, is near existing electrical transmission lines, and has a supply of cooler water for cooling. It also needs a high enough volume of water to keep flowing steadily. In the United States, only the western states and Hawaii have these resources.

### Environmental impact of geothermal power plants

Geothermal power plants are generally environmentally clean. They do not burn fossil fuels, so they help conserve those fuels for other purposes. They produce no emissions to contribute to air pollution, the greenhouse effect, or global warming. There is no smoke surrounding geothermal power plants. Dry steam and flashed steam plants emit excess steam and small amounts of gases, while binary plants emit nothing at all because all the fluids are contained within the system and recycled. Areas that use geothermal power have some of the best air quality readings in the world. Lake County, California, which has five geothermal power plants, is the only county in the United States that has met the strictest governmental air quality standards since the mid-1990s.

Geothermal plants do not need space to store fuels, and they do not create large piles of ash that must be cleared or oil spills that damage oceans. They also do not pollute groundwater, unless the geothermal water has a high concentration of minerals or metals.

Unlike most other power plant types, geothermal plants do not require large amounts of space to function. They can be built right on top of geothermal reservoirs. The pumps that bring water up from geothermal reservoirs are small, especially compared to those used by coal mines or oil wells. They do not tear up large plots of land or destroy forests. There is no need to build major highways, railroads, or pipelines in order to transport fuel to geothermal power plants because their source of power is directly below them. It is actually possible to build geothermal power plants in the midst of farmland or forests, where they can coexist with livestock and wildlife.

#### Economic impact

Geothermal power plants require an initial investment in finding reservoirs, digging wells, and building a plant with turbines. This initial investment can be quite heavy, between $3,000 and $5,000 per kilowatt. Once a plant is built, however, it can be more economical than producing power with fossil fuels. Fuel does not have to be purchased to run the plant, which saves money and makes operations more predictable, as the plant is not affected by fluctuations in the price of oil, gas, or coal.

#### Issues, challenges, and obstacles of geothermal power plants

In developed nations the existing utility companies have a large investment in their currently functioning power plants. These plants usually run on fossil fuels, though there are some nuclear and hydroelectric power plants. The utilities themselves and the oil and gas companies that supply their fuel have an interest in maintaining things as they are. There is little incentive for them to give up their source of income in favor of geothermal power.

Geothermal power plants can only be built on or near geothermal reservoirs. These reservoirs are often on private land or land that is already being used for some other purpose. A company that wants to build a geothermal power plant must first get access to the land over the reservoir, which can be difficult, expensive, and time-consuming. There needs to be a great deal more research and development before geothermal power generation becomes practical around the world.

## GEOTHERMAL HEATING APPLICATIONS

One obvious use of geothermal energy is for heat. Many cities and homes use naturally hot water to keep them warm in winter. There are two main ways to use geothermal water for heating. The older method is using the water directly. Newer technology involves using a geothermal heat pump.

#### *Direct heating*

Direct heating pumps the water from the geothermal reservoir in the ground and passes it through pipes running through buildings.

## Oregon's Geothermal Zone

Klamath Falls, Oregon, has used geothermal heating for homes since 1900. In the early 2000s, more than 550 geothermal wells were in use, heating homes, pools, schools, and businesses. Geothermal pipes run under the sidewalks and highways to keep them clear of snow. In 1982 the city built a geothermal district heating system that heats the entire eastern part of the city. Two wells east of downtown pump water that is about 210°F (98°C) from underground reservoirs to the central mechanical room at the County Museum. This water is treated and then delivered to customers. It is about 180°F (82°C) when it reaches the seven hundred homes and buildings that use geothermal heat. When it returns to the mechanical room, it has lost about 40°F (4°C) of temperature. It is then injected back into the reservoir to be recycled.

The heat from the water moves from the pipes through the walls into the air inside the building. This system can also be used to heat water.

For direct heating, the best geothermal water temperature is under 212°F (100°C). In fact, water with a temperature as low as 95°F (35°C) can be used for direct heating. In some areas, such as Iceland, the geothermal water is pure enough that it can be pumped directly through radiators. In most places, however, chemicals in the water make it necessary to filter the water through heat exchangers that extract the heat from the water.

### *Geothermal heat pumps*

Newer technology uses geothermal water to run a heat pump, similar to an electric heat pump. A geothermal heat pump forces heat in a direction it would not ordinarily go. Most heat pumps can function as both heating and cooling units. In winter they heat air and pump it through the house. In summer they absorb hot air and pump it into the ground. Geothermal heat pumps are particularly efficient because they start with air or water that is already hot and thus do not have to heat it as much as ordinary heat pumps, which start with cold outside air. Geothermal heat pumps use 30 to 60 percent less electricity than traditional heat pumps because they do not have to create their own heat, just move it from place to place.

Reykjavik is the capital of Iceland. Nearly all of the hot water in Reykjavik is obtained from natural geothermal sources. Much of its energy is derived from natural sources such as geothermal and hydroelectric power. These energy sources are non-polluting and essentially inexhaustible, making Iceland a clean and environmentally friendly country. *Martin Bond/Photo Researchers, Inc.*

Geothermal heat pumps work by pumping water or a mix of water and antifreeze through the ground next to a house or building. The ground temperature remains relatively constant throughout the year, generally between 45 and 55°F (7 and 12°C). In winter, underground pipes absorb heat from the Earth. This heated water circulates into the heat pump, where it is concentrated so that it will increase to the desired room temperature. The heat pump then pumps the hot air through the ducts in the building, heating the rooms. In summer the process is reversed; the hot air is sucked from the building and dispersed into the ground. The geothermal heat pump system uses ordinary ductwork, so there is no need to modify existing ducts.

Geothermal heat pumps usually can at least partially heat water for the home. This is not necessarily possible all year round. During the summer the heat pump can use excess heat to warm domestic hot water, but during the winter there is not as much heat available to warm the water. A home with a geothermal heat pump must usually have an alternate source of heat for water, but even so, using excess heat for even part of the year results in an energy savings. New technology is improving this situation; because geothermal heat pumps are so much more efficient than other forms of water heating, some manufacturers are now selling geothermal heat pumps that heat water separately, thereby providing hot water year-round.

Geothermal heat pumps, like all heat pumps, produce slightly warmer air than fossil fuel furnaces. Geothermal heat pumps generally produce hot air between 95 and 103°F (35 and 39°C), as opposed to conventional heat pumps, which produce hot air between 90 and 95°F (32 and 35°C). Geothermal heat pumps require more open ductwork for air flow than fossil fuel furnaces, which can be a problem when converting older houses to geothermal heat.

### Current uses of geothermal heating applications

People have used geothermal water to heat buildings for hundreds of years. People in Paris, France, heated buildings with geothermal water six hundred years ago. Boise, Idaho, began using geothermal heating in 1892. This system is still in use there, where four district heating systems heat over five million square feet (152 million square meters) of space.

Starting in the 1960s, other cities began to take notice of the potential benefits of geothermal energy. By the early 2000s geothermal direct heating was common in Iceland, Hungary, Poland, China, Argentina, Croatia, France, and Turkey. Reykjavik, Iceland, has the world's largest geothermal heating system, with about two hundred miles (320 kilometers) of pipes running throughout the city. The city is almost entirely heated by geothermal heat.

Geothermal heat pumps are gradually gaining popularity as people learn about them. Geothermal heat pumps in the early 2000s were considered much more efficient than the ones made in 1990. Experts foresee some continuing improvements but believe they will be small compared to improvements already made.

### Benefits and drawbacks of geothermal heating applications

Geothermal direct heat is inexpensive and nonpolluting. Places that have sufficient geothermal resources can heat entire cities for just the cost of running the pipes. The heat is always available and does not depend on fuel supplies. However, geothermal direct heat is only possible in areas with substantial geothermal resources. That means it cannot be a worldwide solution to the heating problem.

On the other hand, geothermal heat pumps can be used almost anywhere in the world because they do not require the presence of geothermal reservoirs. They make it possible to use geothermal resources that were formerly considered unusable. They can be used for summer cooling in addition to winter heating, and sometimes they can supply hot water as well. These pumps are easiest to install in new buildings; it is difficult to convert existing homes to geothermal heat pumps, and they cost more than electric heat pumps.

### Impact of geothermal heating applications

Geothermal heating has many obvious environmental benefits. It does not pollute the air at all because geothermal heating involves no combustion and therefore no emissions. Geothermal heat pumps pose few environmental problems. They use an antifreeze substance, but it is usually a nontoxic chemical called propylene glycol or small amounts of methanol, both of which are commonly used in windshield washing solutions.

Economically, geothermal heat can be much less expensive than other sources of heat, such as fossil fuels or wood, but that cost depends on several factors. The initial installation costs can be high, but if the heating system works well it can pay for itself quickly. Geothermal heat works especially well in areas that already have wells dug into geothermal reservoirs. If there are already wells in place, a district or institution only needs to buy pipelines, heat exchangers, and pumps. A heating system is more expensive to install if there is not already a good geothermal reservoir in use.

Geothermal heat pumps currently cost more than conventional ones, but once they are installed the cost of running them is less than that of any other conventional form of heat, including natural gas. This savings depends on the cost of fossil fuels; as fossil fuels get more expensive, geothermal heat may become more economical. It is estimated that geothermal heat pumps can reduce the power used to heat or cool a house by one to five kilowatts of generating capacity at peak time, which can result in major savings on residential heating and cooling costs.

### Issues, challenges, and obstacles of geothermal heating applications

Experts estimate that almost three hundred communities in the western United States are close enough to geothermal heat sources to use them as a district heating system. Many other countries have the potential to use more geothermal energy for district heating. People are gradually taking more interest in geothermal resources as fossil fuels become more expensive and the dangers of air pollution become more apparent.

Implementing a geothermal heating system is a major investment. It requires money, labor, and a willingness to take the risk that it may not work. The technology is still new and does not have a long track record, nor are there many people who are experts in installing geothermal heating systems. There have been unsuccessful attempts to use geothermal heat.

In the early 2000s, there were about 500,000 geothermal heat pumps in use in the United States. Switzerland and several other countries were implementing programs to increase geothermal heat pump usage. There is plenty of potential for expansion. People do not use them mainly because they are not widely available, and few people know that they exist. There is also the problem of persuading people to buy geothermal heat pumps when they cost more than conventional climate control systems.

## INDUSTRIAL APPLICATIONS

Many industries need steam or hot water for their operations. Geothermal water is an excellent low-cost source of this basic item. Industries generally need very hot water, hotter than the water used in agriculture or aquaculture, though there is much variation. Plants can be built right next to geothermal reservoirs and pipe the water or steam straight into the operation.

### Current uses of industrial applications

Geothermal water is useful in any industry that requires steam or hot water. Some uses include:

- Timber processing
- Pulp and paper processing
- Washing wool
- Dyeing cloth
- Drying diatomaceous earth (a light, abrasive soil used as a filtering material and insecticide)
- Drying fish meal and stock fish
- Canning food
- Drying cement

### Geothermal Dye Works

In most cases an industry uses geothermal water because it is a cheap source of heat and/or water. In a few cases, however, industries take advantage of the unique mineral properties of geothermal water. In Iwate Prefecture, Japan, there is a new geothermal dye factory that uses the minerals in geothermal water as a mordant, a substance that makes dye pigments stick to cloth, and also as a substance that can remove dye from cloth. The factory uses a method of folding and tying the cloth with string, soaking it in dye made with geothermal water, and then rinsing it and unfolding it. The combination of steam, heat, and the hydrogen sulfide in the geothermal water leaves beautiful and unique patterns on the cloth.

- Drying organic materials such as vegetables, seaweed, and grass
- Refrigeration

#### Benefits and drawbacks of industrial applications

Using geothermal water and steam saves companies the cost of heating water and saves the environment some of the pollution that would be caused by heating the water. However, geothermal water is only available in a few places, so most industries cannot use it.

#### Issues, challenges, and obstacles

The use of geothermal water in industry is still very new, and as of the early 2000s, not many industries are taking advantage of it. Few people know whether or not geothermal energy is available or how to use it if it is. Implementing geothermal energy requires installing equipment such as pipes, which can be expensive or difficult in an existing plant.

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# Alternative Energy

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## Volume 2

### Neil Schlager and Jayne Weisblatt, editors

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# Contents

# Introduction

*Alternative Energy* offers readers comprehensive and easy-to-use information on the development of alternative energy sources. Although the set focuses on new or emerging energy sources, such as geothermal power and solar energy, it also discusses existing energy sources such as those that rely on fossil fuels. Each volume begins with a general overview that presents the complex issues surrounding existing and potential energy sources. These include the increasing need for energy, the world's current dependence on nonrenewable sources of energy, the impact on the environment of current energy sources, and implications for the future. The overview will help readers place the new and alternative energy sources in perspective.

Each of the first eight chapters in the set covers a different energy source. These chapters each begin with an overview that defines the source, discusses its history and the scientists who developed it, and outlines the applications and technologies for using the source. Following the chapter overview, readers will find information about specific technologies in use and potential uses as well. Two additional chapters explore the need for conservation and the move toward more energy-efficient tools, building materials, and vehicles and the more theoretical (and even imaginary) energy sources that might become reality in the future.

## ADDITIONAL FEATURES

Each volume of *Alternative Energy* includes the overview, a glossary called "Words to Know," a list of sources for more information, and an index. The set has 100 photos, charts, and illustrations to

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## COMMENTS AND SUGGESTIONS

We welcome your comments on *Alternative Energy* and suggestions for future editions of this work. Please write: Editors, *Alternative Energy*, U•X•L, 27500 Drake Rd., Farmington Hills, Michigan 48331-3535; call toll free: 1-800-877-4253; fax: 248-699-8097; or send e-mail via www.gale.com.

# Words to Know

## A

**acid rain:** Rain with a high concentration of sulfuric acid, which can damage cars, buildings, plants, and water supplies where it falls.

**adobe:** Bricks that are made from clay or earth, water, and straw, and dried in the sun.

**alkane:** A kind of hydrocarbon in which the molecules have the maximum possible number of hydrogen atoms and no double bonds.

**anaerobic:** Without air; in the absence of air or oxygen.

**anemometer:** A device used to measure wind speed.

**anthracite:** A hard, black coal that burns with little smoke.

**aquaculture:** The formal cultivation of fish or other aquatic life forms.

**atomic number:** The number of protons in the nucleus of an atom.

**atomic weight:** The combined number of an atom's protons and neutrons.

**attenuator:** A device that reduces the strength of an energy wave, such as sunlight.

## B

**balneology:** The science of bathing in hot water.

**barrel:** A common unit of measurement of crude oil, equivalent to 42 U.S. gallons; barrels of oil per day, or BOPD, is a standard measurement of how much crude oil a well produces.

**biodiesel:** Diesel fuel made from vegetable oil.

**bioenergy:** Energy produced through the combustion of organic materials that are constantly being created, such as plants.

**biofuel:** A fuel made from organic materials that are constantly being created.

**biomass:** Organic materials that are constantly being created, such as plants.

**bitumen:** A black, viscous (oily) hydrocarbon substance left over from petroleum refining, often used to pave roads.

**bituminous coal:** Mid-grade coal that burns with a relatively high flame and smoke.

**brine:** Water that is very salty, such as the water found in the ocean.

**British thermal unit (Btu or BTU):** A measure of heat energy, equivalent to the amount of energy it takes to raise the temperature of one pound of water by one degree Fahrenheit.

**butyl rubber:** A synthetic rubber that does not easily tear. It is often used in hoses and inner tubes.

## C

**carbon sequestration:** Storing the carbon emissions produced by coal-burning power plants so that pollutants are not released in the atmosphere.

**catalyst:** A substance that speeds up a chemical reaction or allows it to occur under different conditions than otherwise possible.

**cauldron:** A large metal pot.

**CFC (chlorofluorocarbon):** A chemical compound used as a refrigerant and propellant before being banned for fear it was destroying the ozone layer.

**Clean Air Act:** A U.S. law intended to reduce and control air pollution by setting emissions limits for utilities.

**climate-responsive building:** A building, or the process of constructing a building, using materials and techniques that take advantage of natural conditions to heat, cool, and light the building.

**coal:** A solid hydrocarbon found in the ground and formed from plant matter compressed for millions of years.

**coke:** A solid organic fuel made by burning off the volatile components of coal in the absence of air.

**cold fusion**: Nuclear fusion that occurs without high heat; also referred to as low energy nuclear reactions.

**combustion**: Burning.

**compact fluorescent bulb**: A lightbulb that saves energy as conventional fluorescent bulbs do, but that can be used in fixtures that normally take incandescent lightbulbs.

**compressed**: To make more dense so that a substance takes up less space.

**conductive**: A material that can transmit electrical energy.

**convection**: The circulation movement of a substance resulting from areas of different temperatures and/or densities.

**core**: The center of the Earth.

**coriolis force**: The movement of air currents to the right or left caused by Earth's rotation.

**corrugated steel**: Steel pieces that have parallel ridges and troughs.

**critical mass**: An amount of fissile material needed to produce an ongoing nuclear chain reaction.

**criticality**: The point at which a nuclear fission reaction is in controlled balance.

**crude oil**: The unrefined petroleum removed from an oil well.

**crust**: The outermost layer of the Earth.

**curie**: A unit of measurement that measures an amount of radiation.

**current**: The flow of electricity.

## D

**decay**: The breakdown of a radioactive substance over time as its atoms spontaneously give off neutrons.

**deciduous trees**: Trees that shed their leaves in the fall and grow them in the spring. Such trees include maples and oaks.

**decommission**: To take a nuclear power plant out of operation.

**dependent**: To be reliant on something.

**distillation**: A process of separating or purifying a liquid by boiling the substance and then condensing the product.

**distiller's grain**: Grain left over from the process of distilling ethanol, which can be used as inexpensive high-protein animal feed.

**drag:** The slowing force of the wind as it strikes an object.

**drag coefficient:** A measurement of the drag produced when an object such as a car pushes its way through the air.

## E

E85: A blend of 15 percent ethanol and 85 percent gasoline.

**efficient:** To get a task done without much waste.

**electrolysis:** A method of producing chemical energy by passing an electric current through a type of liquid.

**electromagnetism:** Magnetism developed by a current of electricity.

**electron:** A negatively charged particle that revolves around the nucleus in an atom.

**embargo:** Preventing the trade of a certain type of commodity.

**emission:** The release of substances into the atmosphere. These substances can be gases or particles.

**emulsion:** A liquid that contains many small droplets of a substance that cannot dissolve in the liquid, such as oil and water shaken together.

**enrichment:** The process of increasing the purity of a radioactive element such as uranium to make it suitable as nuclear fuel.

**ethanol:** An alcohol made from plant materials such as corn or sugar cane that can be used as fuel.

**experimentation:** Scientific tests, sometimes of a new idea.

## F

**feasible:** To be possible; able to be accomplished or brought about.

**feedstock:** A substance used as a raw material in the creation of another substance.

**field:** An area that contains many underground reservoirs of petroleum or natural gas.

**fissile:** Term used to describe any radioactive material that can be used as fuel because its atoms can be split.

**fission:** Splitting of an atom.

**flexible fuel vehicle (FFV):** A vehicle that can run on a variety of fuel types without modification of the engine.

**flow:** The volume of water in a river or stream, usually expressed as gallons or cubic meters per unit of time, such as a minute or second.

**fluorescent lightbulb:** A lightbulb that produces light not with intense heat but by exciting the atoms in a phosphor coating inside the bulb.

**fossil fuel:** An organic fuel made through the compression and heating of plant matter over millions of years, such as coal, petroleum, and natural gas.

**fusion:** The process by which the nuclei of light atoms join, releasing energy.

## G

**gas:** An air-like substance that expands to fill whatever container holds it, including natural gas and other gases commonly found with liquid petroleum.

**gasification:** A process of converting the energy from a solid, such as coal, into gas.

**gasohol:** A blend of gasoline and ethanol.

**gasoline:** Refined liquid petroleum most commonly used as fuel in internal combustion engines.

**geothermal:** Describing energy that is found in the hot spots under the Earth; describing energy that is made from heat.

**geothermal reservoir:** A pocket of hot water contained within the Earth's mantle.

**global warming:** A phenomenon in which the average temperature of the Earth rises, melting icecaps, raising sea levels, and causing other environmental problems.

**gradient:** A gradual change in something over a specific distance.

**green building:** Any building constructed with materials that require less energy to produce and that save energy during the building's operation.

**greenhouse effect:** A phenomenon in which gases in the Earth's atmosphere prevent the sun's radiation from being reflected back into space, raising the surface temperature of the Earth.

**greenhouse gas:** A gas, such as carbon dioxide or methane, that is added to the Earth's atmosphere by human actions. These gases trap heat and contribute to global warming.

## H

**halogen lamp:** An incandescent lightbulb that produces more light because it produces more heat, but lasts longer because the filament is enclosed in quartz.

**Heisenberg uncertainty principle:** The principle that it is impossible to know simultaneously both the location and momentum of a subatomic particle.

**heliostat:** A mirror that reflects the sun in a constant direction.

**hybrid vehicle:** Any vehicle that is powered in a combination of two ways; usually refers to vehicles powered by an internal combustion engine and an electric motor.

**hybridized:** The bringing together of two different types of technology.

**hydraulic energy:** The kinetic energy contained in water.

**hydrocarbon:** A substance composed of the elements hydrogen and carbon, such as coal, petroleum, and natural gas.

**hydroelectric:** Describing electric energy made by the movement of water.

**hydropower:** Any form of power derived from water.

## I

**implement:** To put something into practice.

**incandescent lightbulb:** A conventional lightbulb that produces light by heating a filament to high temperatures.

**infrastructure:** The framework that is necessary to the functioning of a structure; for example, roads and power lines form part of the infrastructure of a city.

**inlet:** An opening through which liquid enters a device, or place.

**internal combustion engine:** The type of engine in which the burning that generates power takes place inside the engine.

**isotope:** A “species” of an element whose nucleus contains more neutrons than other species of the same element.

## K

**kilowatt-hour:** One kilowatt of electricity consumed over a one-hour period.

**kinetic energy:** The energy associated with movement, such as water that is in motion.

**Kyoto Protocol:** An international agreement among many nations setting limits on emissions of greenhouse gases; intended to slow or prevent global warming.

## L

**lava:** Molten rock contained within the Earth that emerges from cracks in the Earth's crust, such as volcanoes.

**lift:** The aerodynamic force that operates perpendicular to the wind, owing to differences in air pressure on either side of a turbine blade.

**lignite:** A soft brown coal with visible traces of plant matter in it that burns with a great deal of smoke and produces less heat than anthracite or bituminous coal.

**liquefaction:** The process of turning a gas or solid into a liquid.

**LNG (liquefied natural gas):** Gas that has been turned into liquid through the application of pressure and cold.

**LPG (liquefied petroleum gas):** A gas, mainly propane or butane, that has been turned into liquid through the use of pressure and cold.

**lumen:** A measure of the amount of light, defined as the amount of light produced by one candle.

## M

**magma:** Liquid rock within the mantle.

**magnetic levitation:** The process of using the attractive and repulsive forces of magnetism to move objects such as trains.

**mantle:** The layer of the Earth between the core and the crust.

**mechanical energy:** The energy output of tools or machinery.

**meltdown:** Term used to refer to the possibility that a nuclear reactor could become so overheated that it would melt into the earth below.

**mica:** A type of shiny silica mineral usually found in certain types of rocks.

**modular:** An object which can be easily arranged, rearranged, replaced, or interchanged with similar objects.

**mousse:** A frothy mixture of oil and seawater in the area where an oil spill has occurred.

## N

**nacelle:** The part of a wind turbine that houses the gearbox, generator, and other components.

**natural gas:** A gaseous hydrocarbon commonly found with petroleum.

**negligible:** To be so small as to be insignificant.

**neutron:** A particle with no electrical charge found in the nucleus of most atoms.

NGL (**natural gas liquid**): The liquid form of gases commonly found with natural gas, such as propane, butane, and ethane.

**nonrenewable:** To be limited in quantity and unable to be replaced.

**nucleus:** The center of an atom, containing protons and in the case of most elements, neutrons.

## O

**ocean thermal energy conversion** (OTEC): The process of converting the heat contained in the oceans' water into electrical energy.

**octane rating:** The measure of how much a fuel can be compressed before it spontaneously ignites.

**off-peak:** Describing period of time when energy is being delivered at well below the maximum amount of demand, often nighttime.

**oil:** Liquid petroleum; a substance refined from petroleum used as a lubricant.

**organic:** Related to or derived from living matter, such as plants or animals; composed mainly of carbon atoms.

**overburden:** The dirt and rocks covering a deposit of coal or other fossil fuel.

**oxygenate:** A substance that increases the oxygen level in another substance.

**ozone:** A molecule consisting of three atoms of oxygen, naturally produced in the Earth's atmosphere; ozone is toxic to humans.

## P

**parabolic:** Shaped like a parabola, which is a certain type of curve.

**paraffin:** A kind of alkane hydrocarbon that exists as a white, waxy solid at room temperature and can be used as fuel or as a wax for purposes such as sealing jars or making candles.

**passive:** A device that takes advantage of the sun's heat but does not use an additional source of energy.

**peat:** A brown substance composed of compressed plant matter and found in boggy areas; peat can be used as fuel itself, or turns into coal if compressed for long enough.

**perpetual motion:** The power of a machine to run indefinitely without any energy input.

**petrochemicals:** Chemical compounds that form in rocks, such as petroleum and coal.

**petrodiesel:** Diesel fuel made from petroleum.

**petroleum:** Liquid hydrocarbon found underground that can be refined into gasoline, diesel fuel, oils, kerosene, and other products.

**pile:** A mass of radioactive material in a nuclear reactor.

**plutonium:** A highly toxic element that can be used as fuel in nuclear reactors.

**polymer:** A compound, either synthetic or natural, that is made of many large molecules. These molecules are made from smaller, identical molecules that are chemically bonded.

**pristine:** Not changed by human hands; in its original condition.

**productivity:** The output of labor per amount of work.

**proponent:** Someone who supports an idea or cause.

**proton:** A positively charged particle found in the nucleus of an atom.

## R

**radioactive:** Term used to describe any substance that decays over time by giving off subatomic particles such as neutrons.

**RFG (reformulated gasoline):** Gasoline that has an oxygenate or other additive added to it to decrease emissions and improve performance.

**rem:** An abbreviation for "roentgen equivalent man," referring to a dose of radiation that will cause the same biological effect (on a "man") as one roentgen of X-rays or gamma rays.

**reservoir:** A geologic formation that can contain liquid petroleum and natural gas.

**reservoir rock:** Porous rock, such as limestone or sandstone, that can hold accumulations of petroleum or natural gas.

**retrofit:** To change something, like a home, after it is built.

**rotor:** The hub to which the blades of a wind turbine are connected; sometimes used to refer to the rotor itself and the blades as a single unit.

## S

**scupper:** An opening that allows a liquid to drain.

**seam:** A deposit of coal in the ground.

**sedimentary rock:** A rock formed through years of minerals accumulating and being compressed.

**seismology:** The study of movement within the earth, such as earthquakes and the eruption of volcanoes.

**sick building syndrome:** The tendency of buildings that are poorly ventilated, lighted, and humidified, and that are made with certain synthetic materials to cause the occupants to feel ill.

**smog:** Air pollution composed of particles mixed with smoke, fog, or haze in the air.

**stall:** The loss of lift that occurs when a wing presents too steep an angle to the wind and low pressure along the upper surface of the wing decreases.

**strip mining:** A form of mining that involves removing earth and rocks by bulldozer to retrieve the minerals beneath them.

**stored energy:** The energy contained in water that is stored in a tank or held back behind a dam in a reservoir.

**subsidence:** The collapse of earth above an empty mine, resulting in a damaged landscape.

**surcharge:** An additional charge over and above the original cost.

**superconductivity:** The disappearance of electrical resistance in a substance such as some metals at very low temperatures.

## T

**thermal energy:** Any form of energy in the form of heat; used in reference to heat in the oceans' waters.

**thermal gradient:** The differences in temperature between different layers of the oceans.

**thermal mass:** The measure of the amount of heat a substance can hold.

**thermodynamics:** The branch of physics that deals with the mechanical actions or relations of heat.

**tokamak:** An acronym for the Russian-built toroidal magnetic chamber, a device for containing a fusion reaction.

**transitioning:** Changing from one position or state to another.

**transparent:** So clear that light can pass through without distortion.

**trap:** A reservoir or area within Earth's crust made of nonporous rock that can contain liquids or gases, such as water, petroleum, and natural gas.

**trawler:** A large commercial fishing boat.

**Trombé wall:** An exterior wall that conserves energy by trapping heat between glazing and a thermal mass, then venting it into the living area.

**turbine:** A device that spins to produce electricity.

## U

**uranium:** A heavy element that is the chief source of fuel for nuclear reactors.

## V

**viable:** To be possible; to be able to grow or develop.

**voltage:** Electric potential that is measured in volts.

## W

**wind farm:** A group of wind turbines that provide electricity for commercial uses.

**work:** The conversion of one form of energy into another, such as the conversion of the kinetic energy of water into mechanical energy used to perform a task.

## Z

**zero point energy:** The energy contained in electromagnetic fluctuations that remains in a vacuum, even when the temperature has been reduced to very low levels.

# Overview

In the technological world of the twenty-first century, few people can truly imagine the challenges faced by prehistoric people as they tried to cope with their natural environment. Thousands of years ago life was a daily struggle to find, store, and cook food, stay warm and clothed, and generally survive to an "old age" equal to that of most of today's college students. A common image of prehistoric life is that of dirty and ill-clad people huddled around a smoky campfire outside a cave in an ongoing effort to stay warm and dry and to stop the rumbling in their bellies.

The "caves" of the twenty-first century are a little cozier. The typical person, at least in more developed countries, wakes up each morning in a reasonably comfortable house because the gas, propane, or electric heating system (or electric air-conditioner) has operated automatically overnight. A warm shower awaits because of hot water heaters powered by electricity or natural gas, and hair dries quickly (and stylishly) under an electric hair dryer. An electric iron takes the wrinkles out of the clean shirt that sat overnight in the electric clothes dryer. Milk for a morning bowl of cereal remains fresh in an electric refrigerator, and it costs pennies per bowl thanks to electrically powered milking operations on modern dairy farms. The person then goes to the garage (after turning off all the electric lights in the house), hits the electric garage door opener, and gets into his or her gasoline-powered car for the drive to work—perhaps in an office building that consumes power for lighting, heating and air-conditioning, copiers, coffeemakers, and computers. Later, an electric, propane, or natural gas stove is used to cook dinner. Later still, an electric

popcorn popper provides a snack as the person watches an electric television or reads under the warm glow of electric light bulbs—after perhaps turning up the heat because the house is a little chilly.

## CATASTROPHE AHEAD?

Most people take these modern conveniences for granted. Few people give much thought to them, at least until there is a power outage or prices rise sharply, as they did for gasoline in the United States in the summer and fall of 2005. Many scientists, environmentalists, and concerned members of the public, though, believe that these conveniences have been taken too much for granted. Some believe that the modern reliance on fossil fuels—fuels such as natural gas, gasoline, propane, and coal that are processed from materials mined from the earth—has set the Earth on a collision course with disaster in the twenty-first century. Their belief is that the human community is simply burning too much fuel and that the consequences of doing so will be dire (terrible). Some of their concerns include the following:

- Too much money is spent on fossil fuels. In the United States, over $1 billion is spent every day to power the country's cars and trucks.
- Much of the supply of fossil fuels, particularly petroleum, comes from areas of the world that may be unstable. The U.S. fuel supply could be cut off without warning by a foreign government. Many nations that import all or most of their petroleum feel as if they are hostages to the nations that control the world's petroleum supplies.
- Drilling for oil and mining coal can do damage to the landscape that is impossible to repair.
- Reserves of coals and especially oil are limited, and eventually supplies will run out. In the meantime, the cost of such fuels will rise dramatically as it becomes more and more difficult to find and extract them.
- Transporting petroleum in massive tankers at sea heightens the risk of oil spills, causing damage to the marine and coastal environments.

Furthermore, to provide heat and electricity, fossil fuels have to be burned, and this burning gives rise to a host of problems. It releases pollutants in the form of carbon dioxide and sulfur into the air, fouling the atmosphere and causing "brown clouds" over cities. These pollutants can increase health problems such as lung

disease. They may also contribute to a phenomenon called "global warming." This term refers to the theory that average temperatures across the globe will increase as "greenhouse gases" such as carbon dioxide trap the sun's heat (as a greenhouse does) in the atmosphere and warm it. Global warming, in turn, can melt glaciers and the polar ice caps, raising sea levels with damaging effects on coastal cities and small island nations. It may also cause climate changes, crop failures, and more unpredictable weather patterns.

Some scientists do not believe that global warming even exists or that its consequences will be catastrophic. Some note that throughout history, the world's average temperatures have risen and fallen. Some do not find the scientific data about temperature, glacial melting, rising sea levels, and unpredictable weather totally believable. While the debate continues, scientists struggle to learn more about the effects of human activity on the environment. At the same time, governments struggle to maintain a balance between economic development and its possible effects on the environment.

## WHAT TO DO?

These problems began to become more serious after the Industrial Revolution of the nineteenth century. Until that time people depended on other sources of power. Of course, they burned coal or wood in fireplaces and stoves, but they also relied on the power of the sun, the wind, and river currents to accomplish much of their work. The Industrial Revolution changed that. Now, coal was being burned in vast amounts to power factories and steam engines as the economies of Europe and North America grew and developed. Later, more efficient electricity became the preferred power source, but coal still had to be burned to produce electricity in large power plants. Then in 1886 the first internal combustion engine was developed and used in an automobile. Within a few decades there was a demand for gasoline to power these engines. By 1929 the number of cars in the United States had grown to twenty-three million, and in the quarter-century between 1904 and 1929, the number of trucks grew from just seven hundred to 3.4 million.

At the same time technological advances improved life in the home. In 1920, for example, the United States produced a total of five thousand refrigerators. Just ten years later the number had grown to one million per year. These and many other industrial and consumer developments required vast and growing amounts of

fuel. Compounding the problem in the twenty-first century is that other nations of the world, such as China and India, have started to develop more modern industrialized economies powered by fossil fuels.

By the end of World War II in 1945, scientists were beginning to imagine a world powered by fuel that was cheap, clean, and inexhaustible (unable to be used up). During the war the United States had unleashed the power of the atom to create the atomic bomb. Scientists believed that the atom could be used for peaceful purposes in nuclear power plants. They even envisioned (imagined) a day when homes could be powered by their own tiny nuclear power generators. This dream proved to be just that. While some four hundred nuclear power plants worldwide provide about 16 percent of the world's electricity, building such plants is an enormously expensive technical feat. Moreover, nuclear power plants produce spent fuel that is dangerous and not easily disposed of. The public fears that an accident at such a plant could release deadly radiation that would have disastrous effects on the surrounding area. Nuclear power has strong defenders, but it is not cheap, and safety concerns sometimes make it unpopular.

The dream of a fuel source that is safe, plentiful, clean, and inexpensive, however, lives on. The awareness of the need for such alternative fuel sources became greater in the 1970s, when the oil-exporting countries of the Middle East stopped shipments of oil to the United States and its allies. This situation (an embargo) caused fuel shortages and rapidly rising prices at the gas pump. In the decades that followed, gasoline again became plentiful and relatively inexpensive, but the oil embargo served as a wakeup call for many people. In addition, during these years people worldwide grew concerned about pollution, industrialization, and damage to the environment. Accordingly, efforts were intensified to find and develop alternative sources of energy.

## ALTERNATIVE ENERGY: BACK TO THE FUTURE

Some of these alternative fuel sources are by no means new. For centuries people have harnessed the power of running water for a variety of needs, particularly for agriculture (farming). Water wheels were constructed in the Middle East, Greece, and China thousands of years ago, and they were common fixtures on the farms of Europe by the Middle Ages. In the early twenty-first century hydroelectric dams, which generate electricity from the power of rivers, provide about 9 percent of the electricity in the

United States. Worldwide, there are about 40,000 such dams. In some countries, such as Norway, hydroelectric dams provide virtually 100 percent of the nation's electrical needs. Scientists, though, express concerns about the impact such dams have on the natural environment.

Water can provide power in other ways. Scientists have been attempting to harness the enormous power contained in ocean waves, tides, and currents. Furthermore, they note that the oceans absorb enormous amounts of energy from the sun, and they hope someday to be able to tap into that energy for human needs. Technical problems continue to occur. It remains likely that ocean power will serve only to supplement (add to) existing power sources in the near future.

Another source of energy that is not new is solar power. For centuries, people have used the heat of the sun to warm houses, dry laundry, and preserve food. In the twenty-first century such "passive" uses of the sun's rays have been supplemented with photovoltaic devices that convert the energy of the sun into electricity. Solar power, though, is limited geographically to regions of the Earth where sunshine is plentiful.

Another old source of heat is geothermal power, referring to the heat that seeps out of the earth in places such as hot springs. In the past this heat was used directly, but in the modern world it is also used indirectly to produce electricity. In 1999 over 8,000 megawatts (that is, 8,000 million watts) of electricity were produced by about 250 geothermal power plants in twenty-two countries around the world. That same year the United States produced nearly 3,000 megawatts of geothermal electricity, more than twice the amount of power generated by wind and solar power. Geothermal power, though, is restricted by the limited number of suitable sites for tapping it.

Finally, wind power is getting a closer look. For centuries people have harnessed the power of the wind to turn windmills, using the energy to accomplish work. In the United States, wind-operated turbines produce just 0.4 percent of the nation's energy needs. However, wind experts believe that a realistic goal is for wind to supply 20 percent of the nation's electricity requirements by 2020. Worldwide, wind supplies enough power for about nine million homes. Its future development, though, is hampered by limitations on the number of sites with enough wind and by concerns about large numbers of unsightly wind turbines marring the landscape.

## ALTERNATIVE ENERGY: FORWARD TO THE FUTURE

While some forms of modern alternative energy sources are really developments of long-existing technologies, others are genuinely new, though scientists have been exploring even some of these for up to hundreds of years. One, called bioenergy, refers to the burning of biological materials that otherwise might have just been thrown away or never grown in the first place. These include animal waste, garbage, straw, wood by-products, charcoal, dried plants, nutshells, and the material left over after the processing of certain foods, such as sugar and orange juice. Bioenergy also includes methane gas given off by garbage as it decomposes or rots. Fuels made from vegetable oils can be used to power engines, such as those in cars and trucks. Biofuels are generally cleaner than fossil fuels, so they do not pollute as much, and they are renewable. They remain expensive, and amassing significant amounts of biofuels requires a large commitment of agricultural resources such as farmland.

Nothing is sophisticated about burning garbage. A more sophisticated modern alternative is hydrogen, the most abundant element in the universe. Hydrogen in its pure form is extremely flammable. The problem with using hydrogen as a fuel is separating hydrogen molecules from the other elements to which it readily bonds, such as oxygen (hydrogen and oxygen combine to form water). Hydrogen can be used in fuel cells, where water is broken down into its elements. The hydrogen becomes fuel, while the "waste product" is oxygen. Many scientists regard hydrogen fuel cells as the "fuel of the future," believing that it will provide clean, safe, renewable fuel to power homes, office buildings, and even cars and trucks. However, fuel cells are expensive. As of 2002 a fuel cell could cost anywhere from $500 to $2,500 per kilowatt produced. Engines that burn gasoline cost only about $30 to $35 for the same amount of energy.

All of these power sources have high costs, both for the fuel and for the technology needed to use it. The real dreamers among energy researchers are those who envision a future powered by a fuel that is not only clean, safe, and renewable but essentially free. Many scientists believe that such fuel alternatives are impossible, at least for the foreseeable future. Others, though, work in laboratories around the world to harness more theoretical sources of energy. Some of their work has a "science fiction" quality, but these scientists point out that a few hundred years ago the airplane was science fiction.

One of these energy sources is magnetism, already used to power magnetic levitation ("maglev") trains in Japan and Germany. Another is perpetual motion, the movement of a machine that produces energy without requiring energy to be put into the system. Most scientists, though, dismiss perpetual motion as a violation of the laws of physics. Other scientists are investigating so-called zero-point energy, or the energy that surrounds all matter and can even be found in the vacuum of space. But perhaps the most sought-after source of energy for investigators is cold fusion, a nuclear reaction using "heavy hydrogen," an abundant element in seawater, as fuel. With cold fusion, power could be produced literally from a bucket of water. So far, no one has been able to produce it, though some scientists claim to have come very close.

None of these energy sources is a complete cure for the world's energy woes. Most will continue to serve as supplements to conventional fossil fuel burning for decades to come. But with the commitment of research dollars, it is possible that future generations will be able to generate all their power needs in ways that scientists have not even yet imagined. The first step begins with understanding fossil fuels, the energy they provide, the problems they cause, and what it may take to replace them.

# Hydrogen

## INTRODUCTION: WHAT IS HYDROGEN ENERGY?

Hydrogen, the first element in the periodic table, is one of the most common elements found on Earth and the lightest one known to exist. An estimated 90 percent of the universe is composed of hydrogen. It can be found in nearly everything organic (that is, any material that contains the element carbon except diamond and graphite) and in all living organisms. In its pure gaseous form, hydrogen is odorless, colorless, tasteless, highly flammable, but not poisonous.

Many experts believe that hydrogen could be used as a fuel source to provide energy to the world. In order for this to happen, the gas must be in its pure form. This is problematic because hydrogen bonds (connects or attaches) relatively easily to other elements. In fact, it does not occur as a gas in nature but rather is found in combination with other elements. For example, hydrogen combines with oxygen to form water. Because water is so common, most methods to produce hydrogen gas focus on extracting it from water.

Electrolysis, a process that uses electricity, can separate the hydrogen from the oxygen in water. Photolysis detaches the elements from each other using sunlight instead of produced electricity. It is also possible to make the hydrogen industrially, by using methods such as steam reformation. In all cases, isolating the hydrogen yields a gas that is suitable for use as a fuel source.

Once the hydrogen is in pure form, it can be used several different ways. One use is to make a hydrogen fuel cell that can be used to power electrical generators or vehicles. Another is to

## Words to Know

**Conductive** A material that can transmit electrical energy.

**Electrolysis** A method of producing chemical energy by passing an electric current through a type of liquid.

**Emission** The release of substances into the atmosphere. These substances can be gases, greenhouse gases, or particles.

**Geothermal** Describing energy that is found in the hot spots under the Earth; describing energy that is made from heat.

**Greenhouse gas** A gas, such as carbon dioxide or methane, that is added to the Earth's atmosphere by human actions. These gases trap heat and contribute to global warming.

**Infrastructure** The underlying foundation or basic framework of a system, such as buildings or equipment.

**Off-peak** Describing periods of time when energy is being delivered at well below the maximum amount of demand, often nights.

use hydrogen to power an internal combustion engine (ICE), just like the ICEs that are already used to power cars and other vehicles. Using hydrogen in these ways can have both benefits and drawbacks, all of which are related to economical, societal, and environmental circumstances present in today's world.

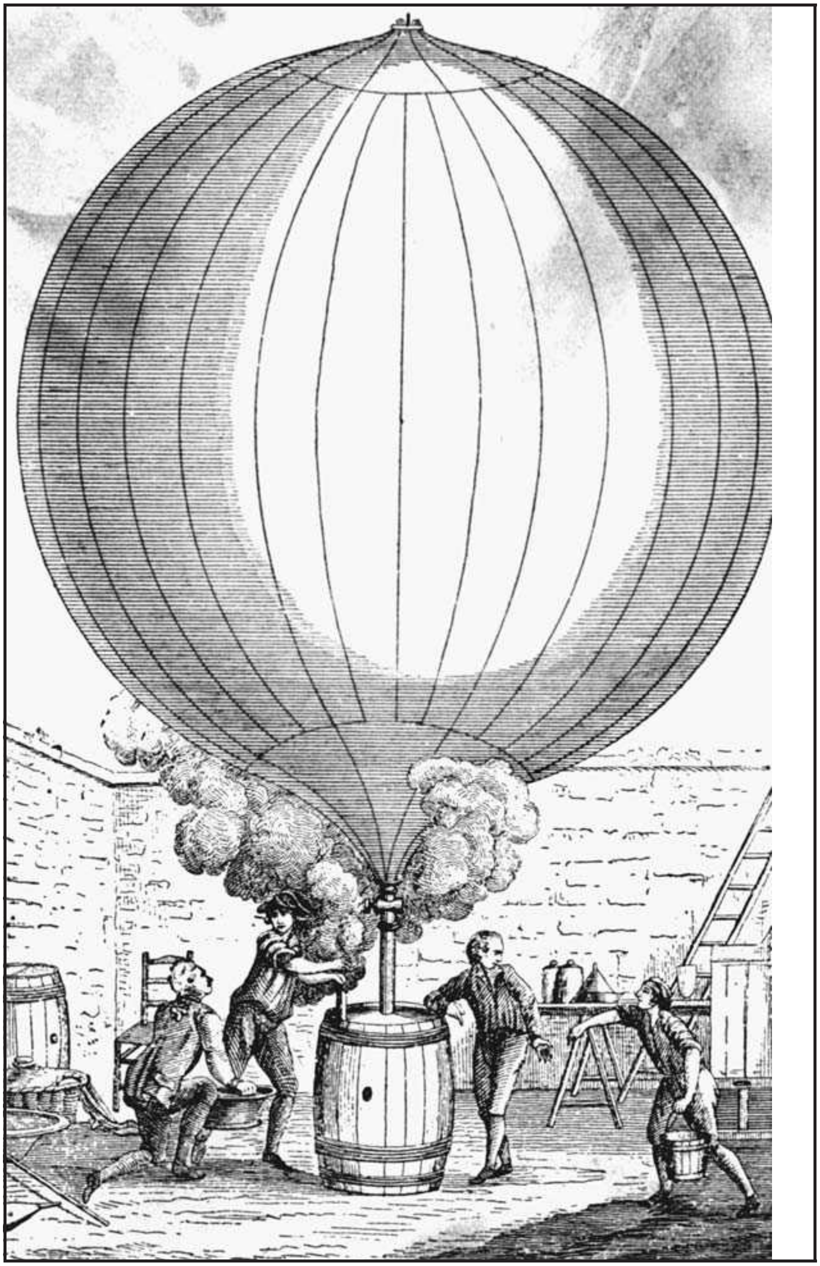
## HISTORICAL OVERVIEW

The use of hydrogen as a fuel source is not a modern notion. Scientists and visionaries have been experimenting with hydrogen since the seventeenth century. Its potential is still being explored in the twenty-first century.

### Finding hydrogen

Hydrogen was first produced as early as 1671, when Robert Boyle (1627–1691), an English chemist, dissolved (mixed or melted) iron in acid. Boyle and other early scientists were unaware that hydrogen was a unique element. In fact, it was not until 1766 that hydrogen was officially recognized as an individual gas. Another English chemist, Henry Cavendish (1731–1810), measured the density of several gases to prove that hydrogen existed. He found that hydrogen was almost fourteen times lighter than ordinary air and called it "inflammable air" (meaning air that is likely to burn or explode).

Following Cavendish's lead, a French scientist named Antoine-Laurent Lavoisier (1743–1794) repeated Cavendish's experiments in 1785 and gave hydrogen its name, from the Greek words *hydro*, meaning water, and *genes*, meaning forming. In addition,



This 18th century engraving shows four men filling a hydrogen balloon in Paris. The gas was produced by pouring sulfuric acid upon filings of iron. © *UPI/Corbis-Bettman.*

Lavoisier's process for isolating hydrogen (a rudimentary form of electrolysis) became the primary method for obtaining hydrogen gas up through the early nineteenth century.

### Hot Air or Hydrogen?

There is often confusion between the first hot air balloon flights and the first hydrogen balloon flights. Hot air balloon flights also originated in France but predated hydrogen flights by only a few months. Two Frenchmen, Joseph (1740–1810) and Étienne (1745–1799) Montgolfier, built a hot air balloon big enough to carry a basket, which in turn carried a duck, a sheep, and a rooster. This balloon's first flight occurred on September 19, 1783, only a few months before Jacques Charles's December flight that same year. The Montgolfier brothers went on to build several hot air balloons, one of which still holds a record as one of the largest balloons ever made. The balloon was flown by Joseph Montgolfier himself in 1784.

After the Montgolfiers' first flight, another Frenchman, Jean Blanchard (1753–1809), and John Jeffries, an American doctor from Boston, crossed the English Channel in a hot air balloon in 1785. Blanchard is also credited with the first hot air balloon flights in Germany, Poland, and the Netherlands. In 1793 Blanchard made a flight from Philadelphia, Pennsylvania, to New Jersey and delivered a letter, which became the first piece of airmail to travel in the United States. The ascent was witnessed by President George Washington, who with other onlookers, had paid Blanchard for the privilege.

#### Hydrogen balloon history

The history of hydrogen balloon flight began in France in December 1783, with the French physicist Jacques Charles (1746–1823). Charles and a companion, Noel Roberts, who helped build the balloon, were the first people ever to ascend in a hydrogen-filled balloon. They traveled 27 miles (43 kilometers) before the balloon came safely to rest. Charles is credited with the first solitary hydrogen balloon flight, during which he rose up 10,000 feet (3 kilometers) before landing again.

#### The first hydrogen fuel cell

In 1839 Sir William Grove (1811–1896) built the first working fuel cell. Grove, an amateur scientist and a Welsh judge, was


The 2005 Honda FCX fuel cell powered vehicle is seen on display during its launch at the Petersen Automotive Museum in Los Angeles on June 29, 2005. © *Mario Anzuoni/Reuters/Corbis.*

aware that an electric current (the movement or flow of electrons) could split a molecule of water into its component parts, hydrogen and oxygen, in a process known as electrolysis. He therefore deduced that, under the right circumstances, he might be able to produce water and electricity by combining hydrogen and oxygen. Grove conducted his experiment by putting strips of platinum into two different bottles, one full of hydrogen and one full of oxygen. He then placed the bottles into an electrolyte (a chemical substance that is capable of conducting current), in this case, sulfuric acid, where current began to flow and water accumulated in the gas bottles. Although Grove's fuel cell did work, he never found a practical use for it, and he never named it. Two chemists, Ludwig Mond and Charles Langer, coined the term *fuel cell* in 1889.

**Moving on to airships**

Airships were introduced in the nineteenth century and became another means of transportation that used hydrogen as a fuel source. Also known as a dirigible, an airship differs from a hydrogen balloon because it has a steering mechanism, often including an engine of some kind. There are three types of airships: a nonrigid airship, or a blimp; a semirigid airship, and a

### What's the Difference Between a Fuel Cell and a Battery?

A battery and a fuel cell are both electrochemical devices that convert chemical energy into electrical energy. The chemical reaction in a battery releases electrons that travel between the terminals and out as electricity. Moreover, when electricity is released from the battery, the battery's stored energy is being used up because the battery is a closed storage system. It can only produce so much energy before it dies and needs to be recharged or replaced. The fuel cell, on the other hand, is more of an energy converter than an energy storage device. Its chemical reaction converts hydrogen and oxygen into water and in the process produces electricity. A fuel cell will provide power as long as it is supplied with fuel. It does not run down or require recharging like a battery. A fuel cell can be refilled with hydrogen like filling an automobile gas tank.

rigid airship (dirigible) or zeppelin, named after the first to build them, Count Ferdinand Adolf August Heinrich Zeppelin. All airships are sometimes known as LTA craft because the gas that provides their lift is lighter than air.

In the early twentieth century airships were used by the militaries of countries such as Germany and Great Britain. Airships also were sometimes used to carry passengers for long-distance travel. When airships were used as a means of transportation, they were often luxurious and expensive. Passengers sometimes boarded the airships to travel across the ocean. When traveling from Europe, for example, a person could reach the United States more quickly than by ocean liner.

One innovative airship that used hydrogen as the means of inflation was called the *Akron*. It was built in 1911 by Melvin Vaniman (1866–1912). The engine that powered the *Akron* could be run on gasoline or hydrogen. A flick of a lever changed which fuel was being used. Unfortunately, the *Akron* never got much use as a passenger carrier.

Germany built the greatest number of hydrogen-filled airships. Some of these airships even traveled around the globe. One of the best known zeppelins was the *Graf Zeppelin*. It began running in 1928 and went around the world twice in 1929 alone. Over its ten-year active lifespan, the *Graf Zeppelin* traveled over one million miles (1,609,344 kilometers). It had no accidents, unlike many other hydrogen airships. In 1937 Hydrogen developed a negative reputation because of a disaster involving another German airship, the *Hindenburg*. International law now bans the use of hydrogen as an inflating gas for airships.

### Syngas

Vehicles were not the only use of hydrogen in the late nineteenth and early twentieth centuries. Hydrogen is part of a fuel called syngas, which is also known as synthetic gas or town gas. Syngas is made up of as much as 50 percent hydrogen. It is made from coal, wood, and some waste that has been gasified (made into a gas). In the United States, syngas was first used as early as the late 1700s. It became a more common fuel in the late nineteenth century and until about 1940. Primarily used in urban areas to provide a fuel for heat and for cooking, it was also used in Europe and other parts of the world in the same time period. In Europe, syngas provided light for city streets, homes, and public buildings. It is still used in parts of China, Europe, and South America, where natural gas is not a fueling option.

### Other twentieth-century research developments

Though some work on hydrogen as a fuel source was done in the nineteenth century, more work was done in the first half of the twentieth century. In the 1920s and 1930s European scientists and engineers experimented with the use of hydrogen as a fuel. Among their accomplishments was converting several types of vehicles to run on hydrogen, including trucks, a bus, and a railcar that was self-propelled.

#### *In planes and space*

Hydrogen did find some uses in aviation and the space program in this time period. Hydrogen was used to fuel a jet engine as early as the late 1950s on an experimental basis. By the late 1980s more research was being conducted in the United States and Russia in the use of plane engines fueled by hydrogen. Some supersonic jets might use hydrogen in the future, if the technology can be developed.

NASA has used hydrogen in various capacities since the 1950s. Hydrogen fuel cells provided power for the manned Gemini and Apollo space flights in the 1960s and 1970s. Fuel cells were used on these craft because they were seen as safer


The Graf Zeppelin approaching the mooring mast at Mines Field (Los Angeles) after completing its trip from Tokyo in 68 hours for the third successful lap of its historic round the world flight. © *Bettmann/Corbis.*

than nuclear power, another option that was considered. Another benefit of using hydrogen fuel cells on these flights was that the by-product of fuel cells—water—could be consumed by the astronauts. Liquid hydrogen has also been used in the space program as a rocket fuel to propel vehicles into space. In addition, space shuttles run by NASA since the 1980s have employed hydrogen as a fuel.

This use of hydrogen led to a tragedy. When a rubber seal failed on the space shuttle *Challenger* as it was lifting off in 1986, hydrogen gas mixed with the flame that was propelling the rocket *Challenger* into space. The mixture caused the space shuttle to explode. There were seven astronauts aboard, all of whom lost their lives.

### *First hydrogen research organization*

There was continued interest in hydrogen as a fuel for other uses in the 1960s and 1970s. In the mid-1970s the modern era of

## The *Hindenburg* Tragedy

In 1937, the German dirigible *LZ 129*, nicknamed the *Hindenburg*, traveled from Germany to the United States with a number of passengers. Including the crew, about 97 people were aboard. When the *Hindenburg* reached Lakehurst, New Jersey, the ship exploded, killing 36 people. Only 13 were passengers. The rest were crew members and one American who was on the ground at the time of the explosion. The investigation into the incident concluded that the hydrogen inside the dirigible probably caused the explosion. Investigators in the 1930s believed that electric discharge from the atmosphere ignited the hydrogen. Because of these findings, hydrogen began developing a negative reputation in the general public's mind.

This reputation was not deserved. Many years later, a scientist named Addison Bain (1935–), who worked for NASA (the National Aeronautics and Space Administration) as manager of its hydrogen program, investigated the *Hindenburg* tragedy. He believed that the *Hindenburg* accident was not caused by the hydrogen exploding. He noted that the outer shell of the dirigible was a cotton cover that was painted with some flammable chemicals to both decorate and reinforce the airship's shell. Bain believed the substances were ignited by the static charges that had built up on the ship's metal frame as a result of a very stormy environment. What had been painted on the dirigible acted like rocket fuel. The resulting explosion caused the disaster.

Bain concluded that the flame color also revealed that the fire could not have been started by the hydrogen. Witnesses from 1937 reported that the flames were colorful. However, hydrogen burns almost clear

hydrogen research began. In this phase, hydrogen was regarded as an energy source to replace fossil fuels. The first international conference was held in Miami Beach, Florida, and was called the Hydrogen Economy Miami Energy Conference. This event led to the founding of the International Association for Hydrogen Energy, an organization that in the 1990s helped get research off the ground and led to a growth of organizations, studies, and research all focused on hydrogen energy.

### Twenty-first century developments

Several countries have put much effort into the study, support, and use of hydrogen as an alternative fuel for the future, including Canada, Japan, Germany, and the United States. Each country has its own vision, but most have pledged at least some public funding. The European Union has also pledged to spend money to help create hydrogen fuel cells through a partnership between

The *Hindenburg* blimp, crashing into metal structure, with its tail and more than one third of body in flames, May 6, 1937. © *Hindenburg, May 6, 1937.*

in the daylight, the time when the incident took place. Despite Bain's findings, many people still believe that the hydrogen exploded and caused the disaster.

government and business. One country in particular, Iceland, has already committed to replacing its oil imports with hydrogen-fueled technology and is currently one of the largest consumers of hydrogen fuel.

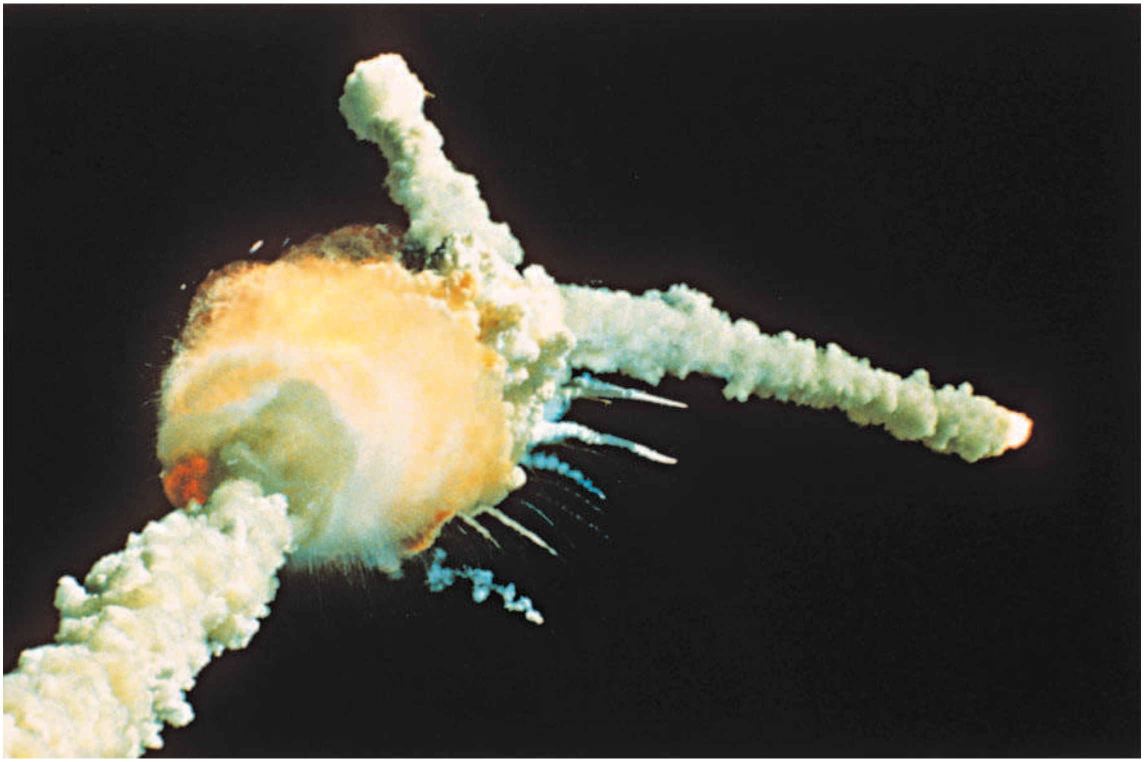
### *Research in the United States*

Most vehicles on the road today are powered by gasoline, which is produced from oil. Because oil will eventually run out, alternatives are needed to fuel vehicles in the future. A significant amount of money from both private and public sources is being invested in the early twenty-first century to develop hydrogen technology for vehicles in the United States. The concentrated movement to embrace hydrogen as an alternative energy began in 1990 with the passage of the federal Clean Air Act. This act called for a reduction in air pollution by changing the design of cars. The act also sought to change the kind of fuels that cars used so that their emissions (the waste by-product that is expelled by each vehicle) would be reduced. In addition, new emission standards were called for. Though hydrogen and other alternative fuels were not named specifically, hydrogen was a technology that was explored as a possible means of meeting this act's goal.

After the passage of the Clean Air Act, California was one state that pursued alternative energy technologies, including hydrogen. The state was especially interested in alternative fuels because the state had a major problem with air pollution. In California, which had about 30 million vehicles on the road as of 2005, about 90 percent of the population live where air quality cannot meet federal standards. California has addressed this problem in several ways. For example, some of the toughest standards for emissions in the United States can be found in California. Another way is through the work of the California Fuel Cell Partnership. This is a group dedicated to making fuel cells and vehicles that run on fuel cells part of American life. The partnership includes the government, companies that make fuel cells, energy providers, and car companies. In addition to educating the public about hydrogen fuel cell technology, the partnership works toward getting hydrogen fuel cell cars on the road and making hydrogen fuel stations available. By 2007 the partnership hopes to have 300 hydrogen fuel cell cars and buses on the road.

In 2002 and 2003 the United States made a significant commitment to embracing hydrogen in the form of fuel cell technology. In 2002, Secretary of Energy Spencer Abraham announced an initiative called FreedomCAR. A partnership between the federal government and U.S. car makers, this initiative pushed for research on hydrogen fuel cell technology. About $500 million was to be spent on this proposal.

President George W. Bush (1946–) built on the proposal in his January 2003 State of the Union address. The president's proposal, called the FreedomCAR and Fuel Initiative, included spending $1.2 billion over five years in research conducted by both the government and private companies, such as car manufacturers, refineries, and chemical companies. The funds were designed to help create fuel cell technology for cars and trucks as well as homes and businesses. The hydrogen to power these cells would be created through electricity production, primarily from next-generation nuclear power plants and electric plants that run on coal. About $720 million of the funds were to go to building the infrastructure (the basic facilities, services and installations) needed to make the hydrogen, store it, and distribute it. Funds



The space shuttle *Challenger* exploding shortly after lifting off from Kennedy Space Center. *AP Images.*

were included specifically to develop new technologies for cars, a significant issue in using hydrogen as a fuel source.

The federal government had a stated goal of putting hydrogen fuel cell cars on U.S. roads by 2010. The government hoped that hydrogen fuel cell cars would be the norm by 2020. The United States also supported the International Partnership for the Hydrogen Economy, which deals with the creation of the hydrogen economy on a worldwide basis. Some scientists and alternative energy supporters were critical of the proposal. Some were not pleased that other alternative energy sources did not receive money. Others were critical of the fact that the proposal still backed energy sources such as coal and nuclear power as the fuel to make the hydrogen. Coal, like oil, will one day run out, and many believe that hydrogen should be made from a renewable resource instead.

### *Japanese research*

The Japanese government is very committed to developing hydrogen-based technologies because the country depends on foreign oil. The Japanese want to lessen or end their need for


The hydrogen genset is capable of producing 114 k VA of power at several voltage levels and is based upon a standard 6.8-liter Ford production engine that has been modified for hydrogen use. © *Reuters/Corbis.*

imported oil through the development of alternative energy sources such as hydrogen. The Japanese government spends several hundred million dollars each year on research into hydrogen fuel and fuel cells. In 2004 alone, the Japanese government spent $268 million on fuel cell research and development.

The Japanese government wants 50,000 cars powered by hydrogen fuel cells to be on the road by 2010. By 2020 the government wants the number to increase to five million. The government also hopes to have 4,000 hydrogen filling stations along Japanese roads by 2020.

### *Research in Canada and Germany*

In the twentieth century Canada spent several decades researching fuel cells—not using hydrogen, but an alkaline electrolyte or phosphoric acid as an electrolyte. Beginning in 1980 and into the late 1990s, the country started to experiment with hydrogen fuel cells. One company, Stuart Energy, promised to build five stations where vehicles could obtain hydrogen fuel by 2005. The Canadian government has pledged $500 million over five years, in the first decade of the twenty-first century, for fuel cell research.

In the 1950s Germany did research into alkaline fuel cells, while hydrogen research blossomed later in the century. By 2003 over 350 groups in Germany were working on hydrogen fuel cell technology.

### *Commitment in Iceland*

Iceland wants to be the first country whose energy system is based on hydrogen. Iceland is a small island of only 40,000 square miles (64,374 square kilometers) near the Arctic Circle. The country's population is fewer than 300,000 people. Iceland's limited space and population make it an ideal place to test whether a hydrogen economy will work. The country decided to embrace hydrogen before the end of the twentieth century, with the goal of being fully hydrogen-based by midway through the twenty-first century.

Icelanders want to be self-sufficient in terms of energy. The country is already capable of producing more than enough of its own energy for heating and cooling purposes. However, because its population uses cars, buses, and ships, Iceland must import oil. This oil accounts for 30 percent of the country's energy consumption. Iceland wants to reduce this figure to zero. To reach this goal, a joint venture company was created in the late 1990s. It is called Icelandic New Energy and includes input from companies including Shell Hydrogen, Norsky Hydro, and DaimlerChrysler. In 2000 the company began creating the infrastructure for production and distribution of hydrogen as fuel. Iceland has already decided that most of its hydrogen energy will come from fuel cells, which will be used in generators and vehicles.

By 2003 Iceland had its first hydrogen retail outlet, a Shell filling station, in its main city of Reykjavik. Hydrogen was produced on site using hydroelectric and geothermal energy to power the reaction. The hydrogen produced there was also being stored and distributed to other locations. Some of the first users of this hydrogen filling station were three public transit buses. These buses look like standard buses, but they are taller because the hydrogen tanks are located on the roof. Iceland has faced some problems with these buses. They must be kept inside at night so they keep warm. Officials do not want to have the water emitted by the fuel cells freeze and damage the cells. While the buses are being gradually introduced, Iceland next wants to get automobiles that run on hydrogen fuel cells to be the standard vehicle of choice. The country expects to introduce such cars in 2006.

Down the road, a bigger challenge will be getting boats and ships to run on hydrogen technology. Most of Iceland's fossil fuel consumption comes from the use of boats for fishing, a staple of the Icelandic economy. Powering boats with fuel cells is more challenging because a trawler (a boat designed to catch fish by dragging large nets), for example, carries a large amount of gasoline and stays at sea for several days. More hydrogen than that would be needed for a trip of the same length. The Icelandic government will have to convince those who use boats to accept hydrogen as a fuel. Iceland wants to run exclusively on hydrogen by 2050.

## PRODUCING HYDROGEN

Hydrogen is sometimes considered to be the energy source of the future, for a few reasons. One reason for this belief is that hydrogen is renewable. Unlike the fossil fuels upon which the world is currently dependent, hydrogen can be produced or "created" and in a short amount of time. There are several methods by which hydrogen can be produced, including, but not limited to, electrolysis and steam reforming.

### Electrolysis

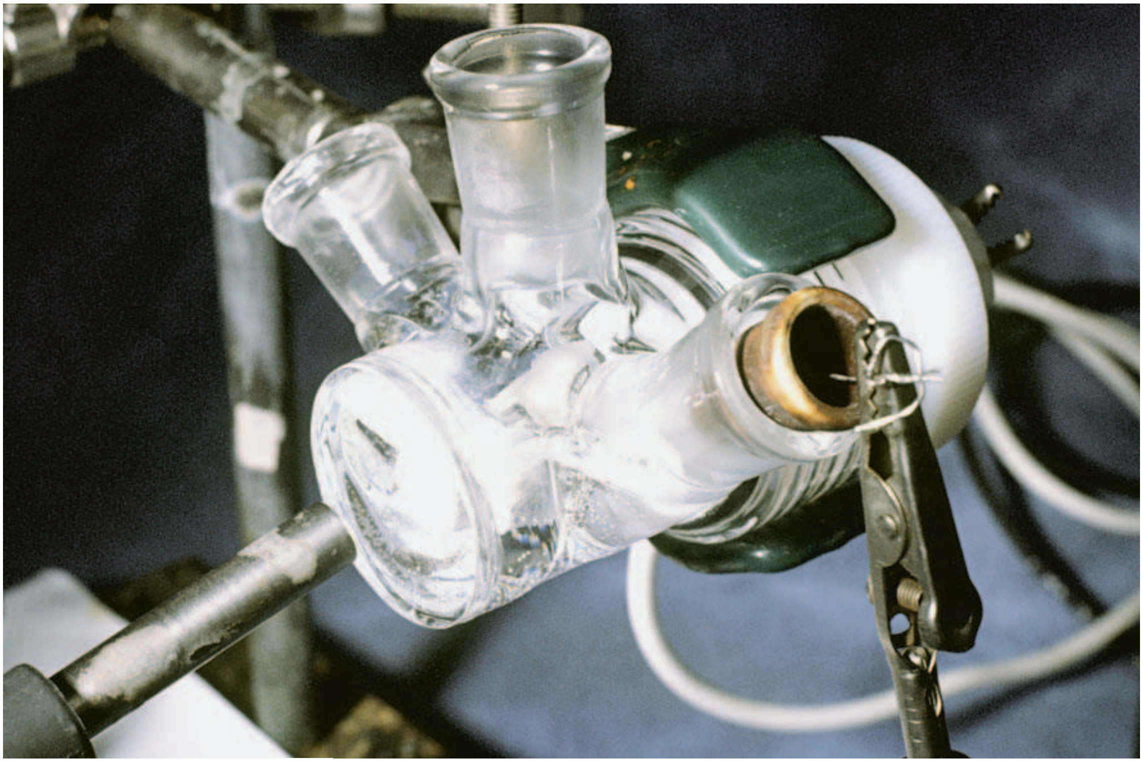
Electrolysis is the process by which an electric current is passed through water and breaks the chemical bonds between hydrogen and oxygen. An electrolyte, a fluid chemical substance that can carry a current, aids in the bond-breaking procedure. Once the bonds are broken, the atomic components (hydrogen and oxygen) become either positive or negative ions (charged particles). Two terminals (anode and cathode) also have positive and negative charges, drawing the resulting ions toward them. Generally, the positive hydrogen ions gather at the anode (which is negative), while the negative oxygen ions reside at the cathode (which is positive). Gas is then formed at either terminal.

It is possible to perform electrolysis at high temperatures. High temperature electrolysis (HTE), also known as steam electrolysis, operates much the same way as conventional electrolysis. The variation occurs in that, rather than using a standard amount of electric current, heat is applied instead. This reduces the total amount of electric energy required to produce hydrogen gas.

### Steam reforming

Steam reforming, sometimes called reforming or steam methane reforming, is another well-known method for making hydrogen. Natural gas is the most common fuel used in steam reforming. To make hydrogen using steam reforming, natural gas is reacted with steam at a very high temperature in a combustion chamber. The temperature can be from 1472°–3982°F (800°–1700°C).

A catalyst (a substance that increases the rate of a reaction without being consumed in the process) is present in some steam reformers. The catalyst is usually made of metal. The catalyst helps



A semiconductor is immersed in the water and splits water molecules using the energy in sunlight. The water molecules split into hydrogen and oxygen gas. Burning the hydrogen in oxygen releases the stored energy and reforms water, completing the cycle. *NREL/U.S. Department of Energy/Photo Researchers, Inc.*

break up the natural gas into methane. When the methane and water react, hydrogen is produced. Carbon oxides such as carbon monoxide and carbon dioxide are made as by-products. In some processes, the carbon monoxide is reacted again to form more hydrogen and carbon dioxide.

The steam reforming process has some positive points. Of all the fossil fuels, natural gas is the cleanest burning. In other words, it gives off fewer by-products that can contribute to pollution. The use of natural gas to make hydrogen might help in the creation of an infrastructure for the distribution of hydrogen. Since there are stations that already distribute natural gas, the natural gas could be transported there and converted to hydrogen via steam reforming on site and on a small scale. This means of production could provide hydrogen for cars that run on either hydrogen fuel cells or hydrogen-powered internal combustion engines.

### Benefits and drawbacks of existing production methods

Each hydrogen-producing method has its own benefits and drawbacks. Electrolysis is considered to be the most environmentally

## Other Production Methods

Scientists from around the world are trying to find the best way to make hydrogen from renewable resources and have come up with many unique ideas. For example, since the 1940s, scientists have worked to use algae (such as pond scum) to make hydrogen. Algae naturally produce hydrogen from water using sunlight energy, a process called photolysis. More recently, a scientist in England, Murat Dogru, proposed that hazelnuts could provide a source of hydrogen, because hazelnut shells produce hydrogen when they are burned.

Bacteria are also being investigated as a way to make hydrogen, but this is not commercially practical yet. Bacteria react like algae in water and can naturally separate the hydrogen and oxygen using sunlight. Experiments are being conducted to alter the structure of the bacteria so that they produce less oxygen and more hydrogen to be used as fuel. Another method of producing hydrogen employs microbes (microorganisms). These microbes are used to make biomass (the leftovers from crops that cannot be used anywhere else) into hydrogen.

Another potential innovation begins with biogas (containing methane, carbon dioxide, water vapor, and other gases) that is caught from the gaseous releases of dairy cows. The biogas is converted to hydrogen and used to power fuel cells. The fuel cells are intended for use in hydrogen-powered generators on the farms. In 2004 scientists working at the University of Minnesota, Twin Cities, discovered a way of taking corn, fermenting it, producing ethanol, and converting it into hydrogen fuel.

friendly procedure, because it produces no by-products that are harmful to the environment. In addition, it has a potentially positive by-product: oxygen. This oxygen could be captured and used elsewhere.

However, large-scale production of hydrogen by electrolysis becomes very expensive because electricity is used to create the electric currents. If renewable energy sources such as solar energy, hydropower, hydroelectric power, or even nuclear power were used to produce the current, the process would become much more affordable. Another source of energy could be obtained through the use of biomass: waste, sewage, and agricultural residue are all endlessly renewable and have little negative effect on the environment.

The steam reforming process is the most common method used to make hydrogen industrially. One benefit is that it is cheaper than producing hydrogen by electrolysis. However, a big drawback is the amount of carbon dioxide produced during the process. If the steam reforming process is to catch on as a means of mass-producing hydrogen fuel, the issue of what to do with the carbon dioxide produced must be addressed. Carbon dioxide can build up and trap heat on the planet. This condition is known as global warming. Potential solutions to the carbon dioxide issue with steam reforming exist, and all are costly. The carbon dioxide could be stored in empty gas wells or oil wells where the reservoirs of gas or oil have been depleted. Saline aquifers, which are underground pockets of saltwater, are another storage possibility. So are coal seams (where coal can be found) that are so deep underground that they cannot be mined.

While the amount of space available to store the carbon dioxide is limited, there is enough space to be able to store the gas produced for many years. However, there is some danger to storing the carbon dioxide. If it mixes with a fresh-water aquifer (underground stream) or gets to the surface, it could change the chemistry of the soil. Even worse, if the carbon dioxide should leave its storage space and end up in a place that is a depression without wind, the gas, which is heavier than air, could start to collect. If enough carbon dioxide collects, it could suffocate animals or people. This tragedy has happened in the past. In 1986 in Cameroon, 1,800 people died after 87 million cubic yards (80 million cubic meters) of carbon dioxide erupted from a volcanic crater.

Another potential problem with steam reforming is that the natural gas needed for the process is available in only a limited supply, like all fossil fuels. Steam reforming produces hydrogen on a large scale, but a method needs to be developed to do steam reforming on a smaller scale so this reaction can take place either on the vehicle or at a filling station that supplies hydrogen.

## USING HYDROGEN

The most commonly researched and most developed application of using hydrogen as a fuel source is in conjunction with a hydrogen fuel cell. Fuel cells operate by mixing hydrogen and oxygen to produce water and electricity. The electricity can then be used to provide power to homes, schools, and even businesses or to power cars and other vehicles. Some experts believe that internal combustion engines (ICEs) that are fueled by hydrogen are just as important. Hydrogen could be used as fuel for transportation by creating internal combustion engines for vehicles that run on hydrogen or hydrogen fuel mixtures.

### Using hydrogen in fuel cells

A fuel cell works sort of like a battery. In hydrogen fuel cells, the hydrogen is converted to electricity through an electrochemical reaction. A fuel cell does not run out of power as long as its fuel, hydrogen, is present. There are several types of fuel cells. Some use phosphoric acid as an electrolyte (a substance that conducts electricity). Others use molten carbonate as electrolytes.

The most common type of hydrogen fuel cell in use is the proton exchange membrane (PEM) fuel cell. General Electric first invented this fuel cell in the 1960s as a source of electrical power for the Gemini spacecraft. Though they were expensive, these fuel cells were efficient producers of energy.

PEM fuel cells are usually stacked when they are used in vehicles. That means a number of identical fuel cells are put together to provide a significant amount of energy. The more fuel cells that are put together, the more voltage created. The number of fuel cells stacked in each vehicle varies by the amount of power needed.

#### *Hydrogen fuel cell vehicles*

While fuel cells were used early in the United States space program, most discussion of hydrogen fuel cells has focused on vehicles such as cars, buses, and vans. Most major car companies around the world are working on fuel cell technology in some form. Each company has produced its own concept cars and is working toward solving the problems related to building such cars on a mass scale. Even a high-end, limited production company like Rolls Royce has researched hydrogen fuel cells for cars. This company is hoping to have a fuel cell–powered hydrogen prototype completed by 2008. Rolls Royce has been working on hydrogen fuel cell research since 1992.

Daimler Chrysler began research on fuel cells in the 1990s. The company's first fuel cell car was introduced in 1994 and called NECAR 1. Many different versions followed, some of which were tested on the road. In 1997 the car company also introduced a fuel cell bus called the NEBUS. This was followed later with the Mercedes-Benz Citaro bus. About thirty of these buses were used on a test basis in cities throughout Europe between 2003 and 2006.

General Motors (GM) has been working on hydrogen fuel cell technology for many years. The company produced its first fuel cell–powered car in 1966. Though this research area was dropped soon after, GM resumed its work on hydrogen fuel cells in the

A Lockheed Martin Atlas IIIB rocket lifts off the foggy launch pad 36B at Cape Canaveral Air Force Station, early February 3, 2005. The Atlas/Centaur upper stage was powered by burning liquid oxygen and liquid hydrogen. © *Thom Rogers/Corbis.*

early 1980s. By the early 2000s GM had about six hundred employees researching fuel cells. The company formed a partnership with Toyota in 1999 to share hydrogen fuel cell research.

Some of GM's experimental vehicles have been used on a limited basis. In 2003 Federal Express agreed to use one of GM's fuel cell vehicles for one year on normal routes to see how it would work. GM has also conducted test runs of one of its hydrogen fuel cell cars, the HydroGen 3. This vehicle contains 200 hydrogen fuel cells and costs


A zero-emission hydrogen fuel cell bus waits at Aldgate bus station on its first day of service in central London, January 14, 2004. The bus emits only water vapor. © *Toby Melville/ Reuters/Corbis.*

about $1 million to build. HydroGen 3s are being used by the federal government in Washington, D.C., on an experimental basis.

Toyota and Honda also have invested in hydrogen fuel cell technologies. Beginning in 1992 Toyota started working on fuel cell hybrid vehicles, coming up with four prototypes. Road testing of one of the company's fuel cell–powered cars began in 2002. These cars were used at the University of California, Irvine, and University of California, Davis.

Honda began its research into this technology in 1989. Its fuel cell vehicles have been tested on roads in the United States since about 1999. One concept car, the Honda FCX, was tested by the city of Los Angeles in 2002. In 2003 this vehicle was certified for commercial use by the Environmental Protection Agency and the California Air Resources Board.

A number of countries are using hydrogen fuel cell–powered buses on an experimental basis. From 1998 to 2000 several hydrogen-powered buses were used in Chicago and in Vancouver, British Columbia, Canada. British Columbia later bought three other buses to use experimentally in the early 2000s. Vancouver had more buses delivered in 2005 for a further three-year experimental run. In London, England, three of these buses began running in 2003.

#### *Fuel cells as generators*

Though most of the media attention has focused on hydrogen fuel cells in vehicles, hydrogen fuel cell–powered generators are already being used in at least 600 buildings around the world. Hospitals, data centers, and office buildings use this technology in their backup generators. Some businesses use these fuel cell generators as part of their source of power. For example, fuel cells provided about 15 percent of the power at a major office building, 4 Times Square, in New York City in 2003.

### Using hydrogen in ICEs

When discussing hydrogen as a fuel source, most of the focus in the twentieth and early twenty-first centuries has been on fuel cells. However, some experts believe that internal combustion engines (ICEs) that are fueled by hydrogen are just as important. One early believer in this vision was German researcher Rudolf Erren. He was concerned with the amount of oil his country imported and the emissions that automobiles produced well before most countries took note of these issues. In 1930 he saw that hydrogen could be used as fuel for transportation. He believed that this hydrogen should be produced by water electrolysis. Erren spent time working on creating internal combustion engines for vehicles that could run on hydrogen or fuel mixtures that included hydrogen.

### How an Internal Combustion Engine Works

An internal combustion engine (ICE) is a vehicle engine in which the combustion of the fuel takes place within internal cylinders. Virtually all cars today use internal combustion engines, with gasoline as the fuel. A hydrogen ICE is not unlike a gasoline-powered ICE. The hydrogen provides power to create the explosions in the engine that power the car. Inside the engine, pistons move up and down within their cylinders. As each piston pushes up, it compresses a mixture of fuel (hydrogen or gasoline) and air. As the piston reaches the top, the combination of fuel and air is ignited by a spark plug. This explosion forces the piston down inside the cylinder. The ignited fuel also turns the crankshaft in the engine, which eventually leads to the wheels of the car turning. The piston again pushes up in the cylinder to make the exhaust from the ignition move out of the valves located at the cylinder's top. After this step, the piston returns to the bottom of its cylinder. This movement allows another mix of air and fuel to fill the cylinder. This mixture comes in through another set of valves. Then the process begins again.

Hydrogen-powered ICEs are intended for use in buses, cars, vans, and other types of vehicles. Although car manufacturers have already created some hydrogen ICEs, there has not been as much focus on the development of hydrogen ICEs as on hydrogen fuel cells. BMW is one manufacturer that has focused primarily on developing a hydrogen ICE. The company began this research in 1978. Since then BMW has developed several kinds of hydrogen ICEs, which use various hydrogen-to-air ratios, depending on the power desired. The company has also explored using liquid hydrogen as opposed to hydrogen's gaseous form. When liquid hydrogen is used, the car does not need to be refueled as often.

Interestingly, most of BMW's hydrogen ICEs can run on gasoline as well as hydrogen. One BMW concept car that can run on either hydrogen or gasoline is called the H2R. This car was introduced in 2005. The engine in this vehicle is very similar to a standard gasoline ICE that BMW uses in another car, the 760i. Though the engine in the H2R can run on hydrogen, it has an efficiency level similar to a traditional engine. Because the engine in the H2R can run on gasoline or hydrogen, the driver has flexibility in fueling. This quality can be especially important if the hydrogen runs out. A tank of hydrogen only lasts about 215 miles on the H2R, much less than a similar tank full of gas. BMW hopes to sell cars using this type of ICE in Europe by 2007 or 2008. The company wants to put them on the market in the United States by about 2010.

Another car company, Ford, has divided its research focus between hydrogen ICEs and fuel cell cars. The company has developed several hydrogen ICE concept cars, including one car called the Model U and a version of the Ford Focus. Ford also has worked on other vehicles that use hydrogen ICEs, including vans and buses. Ford hopes to have 100 such vans in service by 2006. As for its buses, they were first tested at the 2005 Detroit Auto Show, where they were used as shuttles for reporters. In 2006 the company will sell some of these buses to the state of Florida.

### Benefits and drawbacks of existing hydrogen technologies

Each use of hydrogen as fuel has specific benefits and drawbacks. Hydrogen fuel cells are already in use as electrical generators, and they have also been used in the space program. Most experts believe the fuel cell is likely to be the dominant hydrogen technology in the future, not only for electrical generation but also to power vehicles. The only by-product of using a hydrogen fuel cell to power a car is water or water vapor, which exits through the tailpipe. However, hydrogen ICEs are so similar to existing gasoline ICEs that they could be the best first use of hydrogen as a transportation technology for the general public. Also, like fuel cells, hydrogen ICEs do not produce harmful by-products.

#### *Benefits and drawbacks of hydrogen fuel cells*

Hydrogen fuel cells have many good aspects. Fuel cells are very easy to make. They contain no moving parts. This means that there is little maintenance that needs to be performed on each fuel cell. Because they have no moving parts, fuel cells are quiet. Fuel cells are also light and versatile. They can be manufactured big or small and used on a large or small scale. Because they are modular in design, one can work on its own or many can function together as one.

Hydrogen fuel cell-powered cars are very efficient producers of power. They are more efficient than internal combustion engine cars. About 60 percent of the potential energy in hydrogen is made into electricity by a fuel cell. These fuel cell-cars can respond instantaneously to provide fuel when it is needed.

Yet there are several major drawbacks to the development and use of fuel cells. One is the lack of a worldwide standard for fuel cells between manufacturers or most governments. Only one standardization agreement was in place as of 2005. It was between Japan and the European Union. This agreement covered hydrogen fuel cells for automobiles. Because no standards are yet in place, the development of the infrastructure needed to support hydrogen technology has been delayed. Governments and businesses do not want to invest money in creating an infrastructure that could be useless if it does not match the standards that others use.

The cost of the energy produced by a fuel cell is also very high. It costs more per kilowatt produced when compared to a gasoline-powered combustion engine. In 2002 a fuel cell could cost anywhere from $500 to $2,500 per kilowatt produced, while the combustion engine only cost about $30 to $35 for the same amount of energy. The costs for fuel cells have been going down as technology has been developed and improved.

#### *Benefits and drawbacks of hydrogen-powered ICEs*

One positive aspect to hydrogen-powered ICEs is that engineers at car companies are already experienced in the construction of such engines. The engines are similar to gasoline-powered ICEs. These types of ICEs are more familiar to automotive engineers than the technology of fuel cell engines. These vehicles will also be simpler internally than gasoline-powered cars. The catalytic converters and related systems found on gasoline-powered ICEs to clean up the by-products of fossil fuel combustion are not needed if hydrogen is used.

But hydrogen-powered ICEs have several disadvantages. The cars that use this type of engine are not as efficient as fuel cell-powered cars. Hydrogen ICEs can only extract about half of the chemical energy that is contained in a unit of hydrogen as compared to a fuel cell-powered vehicle. The vehicles also need more space to store fuel than gasoline-powered ICEs. These vehicles are built on current fuel tank sizes designed for gasoline or diesel fuel. Because hydrogen is not a very dense gas, the tanks cannot hold very much hydrogen. Therefore, the vehicles cannot travel as far.

### TRANSPORTING HYDROGEN

The form of hydrogen transportation depends on the form of hydrogen being transported. There are different methods for transporting gaseous hydrogen and liquid hydrogen. Most of these

BMW's hydrogen-powered H2R Record Car was styled at its California Designworks USA studio and is powered by a hydrogen-fueled internal combustion engine. © *Ted Soqui/Corbis.*

methods are still being developed and refined; they are not yet in large-scale use.

**Transporting gaseous hydrogen**

In its gaseous form, hydrogen could be transported over a network of pipelines. Pipelines are commonly used today to distribute hydrogen over a short distance for industrial use, but a wider system would have to be introduced if hydrogen becomes the fuel source of choice for vehicles, homes, and businesses. This pipeline system could be similar to the way that natural gas is distributed. The hydrogen pipeline system also would need more compressors than a natural gas system. A small amount of hydrogen that is traveling along the pipeline would have to be used to power the compressors. Some experts believe that one way to address the distribution question is by converting natural gas pipeline systems to hydrogen. These supporters believe that only the seals, the meters, and the equipment at the end of the pipeline would have to be modified to support hydrogen. There are also trucks that transport hydrogen as a compressed gas, but they hold a much smaller quantity than a gasoline tanker.

### Transporting liquid hydrogen

Transporting the liquid form of hydrogen could take many forms. As gasoline is now, hydrogen could be transported via truck, railcar, or ship. This method could be expensive and difficult. It would take about 21 tanker trucks of hydrogen to carry the equivalent of one gasoline tanker because hydrogen has a low density.

### Benefits and drawbacks of hydrogen transport methods

The infrastructure to transport hydrogen does not yet exist. Some experts believe that the questions about how to produce, distribute, and store the hydrogen have to be answered all at once for the infrastructure to be properly implemented. Regardless of which methods are eventually used, it will still cost billions of dollars to create this transportation infrastructure. That cost is one large obstacle to the development of better transportation methods.

## DISTRIBUTING HYDROGEN

At least in the case of hydrogen-powered vehicles, the primary means by which hydrogen would be distributed for public consumption is through a hydrogen filling station. Such a station would be like a gas station, only with hydrogen instead of gasoline. As of 2005 there were only about 100 hydrogen filling stations in existence in the world.

By 2005 the Clean Urban Transport for Europe program was expected to build several hydrogen filling stations in major European cities. Germany is especially committed to building hydrogen filling stations. The German government is helping to pay for the building of the self-sufficient hydrogen filling stations as a step toward the hydrogen economy.

The United States government has also made a commitment to building hydrogen filling stations. In 2004 the U.S. Department of Energy promised to spend $190 million to build gas stations that would offer both hydrogen and gasoline. The money is also intended to support other projects related to the development of the infrastructure needed to support the hydrogen economy. This money will be spent, however, only if private industry will match the amount.

A few hydrogen filling stations already exist in the United States. In 2005 in Washington, D.C., the first hydrogen-gasoline fueling station was opened by Shell. It provides hydrogen for the six fuel-cell cars that General Motors provided to the area. Both the cars and the station were demonstrations to show the potential of hydrogen as a fuel source. The state of California is also committed to building hydrogen filling stations. By 2010 the California government has promised to have 150 to 200 hydrogen fueling stations on the interstate highways in California as part of the California Hydrogen Highway Network. They will be located on all 21 of the state's interstate freeways. Under the California plan, hydrogen filling stations will be found every 20 miles to provide convenient access for consumers.

### Benefits and drawbacks of hydrogen distribution methods

One large benefit to using filling stations to distribute hydrogen fuel is that consumers all over the world already use such stations to fill their gasoline-powered cars. The general public would not need to be educated on the concept of using filling stations for their automobiles.

However, there are drawbacks with this technology. In Europe, for example, the electrolysis system is often employed to convert water to hydrogen at the filling stations. The problem with this kind of filling station is the large amount of electricity needed to make the conversion possible. Electricity is expensive, and current electricity generation depends heavily on fossil fuels. In Germany, experiments are being conducted to use wind as a source of electricity for on-site electrolysis at filling stations. In the United States, wind-driven on-site electrolysis at filling stations is not seen as feasible in most parts of the country. Instead, biomass is the method being examined. In this process, waste from logging and lumber as well as leftover crop plants is used to produce the electricity needed.

In addition to working on the technology behind hydrogen filling stations, governments and companies have to build the stations. The cost will be enormous, and many governments have pledged funds for this to happen.

## STORING HYDROGEN

Hydrogen is usually stored as a liquid, though it can also be stored as a gas or a solid. Because hydrogen is low in density, storing it is a challenge. This is true both for storage at hydrogen production sites as well as on vehicles that might use hydrogen as a fuel. Among the methods for storing hydrogen are the following:

- Compressing it into cylinders of various sizes. This is one of the most common ways to store hydrogen for industrial use.
- Using compressed gas tanks for vehicles. Many automotive manufacturers and researchers have been experimenting with these tanks. Instead of cylinders, hydrogen would be pumped into a compressed gas tank on the car and stored there.
- Storing liquid hydrogen cryogenically (at very low temperatures).

### Benefits and drawbacks of storage options

Storage of hydrogen on vehicles is a major concern. Some scientists believe that the storage of hydrogen on cars is the biggest single problem facing the use of hydrogen as a fuel for cars. Vehicles have very limited space for storing hydrogen, and the amount that needs to be stored for hydrogen to be a viable fuel source is rather large.

As mentioned, hydrogen is usually stored as a liquid. However, liquid hydrogen has many drawbacks. For example, liquid hydrogen has to be stored at temperatures at or below −423°F (−253°C). To keep the liquid this cold requires a significant amount of energy. The system also must be insulated. Also, even if liquid hydrogen is stored at the right temperature, about three to four percent is boiled off daily. This situation could be a problem for vehicles that are not being used for a few days at a time.

Because of the low density of hydrogen, the amount of hydrogen that can be compressed into a cylinder is less than more dense substances. This problem means that compression has a significant energy cost and an economic expense. The cylinders also must be transported from the place the hydrogen is manufactured to the market where it is needed.

The same drawback hinders compressed gas tanks on vehicles. As of 2005 most compressed gas tank systems can only carry about 5,000 pounds per square inch (psi) of hydrogen. For the ideal range for a car, researchers hope to develop a tank system that offers 10,000 psi. For now compressed gas tanks are large and hard to fit onto a car. They are also made from materials that are both heavy and expensive. One such material is carbon fiber. There are also safety concerns for hydrogen compressed gas tanks. To be safe, they must be able to withstand a very powerful impact. This is a goal that has not been fully reached in a workable manner.

## IMPACTS

Using hydrogen as an alternative energy source would have numerous impacts. Perhaps the biggest would be in the environmental arena, as the development of hydrogen-powered vehicles could drastically reduce the pollution that contributes to global warming, depending on the production method. In addition, because the fossil fuels that currently are used for most of the world's power will one day run out, society will need to find alternative energy sources to power its homes, businesses, and transportation needs. Hydrogen can be an important part of this alternative future. However, not all of the potential impacts are positive ones.

### Environmental impact

Much of the impact of adopting hydrogen as an energy source would be positive for the environment. The use of hydrogen would likely come with a reduction of the use of fossil fuels as energy sources. With this reduction would perhaps come a reduction in global warming, because fossil fuel use is believed to be an important contributor to global warming.

However, the production of hydrogen can potentially affect the environment in a negative way. Depending on the production method, carbon dioxide and other negative emissions can enter the atmosphere while hydrogen is being made. This issue can be addressed by catching and storing the carbon dioxide, but even this storage can potentially affect the environment. However, if environmentally friendly, renewable resources such as solar or wind are used to power the means of producing hydrogen, the negative impact can be eliminated.

Another potential problem is that if hydrogen becomes widely used, it could leak into the atmosphere. If the amount is significant enough, this hydrogen could change the percentage of hydrogen present in Earth's atmosphere. Some scientists believe that this could have a profound effect on the atmosphere, including increasing the size of the hole in the ozone layer. More hydrogen in the atmosphere could also lead to more high altitude clouds and increase the number of soil microbes that rely on hydrogen as their primary nutrient. The soil microbe increase could change the ecology of Earth. However, there are soil micro-organisms that consume hydrogen as well, and they might be able to balance these problems out. The outcome of putting more hydrogen in the atmosphere is uncertain.

A final environmental question is what to do with the water or water vapor that would be produced by cars using hydrogen fuel cells. Since such water is pure, it will freeze in temperatures below 32°F (0°C). Scientists will have to come up with a solution for this by-product on the roadways and the environment in colder climates.

### Economic impact

Adopting a hydrogen-based economy could lead to an extreme change in a number of industries. The way the automotive business would be run would change completely as these companies focused on building cars, trucks, and buses that use hydrogen instead of gasoline. The oil/petroleum business would suffer at some point as the use of hydrogen creates less dependence on oil. The adoption of hydrogen could also impact the electric industry, especially if electrolysis is widely adopted as a means of producing hydrogen.

Whole new industries would also be created as the infrastructure needed to support hydrogen is put in place. The production, transportation, distribution, and storage of hydrogen could have a huge economic impact as billions of dollars would be invested around the world to create the infrastructure for the hydrogen economy. As this infrastructure is put in place, those who could fix and maintain hydrogen filling stations, production plants, generators, vehicles, and other such hardware would be needed. This would create new jobs and businesses.

Automotive manufacturers in 2005 expect hydrogen-powered ICE cars to hit the marketplace within five to ten years. Because the public might embrace hydrogen-powered ICEs more easily than fuel cell-powered cars, some observers believe that if these kinds of vehicles can get on the market, the hydrogen economy can grow rapidly. The spread of cars with hydrogen ICEs would create a demand for hydrogen fuel and a place to buy it.

The development of hydrogen fuel cells would also have an economic impact. In addition to creating an industry for the production of fuel cells themselves, the manufacturing processes used for vehicles, generators, and other products that use fuel cells would change.

### Societal impact

The implementation of the hydrogen economy would affect society worldwide. In countries that are already developed, such as the United States and Great Britain, sources of power and the way vehicles run and even sound would be different. Fueling cars would also be a somewhat different experience than it is right now.

Hydrogen could also change the way the whole power grid works. Currently, developed countries receive their power from centralized power stations. These stations produce the electrical power from fossil fuels of one kind or another and then send the power through wires to individual businesses and homes. If a power station goes out, all the homes and businesses connected to it on the grid also go out. In a hydrogen-based system, individual fuel cell sites could generate electricity for homes and businesses independently. If the overall power grid were to become less centralized, it would be less vulnerable to terrorist attacks aimed at crippling a nation's energy supply.

Even hydrogen fuel cell–powered vehicles might act as small generators and provide power for others when they are not in use. The cars would be plugged into something like wall sockets. The fuel cells on the cars could power the local electrical power grid, instead of the grid providing electricity. According to one estimate, only 4 percent of hydrogen fuel cell-powered cars working in this fashion could provide enough power for an entire city.

The impact of major hydrogen use would be even greater on countries that were underdeveloped or undeveloped. Especially if hydrogen is made with a renewable fuel resource such as solar or wind power, energy could be easily accessible to every country on Earth. Developing countries would have better, easier access to electricity and other forms of energy. They could make their own hydrogen energy rather than importing oil to use in generating electricity. The hydrogen economy could better the lives and economies of everyone as local industries spring up, jobs are created, and opportunities abound for social and economic improvement.

In addition to making the United States and other countries less dependent on nonrenewable sources of energy such as oil, hydrogen fuel cell-powered cars in particular could affect noise pollution. Because fuel cell-powered vehicles are very quiet, the familiar sounds of gasoline-powered internal combustion engines would be gone. Urban noise pollution in particular would be greatly lessened, providing a more peaceful environment.

On the other hand, there are a number of safety issues related to the implementation of hydrogen. One problem is that when hydrogen burns, the flame is invisible. In other words, the fire produced by hydrogen is hard to see. The gas itself can also leak out without being detected. Any build up of gas could lead to dangerous explosions, because, although hydrogen is very light weight, is diffuses rapidly. These issues have to be addressed. The first problem could be solved by adding something to the gas so it burns in a way that people can see. One way to solve the second problem is by creating warning instruments that can detect hydrogen gas leaks in the container or the supply chain. Also, colorants can be added to the hydrogen so that the leaks are more easily noticed.

## FUTURE TECHNOLOGY

The future of hydrogen as a fuel source might include power plants based on hydrogen technology. Other means of transportation might also benefit from the use of hydrogen as a fuel. For example, planes could take advantage of the fact that hydrogen weighs less than conventional fuels.

Some researchers believe that hydrogen fuel cell-powered generators will be implemented before cars using that technology become widespread. In a 2004 article in *Scientific American,* Matthew L. Wald noted, "Although most people may have heard of fuel cells as alternative power sources for cars, cars may be the last place they'll end up on a commercial scale." Instead, Wald and others believe that consumer products such as laptop computers, video cameras, and cell phones could be among the first items to be powered by hydrogen fuel cells. Fuel cells are also expected to provide electricity for homes and businesses. Hydrogen fuel cells could potentially provide a source of electric power for electric utilities and in power plants.

For hydrogen fuel cells to become a cornerstone of the hydrogen economy, technological advances must make them cheaper to produce and more powerful when in operation. For example, scientists are working on ways to lessen the need for the platinum catalysts used in PEM fuel cells. Platinum is an expensive precious metal that can add to the cost of building a fuel cell.

## CONCLUSION

There are many technological and economic hurdles to adopting hydrogen as an alternative energy source. Still, many experts believe that hydrogen will be the primary energy source of the twenty-first century and beyond. Perhaps more than any other alternative technology that currently exists, hydrogen has the potential to replace our dependence on fossil fuels with a clean source of energy that will never run out.

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# Nuclear Energy

## INTRODUCTION: WHAT IS NUCLEAR ENERGY?

Nuclear energy is energy that can be released from the nucleus of an atom. There are two ways to produce this energy, either by fission or fusion. Fission occurs when the atomic nucleus is split apart. Fusion is the result of combining two or more light nuclei into one heavier nucleus. Most often, when people discuss nuclear power, they are talking about nuclear fission. Power production from fusion is still in its infancy.

Atoms are made up of several parts: protons, neutrons, electrons, and a nucleus. A nucleus is the positively charged center of an atom. Protons are positively charged particles, and neutrons are uncharged particles. Electrons orbit around the nucleus and are negatively charged. Fission can occur in two ways — first, in some very heavy elements, such as rutherfordium, the nucleus of an atom can split apart into smaller pieces spontaneously. With lighter elements, it is possible to hit the nucleus with a free neutron, which will also cause the nucleus to break apart.

Either way, a significant amount of energy is released when the nucleus splits. The energy released takes two forms: light energy and heat energy. Radioactivity is also produced. Atomic bombs let this energy out all at once, creating an explosion. Nuclear reactors let this energy out slowly in a continuous chain reaction to make electricity. After the nucleus splits, new lighter atoms are formed. More free neutrons are thrown off that can split other atoms, continuing to produce nuclear energy. The first controlled nuclear reaction took place in 1942.

### Nuclear fission

Since at least the 1920s, scientists had believed that it might someday be possible to produce energy by splitting atoms. They

## Words to Know

**Critical mass** An amount of fissile material needed to produce an ongoing nuclear chain reaction.

**Decay** The breakdown of a radioactive substance over time as its atoms spontaneously give off neutrons.

**Enrichment** The process of increasing the purity of a radioactive element such as uranium to make it suitable as nuclear fuel.

**Fission** Splitting of an atom.

**Fusion** The joining of atoms to produce energy.

**Meltdown** Term used to refer to the possibility that a nuclear reactor could become so overheated that it would melt into the earth below.

**Pile** A mass of radioactive material in a nuclear reactor.

based this belief on their growing understanding of the physics of the atom. They knew that atoms contain energy, and they believed that by "splitting" the atom, or breaking it apart, they could release that energy. The process would come to be called nuclear fission.

An atom is made up of three kinds of particles: neutrons, protons, and electrons. Two of these particles, neutrons and protons, are found in the nucleus, or center, of an atom. A neutron does not have an electrical charge. It is called a neutron because its electrical charge is neutral. A proton has a positive electrical charge. Circling around the nucleus of an atom in layers are electrons, which have a negative electrical charge. To keep the overall electrical charge neutral, an atom has to have the same number of protons and electrons. Positive and negative electrical charges attract each other. The charges bind the particles of an atom together. When an atom is split, some of this energy is released.

The atoms of different elements have different numbers of particles. Some elements are very simple and light. Hydrogen is the simplest and lightest element because it has only one proton, one electron, and no neutrons. In contrast, the heaviest element in nature is uranium. (Some heavier elements have been artificially produced in laboratories, but these elements do not exist in nature.) Uranium atoms contain ninety-two protons and ninety-two electrons. The number of neutrons can vary, depending on the isotope of uranium under consideration. An isotope is a "species" of an element. It contains a different number of neutrons from other isotopes of the same element. Generally, uranium nuclei contain either 143 or 146 neutrons.

### Spontaneous Fission

Some elements, including uranium, undergo fission spontaneously, or on their own, as neutrons break away from the atom. These elements are said to be radioactive because they release subatomic particles and energy. This spontaneous fission is generally a very slow process. Scientists use the word *decay* to refer to the breakdown of a radioactive substance over time as it releases its neutrons.

For nuclear energy, uranium is the most important element. Uranium is used as fuel to produce nuclear reactions. It makes a good fuel source because uranium atoms are so big and heavy. They are easier to break apart. These large atoms can be thought of as a house built with playing cards. The house becomes increasingly unstable as cards are added, and is more likely to fall apart the bigger and heavier it gets. In a nuclear power plant, the goal is to create fission from uranium fuel and to be able to speed the reaction up (or slow it down) to control the amount of energy being produced.

## HISTORICAL OVERVIEW: NOTABLE DISCOVERIES AND THE PEOPLE WHO MADE THEM

Scientists such as Enrico Fermi (1901–1954) noticed that the free neutrons in elements such as uranium bombard other uranium atoms. This bombardment causes the other atoms to split and release additional neutrons. These additional neutrons then bombard other atoms. The process continues in a chain reaction, or a reaction that keeps going on its own. A neutron in this way can be thought of as similar to a cue ball on a pool table. The cue ball bombards the cluster of balls at the other end of the table, causing the cluster to break apart. All the balls then bounce around, bumping into one another, causing further collisions, and so on.

Fermi had conducted experiments in nuclear fission in 1934 while he was still living in Rome, Italy. He had bombarded uranium with neutrons and discovered that what was left over afterwards were elements that were much lighter than uranium. This led him to believe that the uranium atoms had been split. The mass number of the leftover elements was smaller, so the uranium must have transformed into different elements as it broke down. In 1938

## The Periodic Table of the Elements

Elements are the fundamental building blocks of nature. Each box in the Periodic Table of the Elements provides basic information about the size and weight of each element. It arranges the elements from lightest to heaviest. It also arranges them into families that share some important characteristics. Each element has a name and a chemical symbol. In the case of uranium, the symbol is simple, U. The symbols for some elements seem strange. The symbol for lead, for example, is Pb because the symbol is taken from the Latin word for lead, *plumbum.*

The periodic table also contains each element's atomic number and atomic weight. The atomic number is found in the upper left-hand corner of the element's box. It specifies the number of protons in the element's nucleus. Thus, it is equal to the number of electrons. The atomic number for hydrogen is 1, for uranium, 92.

At the bottom center of each box is the element's atomic weight. Atomic weight is a little more complicated. Basically, it represents the combined total of protons and neutrons in the nucleus, called the mass number. But the atomic weight of uranium is given as 238.02891 rather than just 238. The reason for the digits to the right of the decimal point is that many elements, including uranium, occur in different isotopes.

Uranium, for example, has sixteen different isotopes, though only three are found with any frequency. These isotopes are $U_{234}$, $U_{235}$, and $U_{238}$. (Sometimes scientists write these differently, as $^{234}U$ and so on or U-234.) While the number of protons and electrons in a given element is always the same, the number of neutrons can vary, producing different isotopes. This accounts for the different atomic weights (234, 235, and 238 for uranium). For uranium and other elements, the odd digits to the right of the decimal point occur because on the Periodic Table scientists provide a weighted average of the different isotopes. Therefore, the number may not be a whole number. As a practical matter, the atomic weight figure can be rounded off to the closest whole number.

German scientists Otto Hahn (1898–1968) and Fritz Strassman (1902–1980) conducted a similar experiment. They discovered that what was left over after bombarding uranium with neutrons

## The Italian Navigator

In December 1942 a message was sent to a number of high officials in the U.S. government. The message was written in code because at the time, the United States was at war and the authorities wanted to keep the contents of the message secret. The message read: ''The Italian navigator has just landed in the new world.''

The ''Italian navigator'' was physicist Enrico Fermi. Fermi had left his native Italy for the United States in 1938 because he saw the storm clouds of World War II (1939–1945) gathering over Europe. ''The new world'' referred to the successful outcome of an experiment. The experiment was conducted by Fermi and a team of researchers at the University of Chicago. On December 2, 1942, in a squash court under the athletic stadium, Fermi oversaw the world's first controlled nuclear reaction. On that date, humanity did indeed land in a new world, the world of nuclear energy.

was the much lighter element barium. This experiment confirmed that the uranium atoms had split.

Other scientists such as Lise Meitner (1878–1968) from Austria and Niels Bohr (1885–1962) from Denmark arrived at similar results. But they also made a startling discovery. When the atomic weights of the by-products of their experiment were added together, something was missing. If every piece of a broken window is swept up and weighed, the total weight of the pieces should be the same as the weight of the original window. Scientists expected that the same principle would apply to atoms. If atoms broke down because of fission, the atomic weight of the new elements formed, when added together, should be the same as the atomic weight of the original uranium. But Meitner and Bohr found that the elements in the reaction lost mass. Some of the mass had changed to energy. In this way they proved the truth of the famous equation from Albert Einstein (1879–1955), $E = mc^2$. This equation says that energy (E) is equal to mass (m) multiplied by the speed of light (c) squared. Mass, or matter, could be converted into energy.

None of these experiments produced a chain reaction, or a continuing fissioning of atoms. However, in 1942 Fermi thought of a way to create such a chain reaction. He took 40 tons of

## Lise Meitner

Lise Meitner's contributions are often overlooked in the history of nuclear power development. As a woman, Meitner was barred from higher education in her native Austria until 1901, when she began studying physics at the University of Vienna. After she completed her doctorate in 1907, she worked with the famous German physicist Max Planck (1858–1947) and chemist Otto Hahn.

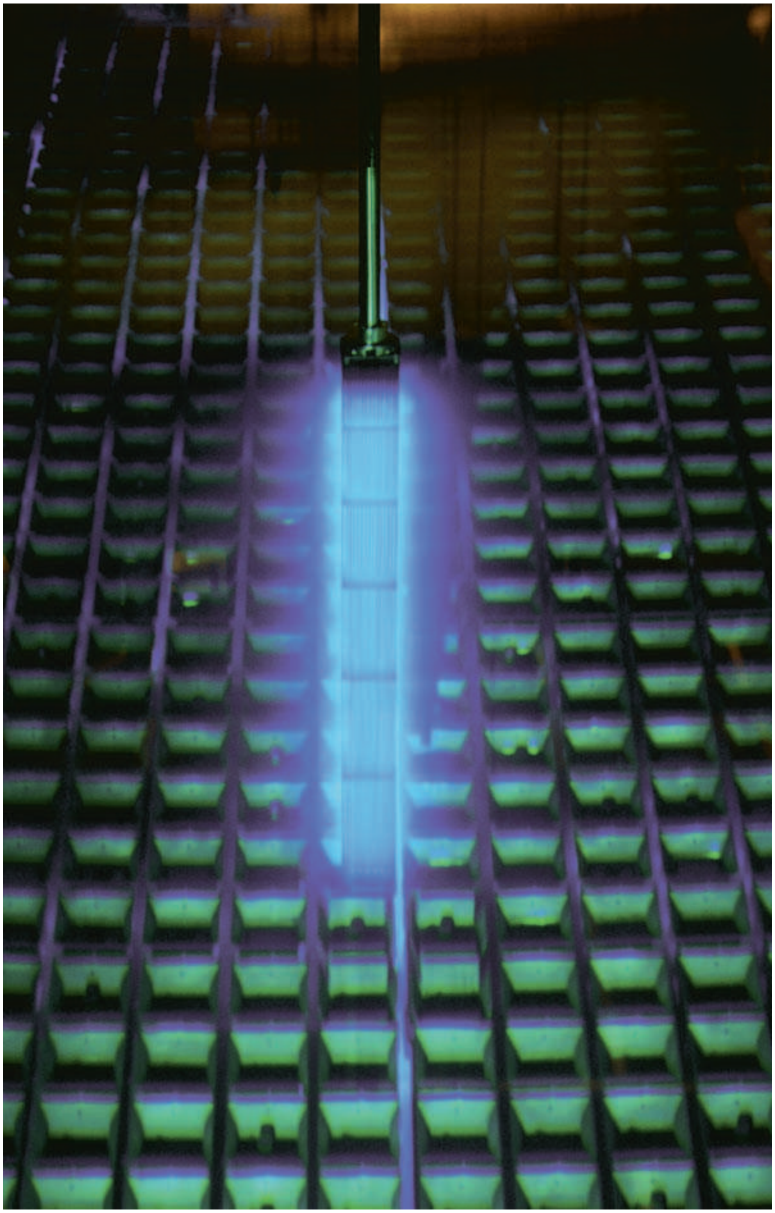
Meitner was born into a Jewish family. Although she had converted to Christianity, she was still driven out of Austria and Germany after the Nazi regime took power. She settled in Stockholm, Sweden, where she continued her work on radioactivity. There she worked with Hahn and Strassman. She and another physicist, Otto Frisch (1904–1979), actually coined the phrase ''nuclear fission.''

One of science's worst scandals took place in 1945. That year, Otto Hahn was given the Nobel Prize in Chemistry for the discovery of nuclear fission. The contributions of Lise Meitner were entirely ignored. While such names as Planck, Fermi, Hahn, Einstein, and others were famous in the scientific community, Meitner's name was largely forgotten. Later scientists acknowledged her important role, and in 1966 she was awarded the U.S. Fermi Prize in Physics.

uranium, a nuclear "pile," and surrounded it with 385 tons of graphite blocks to contain the uranium. (A "pile" of nuclear materials is not literally a pile. "Pile" refers to a quantity of nuclear materials in a nuclear reactor.) This would provide him with the "critical mass" needed to produce an ongoing atomic reaction.

Fermi's main concern was to make sure that the reaction did not get out of control. A controlled chain reaction produces a flow of energy, but an uncontrolled chain reaction produces an explosion. Fermi needed a way to make sure that he did not blow up Chicago by letting his planned reaction get out of control. The graphite blocks would help, but he also inserted rods made of cadmium, a soft bluish-white element, into the pile. Cadmium absorbs neutrons, so it can keep nuclear fission reactions under control.

On that December afternoon in 1942, Fermi and his team slowly pulled a few of the cadmium rods out of the pile. Now some of the



A spent nuclear fuel rod in a cooling pond glows a bright blue. Once the rods are used up, they are hot and radioactive. Water-filled pools are sometimes used to cool and store the fuel rods. © *Tim Wright/Corbis.*

spontaneously released neutrons in the uranium could bombard other uranium atoms. Each collision produced an average of 2.5 new free neutrons, which in turn bombarded other atoms, releasing 2.5 more free neutrons, and so on. More rods were slowly pulled out, and the pace of the reaction increased. When rods were pushed back in, the reaction slowed as the cadmium soaked up

### The World's First Nuclear Reactor

Enrico Fermi is credited with building the world's first nuclear reactor. Strictly speaking, this is only partially true. He actually built the first ''artificial'' nuclear reactor. In 1972 a team of French scientists came across an old mine in West Africa. Inside they found some uranium ore. In this ore they found concentrations of $U_{235}$ of 0.4 percent. But the concentration of $U_{235}$ in uranium ore found in nature is always 0.72 percent. By analyzing the trace elements in the ore, the scientists concluded that the amount of $U_{235}$ was less than normal because a chain reaction had occurred. In other words, a naturally occurring nuclear reactor had developed in the mine. The scientists estimate that the reaction occurred more than two billion years ago over a period lasting about 600,000 to 800,000 years.

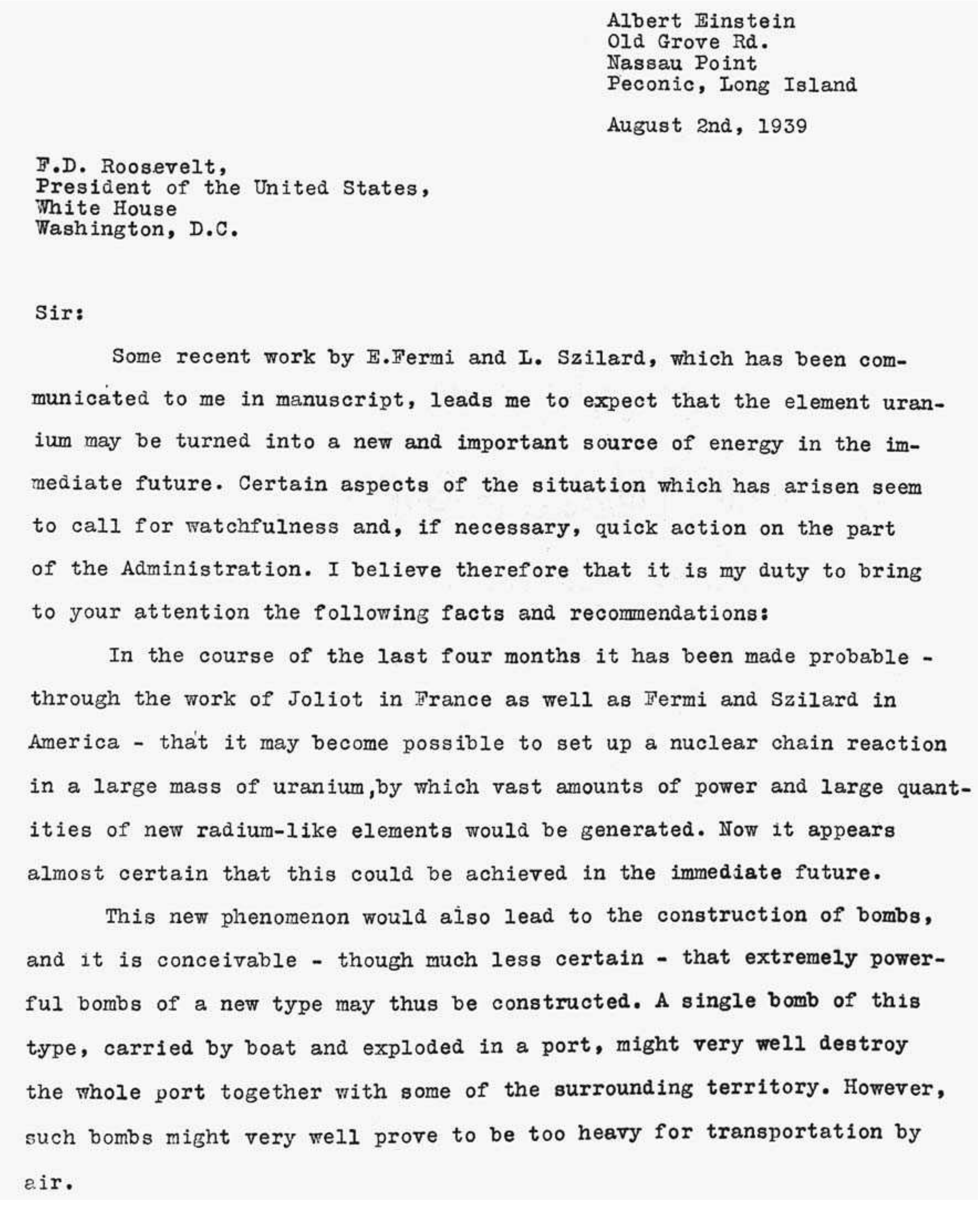
neutrons. Chicago did not blow up, and Fermi had created the world's first nuclear reactor.

#### From the Manhattan Project to Atoms for Peace

Fermi conducted his successful experiment almost exactly one year after the Japanese attacked the U.S. naval base at Pearl Harbor, Hawaii, on December 7, 1941. This event pulled the United States into World War II. The war had begun in September 1939, when German dictator Adolf Hitler (1889–1945) ordered his troops to invade Poland. In the years that followed, Germany occupied much of Europe. Meanwhile, the Japanese empire was spreading throughout Asia and the Pacific.

Most of the leading scientists involved in nuclear research were from Germany. U.S. policy makers learned that German scientists were trying to develop an atomic bomb, a bomb whose enormous destructive force would come from an uncontrolled fission reaction. Such a bomb in the hands of Germany could have changed the outcome of the war. Thus, American policy makers developed a plan for the United States to create such a bomb first. This is the reason for the secrecy surrounding the message informing the government that Enrico Fermi's experiment had been successful.

The research program to develop the bomb was the Manhattan Project. (The name Manhattan has no particular meaning. The



Albert Einstein
Old Grove Rd.
Nassau Point
Peconic, Long Island

August 2nd, 1939

F.D. Roosevelt,
President of the United States,
White House
Washington, D.C.

Sir:

Some recent work by E.Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and, if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to your attention the following facts and recommendations:

In the course of the last four months it has been made probable - through the work of Joliot in France as well as Fermi and Szilard in America - that it may become possible to set up a nuclear chain reaction in a large mass of uranium,by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.

This new phenomenon would also lead to the construction of bombs, and it is conceivable - though much less certain - that extremely powerful bombs of a new type may thus be constructed. A single bomb of this type, carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by air.

First page of a letter dated August 2, 1939 from Albert Einstein to President Roosevelt discussing the possibilities and implications of nuclear research. © *Corbis.*

branch of the army that oversaw the project was based in Manhattan, New York.) Beginning in 1943, the nation's top scientists, many of them from top-ranked universities, came to Los Alamos, New Mexico. The brilliant physicist J. Robert Oppenheimer (1904–1967) directed the research. They worked in shacks and lived in primitive conditions, all the while keeping their work top secret.

Continuing the research of Fermi and others, the scientists succeeded in building an atomic bomb, which they tested in the New Mexico desert on July 16, 1945. By this time, though, Germany had surrendered and the war in Europe was over. The war continued to rage in the Pacific as the United States and its allies fought the determined Japanese empire. During the final months of the war with Japan, both countries lost large numbers of troops in bloody island battles, such as those on the Japanese island of Iwo Jima. The Japanese were defeated, but the nation refused to surrender. To put a quick end to the war, the United States released an atomic bomb over the Japanese city of Hiroshima on August 6, 1945. A similar bomb destroyed Nagasaki three days later. Together, the two bombs immediately killed over one hundred thousand people, and many more would later die as a result of burns and radiation sickness. Faced with such a destructive weapon, the Japanese finally surrendered.

The decision to use the atomic bomb was highly controversial. Many U.S. policy makers urged use of the bomb as a way to save the lives of U.S. (and Japanese) troops, who faced the possibility of a difficult invasion of Japan. Others, including many nuclear scientists, believed that using the bomb would cause too much destruction and death. Many believed that it was just a matter of time before Japan would surrender.

After the Soviet Union developed its own atomic weapons, the world's two superpowers began to stockpile them. They accumulated far more nuclear weapons than would ever be needed to defeat the other side. In the 1950s and beyond, the world lived in fear that a nuclear war would erupt, with devastating consequences. Scientists, though, searched for peaceful ways to use nuclear energy. On December 8, 1953, U.S. president Dwight D. Eisenhower (1890–1969) addressed the United Nations. In his speech, he outlined the "Atoms for Peace" program. He suggested that atomic development and research be turned over to an international agency and that research be conducted to find peaceful uses for atomic energy. This speech gave a major push to efforts to harness atomic energy for the benefit of humankind rather than as a weapon.

### Atomic energy development

Those efforts had already begun in the United States. In 1946 the government created the Atomic Energy Commission. Its job was to oversee the development of nuclear power. One of its first steps was to authorize the development of Experimental Breeder Reactor I in Arco, Idaho. On December 20, 1951, the reactor produced the world's first electricity fueled by nuclear power, lighting four 200-watt light bulbs. On July 17, 1955, Arco, home to one thousand people, became the world's first town to be powered by nuclear energy.

Until this time, nuclear energy had been firmly under the control of the military. The first civilian power plant began operating in Susana, California, on July 12, 1957. The world's first commercial-sized nuclear power plant reached full operating power in 1957 in Shippingport, Pennsylvania. (Most nuclear power plants, for safety reasons, operate at about 70 to 90 percent of their maximum capacity.) Meanwhile, on July 14, 1952, the keel had been laid for the world's first nuclear-powered submarine, the *Nautilus*. On March 30, 1953, the sub powered up its nuclear generators for the first time.

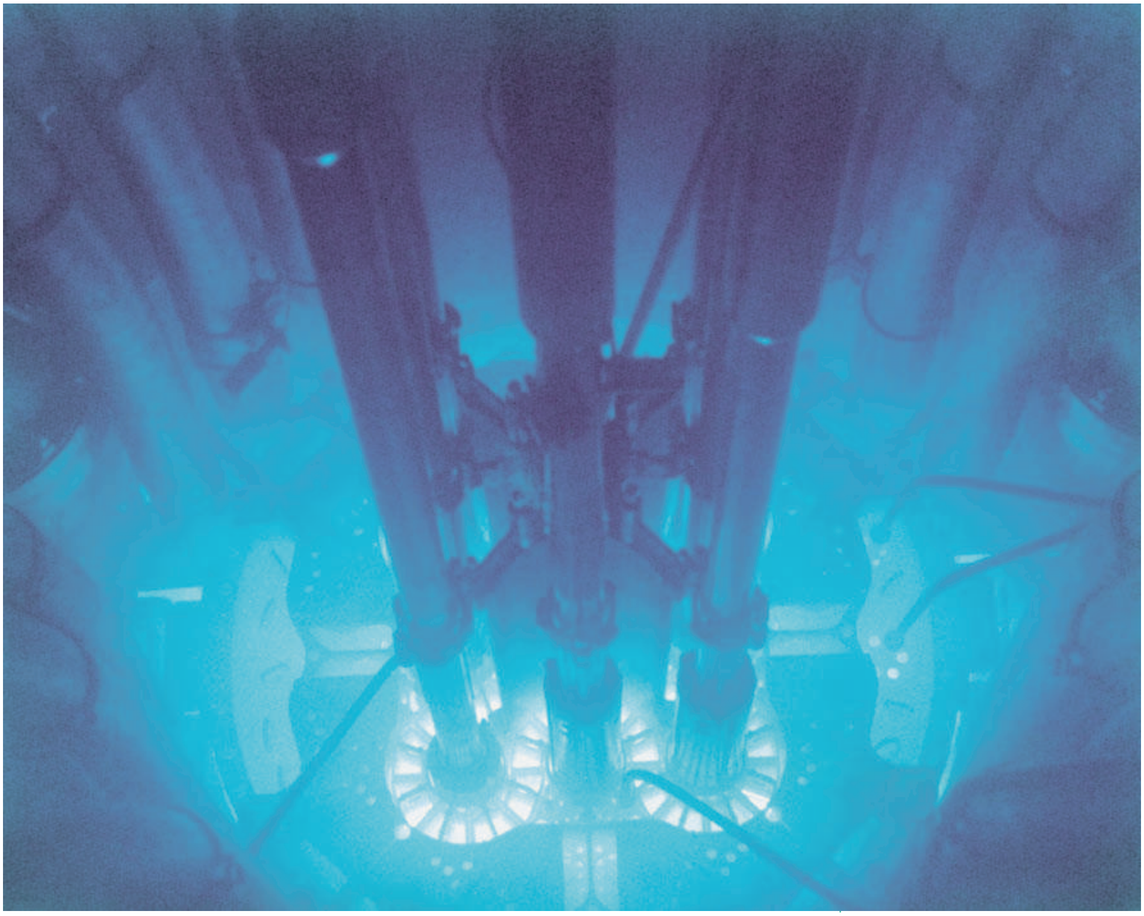
Nuclear power developed rapidly in the late 1950s and into the 1960s. On October 15, 1959, the Dresden-I Nuclear Power Station came online (that is, began to operate) in Illinois. This was the first nuclear power plant to be built entirely without money from the government. On August 19, 1960, the Yankee Rowe Nuclear Power Station in Massachusetts became the nation's third nuclear power plant. On November 22, 1961, the U.S. Navy commissioned the U.S.S. *Enterprise,* the world's largest ship. Powered by nuclear energy, the aircraft carrier could operate at speeds up to 30 knots for as far as 400,000 miles (740,800 kilometers) without having to refuel. Another milestone was passed on December 12, 1963, when the Jersey Central Power and Light Company launched construction of the Oyster Creek nuclear power plant. This was the first nuclear plant to be ordered as an economic alternative to a fossil-fuel plant.

By 1971 the United States was operating twenty-two nuclear power plants that provided 2.4 percent of the nation's electricity. By the end of the 1970s, seventy-two plants were producing 12 percent of the nation's electricity. And by the end of the 1980s, 109 power plants were generating 14 percent of the nation's

The world's first nuclear powered submarine, the U.S.S. *Nautilus*. © *Bettmann/Corbis.*

electricity. These numbers peaked in 1991, when the number of plants rose to 111, together supplying about 22 percent of the nation's electricity. By the early 1990s nuclear power plants were generating more power in the United States than all power sources combined generated in 1956.

Similar developments were taking place worldwide. As of late 2005, 441 nuclear reactors were producing 2,618.6 billion kilowatt-hours of electricity in thirty countries. The United States led the way with 103 nuclear reactors still in operation. Other countries with a large number of nuclear reactors included Canada (18), France (59), Germany (17), Japan (55), Russia (31), and the United Kingdom (23). The country that generated the highest percentage of its electricity needs from nuclear power was France, at 78 percent. Close behind was Lithuania, whose one power plant generated 72 percent of the nation's electricity.



This large reactor in Idaho, USA, operates with a thermal power of 250,000 kilowatts. The reactor is water-cooled and the blue glow results from Cerenkov radiation, emitted when energetic charged particles travel faster through the water than light. *United States Department of Energy/Photo Researchers, Inc.*

**Setbacks**

In the 1950s and 1960s scientists around the world believed that nuclear power had unlimited potential. Along with most of the public, they believed that nuclear plants would provide an endless source of cheap, renewable, clean energy. Yet by late 2005 only thirty-nine new nuclear power plants had been proposed by the nations of the world, and none were proposed for the United States. The percentage of electricity produced worldwide amounted to just 16 percent. The nuclear energy industry seemed to be stagnating (standing still; not moving forward).

Throughout the 1980s and 1990s and into the new millennium, the public began to have serious doubts about the safety of nuclear power. Those doubts arose because of the industry's first major setback, which took place on March 28, 1979. On that day an accident occurred at the Three Mile Island nuclear power plant

A nuclear accident occurred at Three Mile Island in 1979 which increased public awareness of some of the dangers of nuclear energy. *© W. Cody/Corbis.*

near Harrisburg, Pennsylvania. No one was injured or killed, and no one was overexposed to radiation from the plant. Still, the accident shut the plant down. If the accident had not been contained, a meltdown could have occurred. ("Meltdown" refers to an out-of-control reaction that overheats the reactor, causing it potentially to melt into the earth below, releasing radiation into groundwater and the atmosphere.) Many Americans started to distrust nuclear power, believing that the possibility of a catastrophe was too great. Not helping the industry was a major movie that year called *The China Syndrome.* The movie dramatized events at a fictional California nuclear power plant that were eerily similar to the Three Mile Island accident. Its title referred to the theoretical possibility that an overheated nuclear reactor could melt its way through the Earth to China.

## Measuring Radiation

In measuring radiation and radiation exposure, physicists use a number of units of measurement, depending on exactly what they are trying to measure. Complicating matters is that there are "common units" of measurement and so-called "SI units," or "standard units." SI units are those recommended by the worldwide General Conference of Weights and Measures. Some of these units, such as curies (named after French physicists Pierre [1859–1906] and Marie [1867–1934] Curie) measure amounts of radiation. Others, such as rems, measure doses of radiation people might receive.

Then in 1986 a major disaster struck. On April 26 an explosion took place in reactor number 4 at the nuclear power plant in Chernobyl, a city in Ukraine (formerly part of the Soviet Union) about 70 miles (112 kilometers) north of Kiev. In this accident, a large amount of radiation was released into the atmosphere. Scientists estimate that the amount of this radiation was 100 to 150 million curies (although this unit is well known scientists now use the Bequerel as the unit of radiation), primarily in the form of radioactive cesium and iodine. Thirty-one people were killed in the accident, including firefighters, and 135,000 people within a 20-mile (32-kilometer) radius had to be permanently evacuated. Several years later, an additional 110,000 people were evacuated. Entire villages had to be decontaminated, and in the years that followed the rates of certain cancers among people in the area were noticeably higher. (Exposure to radiation increases the risk of developing cancer.) Radioactivity spread over large areas of the Soviet Union, into Eastern Europe, and as far away as Scandinavia. It is estimated that the accident cost the Soviet Union $12.8 billion. The human costs—stress, lost homes, poor health—cannot be measured.

These accidents burst the nuclear industry's bubble. People began to fear a major accident that would dwarf the kinds of accidents that took place at conventional coal-fired electric-generating stations. On December 16, 2005, the world held its breath when a large explosion damaged a Russian nuclear power plant outside the city of St. Petersburg.

The nuclear industry began to face other problems in the 1980s and beyond. The cost of building nuclear power plants was spiraling out of control. Most new plants went far over budget. Also in the 1980s and 1990s, the first aging nuclear plants had to be shut down and taken out of operation. It was discovered then that the cost of decommissioning (shutting down) a nuclear power plant was high because extreme care had to be taken to dispose of radioactive components properly. On top of these problems, the waste from nuclear power plants was beginning to accumulate, and no one knew quite what to do with it.

Because of these problems, plans for construction of new plants were in many cases canceled. By 2005 the number of operating plants in the United States had declined (to 103) as older plants were decommissioned. Nuclear power had become an emotional issue. Its supporters believe that by the year 2050, the energy needs of the United States will triple. They believe that other forms of alternative energy can help, but only nuclear plants can provide power on a large scale. Opponents of nuclear power, however, believe that the costs and the risks are too high.

## HOW NUCLEAR ENERGY WORKS

Generating electricity through nuclear power is an enormously complex technical feat. It takes the combined skills of geologists (scientists who study Earth's structure, especially rocks), mine operators, engineers, and scientists, as well as large numbers of highly trained and skilled plant operators. The federal government oversees the construction and operation of these plants to make sure that they are built and operated to the very highest standards.

### Uranium

Producing nuclear power begins with the fuel, uranium. Uranium was discovered in 1789 by a German chemist, Martin Klaproth (1743–1817). He discovered uranium in a mineral called pitchblende. The element was named after the planet Uranus, which had been discovered just eight years earlier. Scientists' best guess is that uranium was formed in supernovas (or exploding stars) about 6.6 billion years ago. In the Earth, radioactive decay of uranium is the planet's main source of internal heat.

Uranium is used primarily in the nuclear industry, but it has other uses as well. Because it is a dense, heavy element (18.7 times as dense as water), it is sometimes used in the keels of boats as a weight to keep them upright. (Density refers to weight relative to volume. A ton of feathers weighs as much as a ton of lead, but because lead is denser than feathers, it takes up far less volume.)

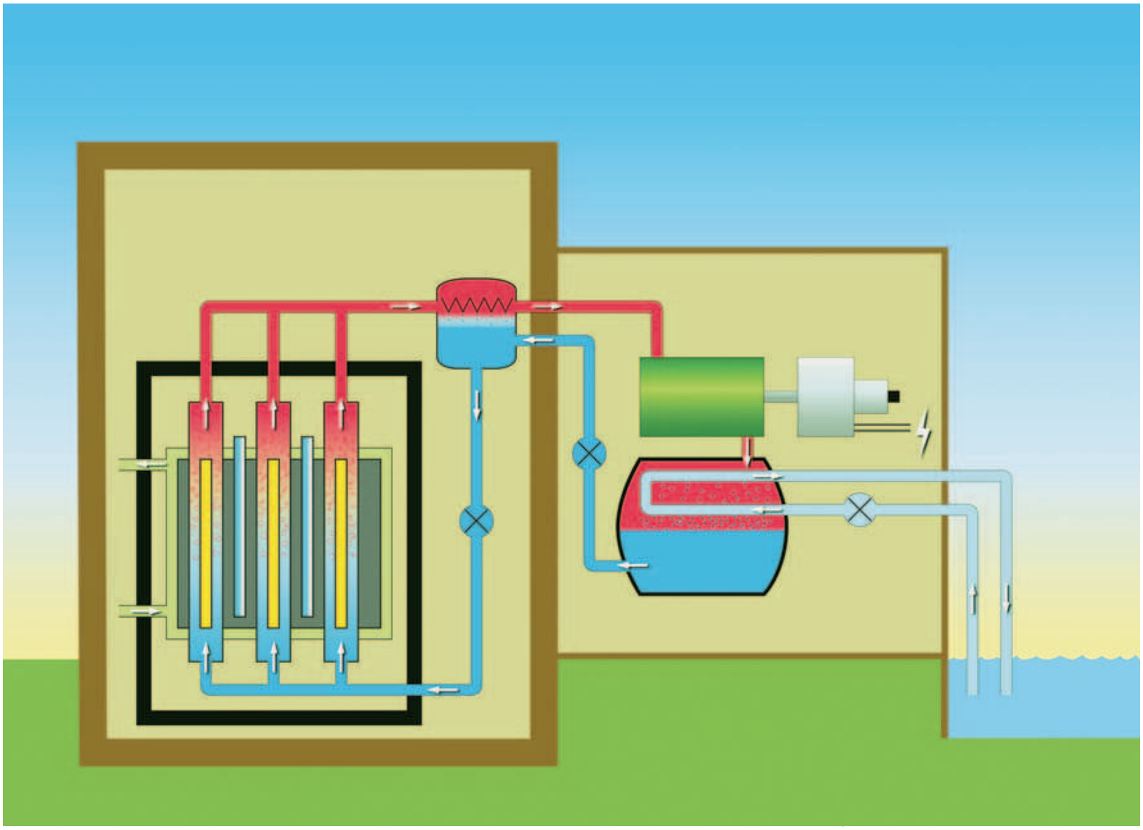


Diagram of the workings of an RBMK nuclear reactor, the type used in the Chernobyl power station. In this reactor, the core comprises fissile fuel rods (yellow) surrounded by water, encased in graphite. The water is heated by the reactions, producing steam (red). The steam passes through a moisture separator (upper center) and then to a turbine, which drives the electricity generator. The steam is condensed back to water by a cooling circuit. The flaw in this design is that power output increases with loss of cooling water. This was responsible for the 1986 Chernobyl disaster, which caused radioactive contamination of much of northern Europe. *SPL/Photo Researchers, Inc.*

Its density also makes it useful as a counterweight in such applications as airplane rudders, and it makes a good radiation shield.

**The uranium atom**

Uranium is the heaviest naturally occurring element. It has sixteen different isotopes, although the most common ones are $U_{235}$ and $U_{238}$. $U_{234}$ is found in trace amounts and results from the decay of $U_{238}$. The more abundant isotope, $U_{238}$ (which accounts for 99.3 percent of the uranium in the Earth's crust) plays a role in keeping the Earth warm. Like any radioactive substance, $U_{238}$ decays, but it decays very slowly. Its half-life is about the same as the age of the Earth, 4.5 billion years. ("Half-life" is a term scientists use to refer to the rate at which a radioactive substance decays, or breaks down. Thus, half of all $U_{238}$ has broken down over the past 4.5 billion years. Half of the half that is left will break down over the next 4.5 billion years, and so on.) From the standpoint of nuclear energy, the important isotope of uranium is $U_{235}$.

The nucleus of a $U_{235}$ atom consists of ninety-two protons and 143 neutrons. This is the isotope of uranium whose atoms can be split relatively easily. When a $U_{235}$ atom is struck by a neutron, the atom splits, releasing energy. It also releases two or three neutrons of its own, which in turn split other atoms, and on and on in a chain reaction. In a nuclear reactor, the released energy is at first kinetic energy. Kinetic energy is the energy contained in anything (such as water, wind, or a neutron) that is in motion. But submicroscopic particles travel only tiny distances, so the kinetic energy is rapidly converted to heat (similar to the way the brakes on a car get hot when they stop the kinetic energy of a moving car). This heat is then used to produce steam, which turns a generator to produce electricity. Heat makes up about 85 percent of the energy released. Most of the rest of the energy is in the form of gamma rays. (A gamma ray is a photon that is released by a radioactive substance. A photon is a form of energy, like light.)

In many respects, the process as described is much more complex. For example, physicists note that only isotopes with an odd number of particles in the nucleus, like $U_{235}$, are fissile (able to be split). Further, not every neutron that hits a uranium atom causes fission. Sometimes the neutrons are absorbed by the atoms they strike, so no fission takes place. Other neutrons simply escape and do nothing. Another complication has to do with the speed of the neutrons. Some are called “prompt neutrons,” but others experience a delay of up to 56 seconds.

The challenge for nuclear engineers is to keep the ongoing fission reaction in precise balance. When the reaction is in balance, scientists say that it has reached “criticality.” At criticality, the neutrons are doing their work in balance, meaning that their numbers remain constant and under control. The pace of the reaction can be speeded up or slowed down by increasing or decreasing the number of neutrons. If the increase is too rapid, the reaction can almost instantaneously get out of control.

### Plutonium

Plutonium (chemical symbol Pu), named after the planet Pluto, is an element that forms in a reactor core as the isotope $Pu_{239}$. It forms when $U_{238}$, which is also present in nuclear fuel, absorbs a neutron. Now the atom has an odd number of particles in the nucleus, making it fissile in the same way that $U_{235}$ is. But like $U_{235}$, it sometimes just absorbs the neutron, creating the isotope $Pu_{240}$, which is not fissile. Over time, the amount of $Pu_{240}$ builds up in the fuel rods. When the rods are “spent,” or no longer usable as fuel, this plutonium can be recycled. It undergoes a conversion process that makes it usable as nuclear fuel. Not all nuclear reactors are designed to allow this recovery and conversion process. Those that do are called "breeder reactors," for they "breed," or produce, additional fuel.

Plutonium is perhaps the most highly toxic substance that exists. The smallest amount can cause such diseases as lung cancer. Workers who handle plutonium observe the strictest safeguards to avoid exposure.

### Uranium: From the ground to the reactor

While uranium can be found in seawater, it is found most commonly in rocks and is as common as the elements tin and gold. It exists in concentrations of about two to four parts per million. Uranium is mined in at least two ways. One is to dig up the ore that contains it, crush the ore, and then treat it with acid, which dissolves the uranium to remove it from the ore. The other is a process called in situ leaching (*in situ* is Latin for "in place"). In this process, the uranium is dissolved from rock and pumped to the surface of the Earth. Either way, the end result is a compound called uranium oxide, or $U_3O_8$. This material is often referred to as "yellowcake."

The uranium, though, cannot be used as fuel in this form. It first has to be "enriched," so mine operators sell the yellowcake to uranium enrichment plants. The first step in converting it into a usable fuel is to convert it into a gas, uranium hexafluoride, or $UF_6$. This increases the amount of uranium from its natural level of 0.7 percent to 3 to 4 percent, so the uranium is said to be "enriched." The next step is to convert the uranium hexafluoride to uranium dioxide, or $UO_2$. Uranium dioxide can then be processed into pellets that are about the size of a knuckle on a person's finger. The pellets are then inserted into thin, 12-foot-long (3.5-meter-long) metal tubes, called fuel rods. Bundles of these tubes are then inserted underwater into the core of the nuclear reactor.

### Inside the reactor

A nuclear power plant has been constructed, probably at a cost of anywhere from $3 billion to $5 billion, or even more. Construction of the plant took at least four years, possibly up to ten years. Geologists have carefully considered the site of the plant to make sure that the chances of it being damaged by an earthquake or volcanic activity are small. Engineers and construction workers have carefully built the plant. The materials used were of the highest standards. Every weld in metal components was closely examined and even x-rayed to be sure it is as close to perfect as possible. Provisions were made to ensure that the plant is secure, so that terrorists or others cannot enter and take it over. Provisions have also been made for the safety of the plant's employees so they can quickly shield themselves from radiation in the event of an accident. The plant is built with "redundant," or repetitive, safety systems, so that if something breaks down, there is a backup. The most critical of these systems is water that can be used to cool an overheated reactor. No detail is overlooked.

As the time approaches for the plant to come online and begin producing power, the fuel is inserted into the tubes and the tubes, up to 200 of them, are inserted into the reactor core. Then, at the appropriate moment, the control rods are slowly pulled out. These rods are generally made of graphite or boron, and they control the pace of the nuclear reaction by absorbing neutrons. The farther the rods are inserted, the more neutrons they absorb, slowing down or stopping the reaction. As they are withdrawn, more and more neutrons make it to their target, and the chain reaction begins.

At this point the plant is nowhere near ready to operate at maximum power output. For weeks, the plant's engineers will fire up the reactor very slowly. They will check and recheck every component of the plant to make sure that everything is operating properly and safely. After a period of several weeks of testing, the reactor will begin producing power at its normal operating level, and consumers will begin enjoying the benefits of the electricity it produces.

## CURRENT AND FUTURE TECHNOLOGY

Nuclear power plants come in many different shapes and designs. Many of the first plants to be constructed were huge, enabling them to produce the greatest amount of power possible. More recent designs are smaller, making them less costly and easier to build. But despite their many technical and engineering differences, nuclear reactors come in two basic types: pressurized water systems and boiling water systems.

### Pressurized water reactor system

One system in common use is called the pressurized water reactor system. It is given this name because it relies on water under pressure to produce the heat needed to produce electricity. In such a system, the fuel rods are inserted into a steel pressure tank that contains ordinary water. The water acts as a coolant, but it also moderates the reaction because it can absorb neutrons. Protruding (sticking out) through the lid of the pressure tank are the control rods.

As the control rods are slowly pulled out, the chain reaction begins. The reaction produces heat, which heats the water in the pressure tank. The water heats to 518° Fahrenheit (270° Celsius). The water does not boil, though, because it is under intense pressure.

The heated water is then channeled to a heat exchanger in a closed circuit. The water in the heat exchanger is then heated up, producing steam. The steam drives a turbine generator that is little different in principle from a turbine used in a windmill or a hydroelectric dam. As the generator turns, it produces electricity. Meanwhile, the steam is condensed, usually by cool water from a lake or river, and returned to the heat exchanger.

### Boiling water reactor system

The other major system, the boiling water reactor system, is more efficient than the pressurized water system. One noticeable difference is that with a boiling water system, the control rods protrude from the bottom of the containment chamber. Inside the chamber is the reactor core. The control rods are at the bottom because the water inside the chamber is allowed to boil. The steam created by the boiling water is allowed to rise to the top of the chamber. Pipelines carry the steam directly to the turbines, where its heat causes them to turn to create electricity. The steam then condenses and is channeled back into the containment chamber. Underneath the reactor is a circular tunnel filled partway with water. This tunnel is a safety mechanism. If any steam or water were to escape from the containment chamber, it would fall into the tunnel, where it could do no immediate harm.

### The possibility of nuclear fusion

Scientists look forward to the discovery of a power source that is clean, safe, universally available at all times to all people throughout the world, and that uses a fuel that is abundant, cheap, and efficient. It would not contribute to global warming or air pollution, require large plants that would disrupt the natural environment, or produce dangerous by-products. To that end, some scientists conduct research into what is called "cold fusion." Cold fusion uses fuel that is commonly available from the hydrogen in water. However, governments have favored a more conventional approach to fusion at extremely high temperatures. In 2005, Cadarache in

France was chosen as the site for the International Thermonuclear Experimental Reactor. This will be built as a cooperative venture between the EU, U.S., Russia, China, Japan, and South Korea. This is a major step in the development of fusion as a potential large-scale source of electricity that will not contribute to climate change.

Nuclear *fission* refers to the splitting, or breaking apart, of atoms. Nuclear *fusion,* as the name suggests, involves the fusing, or joining together, of atoms. The light nuclei of two atoms bind together during nuclear fusion to form a single heavier nucleus. One example is the deuteron, a single particle formed by the combination of a neutron and a proton. When a deuteron or similar particle is formed, its mass is generally less than the total mass of the two original particles. The mass that disappears is released as energy. What appeals to scientists seeking to harness nuclear fusion is that such reactions occur in nature throughout the universe, particularly in stars. Fusion takes place in stars because of their high temperatures, up to 18,000,032° Fahrenheit (10 million° Celsius), possibly even hundreds of millions of degrees. The problem is that while such high temperatures can be found in the center of stars, including the Earth's sun, they do not occur naturally on Earth.

Despite the high temperature needed for fusion to occur, scientists have tried to reproduce fusion reactions on Earth. The process they formulated was to use two isotopes of hydrogen. These isotopes, called "heavy hydrogen" because they contain extra atomic particles, are deuterium and tritium. While a normal hydrogen atom consists of a single electron and a single proton in the nucleus, deuterium also contains one neutron in the nucleus and tritium contains two. These isotopes fuse at lower temperatures than do the nuclei of regular hydrogen atoms, and they are relatively abundant. In the oceans, about one in 6,500 or 7,000 hydrogen atoms are deuterium, and they can be easily extracted. The source of tritium is an element called lithium, which is abundant in the Earth's crust.

Scientists discovered that when a mixture of deuterium and tritium is raised to a high enough temperature, or when the elements are accelerated to a very high speed, one deuterium nucleus fuses with one tritium nucleus. The result is a new element, helium. More importantly, excess energy is given off in the form of a neutron that moves at a very high speed. Scientists believe that fusion could be the "fuel of the future" because the fuel—deuterium and tritium—contains an enormous amount of energy, called "density" by scientists. It has been estimated that a single thimbleful of heavy hydrogen contains the same amount of energy as 20 tons of coal. An amount that would fill the bed of a pickup truck would provide the same amount of energy as 21,000 rail cars full of coal or 10 million barrels of oil. Further, using such fuel would be extremely safe. The only by-product is helium, and there is no danger of a fusion reaction spinning out of control. If the fuel escapes, the fusion reaction simply stops.

So far, fusion experiments have failed to produce any power in excess of the power needed to produce the fusion reaction. In other words, there was a net power loss. For many scientists, the enormous energy demands of hot fusion make it impractical. Instead, they have searched for a way to create fusion reactions at low temperatures, called "cold fusion." Cold fusion is a term coined in 1986 by Dr. Paul Palmer of Brigham Young University in Utah. It is the popular term for what scientists call "low energy nuclear reactions" in a field that is sometimes called "condensed matter nuclear science."

In 1984 two scientists, Stanley Pons of the University of Utah and Martin Fleischmann from England's University of Southampton, began conducting cold fusion experiments at the University of Utah. On March 23, 1989, Pons and Fleischmann made an announcement that startled the world. The two claimed that they had successfully carried out a cold fusion experiment. This experiment produced excess heat that could be explained only by a fusion reaction, not by chemical processes. Many scientists, though, disputed their claim. They tried to duplicate the Pons-Fleischmann experiment and failed.

So the question remains: Is cold fusion possible? Some scientists answer with a no. Many other scientists, though, disagree. They point out that cold fusion research is still just beginning. Some of the problems reported with duplicating the Pons-Fleischmann findings have been the result of normal uncertainties about how to design and conduct experiments to get consistent results.

Meanwhile, many scientists have made claims that they have produced cold fusion. Some of the most prominent researchers in the field are in Japan, where the level of funding for cold fusion research is much higher than it is in the United States. At Japan's Hokkaido University, for example, D. T. Munzo reported experiments in which the ratio of energy output to energy input was seventy thousand to one. As of 2005, though, the world seemed decades away from seeing a commercial fusion reactor, whether hot or cold.

In 1991 Greenpeace activists placed some 3,000 wooden crosses next to the Chernobyl nuclear power plant, commemorating the nuclear disaster five years earlier. ©.*Reuters/Corbis.*

## BENEFITS AND DRAWBACKS

In the imaginations of many people, nuclear power plants are surrounded by a field of radiation. As they drive down the highway and see the characteristic cooling tower of a nuclear power plant rising on the horizon, some people feel a slight twinge of anxiety. They know that they are not being exposed to radiation, yet their emotions make them wonder whether maybe they are.

Supporters of nuclear energy dismiss these concerns. They argue that nuclear power plants are safe and that nuclear power offers many significant benefits. At the same time, nuclear power has significant drawbacks, particularly the potential for accidents, the problem of nuclear waste disposal, and the possibility that terrorists could attack nuclear power plants.

### Benefits

The benefits of nuclear energy include the following:

1. Many scientists believe that nuclear energy remains the best way to provide large amounts of power for a large and growing world population. A typical nuclear power plant produces 1,000 megawatts, or 1 billion watts, of electricity. Other forms of alternative energy produce far less, particularly relative to their size. For example, the largest wind farm in the United States is the Stateline Wind Energy Center along the Columbia River on the Washington-Oregon border. This massive farm consists of 454 wind turbines, each 166 feet (50 meters) tall and, at peak capacity, generating 660 kilowatts, or 660,000 watts of power. Because of changing wind conditions, the windmills do not always operate at peak capacity. To provide power equivalent to that of nuclear power plants, immense numbers of large wind farms would have to be built.
2. Nuclear energy is reliable. In contrast to most other forms of alternative energy, nuclear energy can be provided on a consistent, predictable basis nearly anywhere in the world. It is not subject to weather conditions. In contrast, solar power requires consistent sunshine, so not all areas are suitable for solar power. Wind power has similar limitations. Hydroelectric dams provide large amounts of power worldwide, but the number of rivers that remain suitable for damming is limited. Such alternatives as ocean wave power and tidal power are likewise limited by geography and unpredictable weather patterns.
3. The supply of fuel for nuclear power is abundant. Uranium exists throughout the Earth's crust, although in some places, it can be mined more easily than in others. Scientists estimate that the amount of uranium known to be readily available is enough to last fifty years. However, they also point out that its relative abundance has not made it necessary for mining companies to search very hard for it. Scientists are confident that more intensive searching will yield abundant new reserves of uranium. While uranium is not renewable, as wind and solar power are, enough probably exists for many centuries to come. Further, nuclear plants produce plutonium as a by-product of the nuclear reaction. This plutonium can be reprocessed into fuel.

4. The price of nuclear fuel remains relatively constant, and its sources remain relatively consistent. Uranium is mined extensively in about twenty countries throughout the world. The relatively large number of suppliers ensures that prices do not change rapidly and unexpectedly. In contrast, the world's petroleum reserves are in the hands of a small number of countries. Many of these countries are politically unstable. As the Arab oil embargoes of the 1970s showed, oil supplies to the United States and other countries can be cut off overnight for political reasons. Uranium is not subject to these uncertainties, and nations such as the United States and Canada can mine their own uranium. In fact, Canada leads the world in uranium mining. Another leading producer is Australia, which, ironically, has no nuclear power plants.
5. Nuclear power plants have a low impact on the environment. A chief advantage of nuclear power is that it does not require the burning of fossil fuels such as coal. Thus, it is cleaner than fossil fuels and does not contribute to pollution.
6. Nuclear power plants are safe. As of late 2005 the only deaths that have ever resulted from a nuclear power plant accident occurred at the Chernobyl plant in Ukraine. Nuclear experts, though, note that the design of the Chernobyl plant was extremely outdated and that the plant was not very well constructed. This was a common problem for all types of construction under the Communist regime of the old Soviet Union. They believe that the kind of accident that happened at Chernobyl is much less likely with more modern and better built plants. This has meant that despite worries among the public, politicians have increasingly seen modern nuclear reactors as a source of energy that avoids emission of greenhouse gases and after a period where few reactors have been built they are being re-considered as energy sources.
7. With regard to safety, the track record of the nuclear industry has improved over the 1990s and early 2000s. For example, when something in the operation of a nuclear plant gets out of kilter, a "scram" takes places. This refers to a wide range of automatic safety mechanisms. Alarms sound, backup systems kick in if necessary, and the plant's controls automatically make necessary adjustments, particularly making sure that water surrounds the reactor

core to keep its temperature under control. If necessary, the nuclear reaction stops and the reactor shuts down. The nuclear industry keeps track of the number of scrams per 7,000 hours of operation, or about one year. In the late 1990s two-thirds of U.S. nuclear power plants had zero scrams. The number of scrams at the other third was extremely low, and usually the problems that caused them were minor and easily fixed.

8. A major concern for nuclear plant workers is exposure to radiation. People are exposed to radiation every day of their lives. Radiation reaches the Earth from the sun, and it radiates from rocks in the earth. This radiation is referred to as "background radiation," and it varies with altitude (height above sea level) and geography. People in such countries as Finland are exposed to three times as much background radiation as Australians. Even on an airline flight over the North Pole from, say, Tokyo to London, people are exposed to cosmic radiation seven to eight times the normal level.

## Drawbacks

Despite its many benefits, nuclear power has significant drawbacks as well. Throughout the 1990s and into the new millennium, scientists, environmentalists, and the public have focused more of their attention on these drawbacks. As a result, nuclear power has become an emotional political issue. Its opponents are passionate in their belief that nuclear power poses a significant danger to the world. Some of their concerns include the following.

### *Catastrophic accident*

The potential for a catastrophic accident continues to exist. The world's nuclear power plants have accumulated a total of about twelve thousand years of operation. During that time, there have been only two significant accidents, Three Mile Island (although the public was not exposed to radiation during that accident) and Chernobyl. Supporters of nuclear power point out that far more people lose their lives in accidents at conventional power plants in one year than have lost their lives in nuclear accidents.

The problem is one of public attitudes rather than statistics. Opponents of nuclear power note that a catastrophic accident at a conventional power plant might be tragic for those injured and killed. Still, the effects would be limited to the plant itself and perhaps the immediately surrounding area. Deadly radiation would not be released into the atmosphere. People would not have

## Safety Stats

In 1998 the U.S. Bureau of Labor Statistics reported that for every 200,000 hours of work performed in nuclear plants, there were 0.34 accidents that resulted in injury. In contrast, for all other industries, the number was seven times greater, or 2.3 accidents per 200,000 worker hours.

to be evacuated, and those nearby when the accident occurred would not suffer the ill effects of radiation.

In contrast, a catastrophic accident at a nuclear plant could have enormous effects on the surrounding environment, effects that would last for decades, if not longer. Nuclear opponents believe that the risk is simply too great. One mistake, one faulty component, one operator error could create an environmental catastrophe. The margin for error is nearly zero. While the risk of a nuclear catastrophe is low, such a catastrophe would have high consequences.

Adding to the problem is the mysteriousness of anything nuclear. Ever since the atomic bombings of Japan at the end of the Second World War, people have been afraid of nuclear power. Excessive exposure to nuclear radiation can cause cancer, another word people respond to with fear. Few people understand nuclear physics. That sense of awe and mystery spills over into fear of anything "nuclear," including nuclear power plants.

### *Waste storage and disposal*

Nuclear waste comes in two types: low-level and high-level. Low-level waste is produced by hospitals, which use radioactive materials for certain medical tests. Similar low-level waste is also used for research purposes at universities and other research facilities. This material has to be disposed of safely, and if it is done so, it poses little health risk to the public. The radioactivity in these materials breaks down quickly (usually in days or at most weeks), and the material can then be disposed of as normal trash.

High-level nuclear waste, such as that produced by nuclear power plants and in producing and dismantling (taking apart) nuclear weapons, is another matter. As of 2003 the United States had accumulated about 49,000 metric tons (a metric ton is about 2,200 pounds) of spent nuclear fuel rods. These are fuel rods that have been removed from power plants because the fuel is depleted.


A steel and concrete tube holding over 600 tons of nuclear waste sits in a secured holding area along the Pacific Ocean at the San Onofre Nuclear Power Plant near San Clemente, Calif. Storage of nuclear waste contintues to be a controversal issue. *AP Images.*

This amount would cover a football field to a height of 10 feet (3 meters). The U.S. Department of Energy estimates that the amount will total 105,000 metric tons by the year 2035. Much of this material is stored in water pools on the sites of nuclear power plants. No one knows what to do with this accumulating waste.

The problem with nuclear waste is the half-life of such elements as uranium and plutonium, as well as other radioactive materials produced in nuclear power reactors as by-products. Some of these by-products include cesium-137 and strontium-90, both highly radioactive. Most of these elements have extremely long half-lives. The half-life of plutonium is 24,000 years. The half-lives of some other radioactive elements are 100,000 years, even longer. This means that nuclear waste disposal has to be thought of in terms of geologic time, not next year or even next century. The ancient Roman Empire was thriving just 2,000 years ago; the ancient Egyptians, 3,000 years ago. Humans find it hard to think that far ahead.

Roughly every twelve to eighteen months, a nuclear plant has to shut down and all the fuel rods have to be replaced. These fuel rods are highly radioactive, so they cannot simply be taken to the nearest landfill. Strict precautions have to be taken to make sure that the spent rods do not pose a risk to the environment or to the public. Further, when a nuclear plant is "decommissioned," or shut down, the radioactive components in the core have to be disposed of properly. All of this is a difficult technical undertaking and one that carries a high expense.

Several proposals have been made for ways to dispose of high-level nuclear waste. One proposal is to launch it into space. Others are to bury it on a remote island or in the polar ice sheets. So far, these have not been attempted. Another proposal is to bury the waste under the seabeds. While technically possible, the expense of doing so would be enormous.

The most widely accepted possibility is to bury nuclear waste underground in stable geological formations. The waste would undergo first a process called vitrification (from the Latin word *vitrium,* meaning "glass"). This means that the waste is mixed with silica (like sand) and melted into glass beads. This process makes the waste more stable and reduces the chance that radiation could seep out into the air or water. The beads are then buried in an area that is geologically stable (that is, it does not experience earthquakes, tremors, or volcanic activity). When the storage facility is full, it would be sealed with rock.

The problem with this method is that no community wants to be home to the storage site. Nuclear waste would have to be trucked in, with the potential for accidents. Then the nuclear waste would be stored nearby, essentially forever. In 1983 President Ronald Reagan signed into law the Nuclear Waste Disposal Act. Under the act, the federal government took on responsibility for nuclear waste disposal. The act required the U.S. Department of Energy to find a suitable site for underground storage, then build the facility. In 2002 the department identified Yucca Mountain in Nevada as the most suitable site. Understandably, Nevadans do not want to be the dumping ground for the nation's nuclear industry and have opposed this plan. The state's governor notified the federal government that Nevada opposed the plan. The U.S. Congress voted to override the governor's objections. Accordingly, the federal government has designated the Yucca Mountain site as a long-term storage facility for about 70,000 metric tons of nuclear waste. As of late 2005, however, the issue was still not entirely resolved. No steps had been taken to construct the facility.

Another problem the nuclear industry has created is "mill tailings." These are waste materials created in mining uranium ore.

A worker walks down the tunnel almost half a mile inside Yucca Mountain, where the U.S. Department of Energy hopes to store the nation's high level nuclear waste. © *Dan Lamont/Corbis.*

The materials contain trace amounts of uranium left behind, as well as radium and thorium, both radioactive. The radioactive material cannot simply be left in place. The federal government, specifically the U.S. Nuclear Regulatory Commission, regulates the removal, storage, and monitoring of mill tailings.

### *Terrorism*

After the terrorist attacks on the United States on September 11, 2001, policy makers raised concerns about the security of the nation's nuclear power plants. It is known that members of al-Qaeda, the Islamic terrorist network, have been instructed and trained in ways to attack power plants. The concerns of policy makers and nuclear regulatory officials are many:

As they did on September 11, terrorists could hijack an airliner and fly it into a nuclear power plant. The scientific director of the Nuclear Control Institute believes that a direct, high-speed impact by a large airliner "would in fact have a high likelihood of penetrating a containment building" with a nuclear reactor inside. "Following such an assault," he said,

## Why Yucca Mountain?

The federal government identified Yucca Mountain, about 100 miles (161 kilometers) northwest of Las Vegas, as the best site in the United States for long-term nuclear waste disposal. This site was selected for a number of reasons that highlight the problems of disposing of nuclear waste:

The area has a dry climate. Yucca Mountain receives only about 7.5 inches (19 centimeters) of rainfall each year. Most of the rain runs off or evaporates. The rainfall that remains moves through the rock at a rate of only about .5 inch (1.27 centimeters) per year.

Yucca Mountain is stable geologically. Studies have shown that Yucca Mountain has not changed much for at least one million years. The earth surrounding the mountain does not shift because of volcanoes or earthquakes. Because the waste would be 1,000 feet (305 meters) below the surface, any earthquakes that did take place would likely not allow any of the material to leak out. This is because earthquakes are most intense at the Earth's surface.

The Yucca Mountain site has a deep water table. The water table, the level at which underground water is reached, is about 2,000 feet (610 meters) below the surface. The nuclear waste would be stored about 1,000 feet (305 meters) below the surface. Therefore, the water would

"the possibility of an unmitigated [unstopped] loss-of-coolant accident and significant release of radiation into the environment is a very real one." Other scientists believe that most nuclear plants could withstand the impact of an airliner.

Terrorists could steal plutonium or highly enriched uranium, either from the plants themselves of from uranium enrichment facilities. It takes only about 18 pounds (8 kilograms) of plutonium or 55 pounds (25 kilograms) of highly enriched uranium to build a nuclear weapon. But in the nuclear industry, these materials are moved about by the ton, and accurate records are not always kept. Policy makers believe that a sophisticated terrorist group could steal these materials and make a nuclear bomb. The materials could also be used to construct so-called "dirty bombs," or what experts call never reach the waste. If by some chance it ever did, the water that flows under Yucca Mountain continues to flow underground into Death Valley, a forbidding desert. None of this water is used to supply water to nearby cities. Further, the Yucca Mountain site is in an enclosed water basin. This means that the area is completely surrounded by higher land. This in turn means that water flows downward and stays put. It does not spill into aquifers (water-bearing rock and sand) that supply drinking water.

The area is in a remote location. No one lives on Yucca Mountain, and the nearest people are 15 miles (24 kilometers) away. Most of the land around Yucca Mountain, about 1,375 square miles (3,561 square kilometers), has been taken over by the federal government. It is also on the edge of sites that were once used to test nuclear weapons, sites on which no one wants to live or work. If that area is added in, the unpopulated area is 5,470 square miles (14,167 kilometers).

Finally, access to the Yucca Mountain site is highly restricted. The U.S. Air Force maintains training sites and gunnery ranges in the area. The area is dense with security personnel and procedures, so it would be nearly impossible for anyone to disturb the site. Further, geologists have determined that the site has no valuable minerals, oil, precious metals, or other assets. Therefore, geologists believe that, even thousands of years from now, no one would have any reason to dig the site up.

"radiation dispersal devices." These are bombs made of conventional explosives such as dynamite that are packed with nuclear materials, even nuclear waste. The explosion would disperse, or distribute, the radioactive materials around a wide area. The result would be public panic and an area contaminated with radiation.

Policy makers are also concerned about security at nuclear facilities. After September 11, training exercises were carried out at nuclear plants to see how well the plants' personnel could resist a terrorist attack. Military personnel disguised as terrorists attempted to gain access to these plants. Some experts claim that at nearly one-half of U.S. nuclear power plants, armed guards were not able to stop these mock attacks.

A final concern is nuclear proliferation. *Proliferation* means "spreading," and the concern is that nations can develop nuclear power—or claim to—and convert their nuclear capabilities into weapons. In 2005 many nations of the world, including the United States, were opposing nuclear development programs in Communist North Korea and Iran. While these countries insisted that their programs were for peaceful purposes, worries persisted that they were trying to develop nuclear weapons.

## ENVIRONMENTAL IMPACT

The chief benefit to the environment of nuclear power plants is that they do not emit (give off) harmful gases, such as carbon dioxide and sulfur dioxide. In this way they differ from conventional power plants, which emit these gases primarily because they burn coal, a fossil fuel. If the energy generated by nuclear power plants worldwide were instead generated by burning coal, the amount of additional carbon dioxide released into the atmosphere would be about 1,600 million tons. Moreover, burning coal releases toxic heavy metals, including arsenic, cadmium, lead, and mercury. Nuclear energy prevents release into the atmosphere of about 90,000 tons of these metals each year. France's heavy reliance on nuclear power has lowered that country's air pollution from electrical generation by 80 to 90 percent.

By not emitting these gases, nuclear energy does not contribute to environmental problems such as air pollution, smog, and the "greenhouse effect." The greenhouse effect refers to the ability of some gases, such as carbon dioxide, to accumulate in the air. The theory is that in doing so, they act like a greenhouse, trapping the sun's heat. In turn, many scientists believe that this trapped heat is increasing average temperatures around the world. This increase is referred to as "global warming." Global warming is blamed for the melting of the polar ice, raising sea levels and endangering coastal cities. (Not all scientists agree that this is happening.) Further, by not emitting pollutants, nuclear power plants do not contribute to acid rain. Acid rain is any form of precipitation that is more acidic than normal because the water has absorbed acidic pollutants from the air. Acid rain can harm crops and forests. It can also contribute to the deterioration of buildings and public monuments, which dissolve because of the acid in precipitation.

Nuclear power plants also do not harm surrounding bodies of water. A myth that some people believe is that nuclear plants discharge water into nearby lakes and streams that is either radioactive or extremely hot. This is not true. The water released from a nuclear plant never comes into contact with the radiation. Further, if the water is too hot to be discharged, it is cooled either in a cooling pond or in cooling towers before release.

Supporters of nuclear power point out that some other alternative forms of energy do not have the same low impact on the environment, especially hydroelectric dams. While such dams have the benefit of not emitting harmful gases or pollutants, the dams have a major impact on the surrounding environment. By turning rivers into huge lakes, they disrupt vegetation and wildlife. Many dams have displaced (driven out) large numbers of people. Further, the reservoirs behind hydroelectric dams emit their own form of pollution. As the water level of the reservoir falls, the wet ground that surrounds it supports the growth of vegetation. As the water rises, this vegetation is covered and rots. The rotting vegetation emits methane gas, a pollutant. In addition, hydroelectric dams have an adverse effect on fish because they disrupt breeding and spawning grounds.

Nuclear power plants do not have harmful effects on wildlife. In fact, they often can have beneficial effects. For example, when cooled water is released from the plant, the water often contributes to the formation of wetlands. These wetlands can become nesting grounds and provide habitat for birds, fish, and other animals. Some companies that build and run nuclear plants even develop wildlife preserves and parks in the surrounding area, where plants grow abundantly in the moist soil.

Even species that are endangered (that is, in danger of becoming extinct) have found new life around nuclear plants. Some of these species thrive nearby, including such endangered species as bald eagles, red-cockaded woodpeckers, peregrine falcons, osprey, and the beach tiger beetle. The areas around nuclear plants are also home to such nonendangered species as wild turkeys, sea lions, bluebirds, kestrels, wood ducks, and pheasant.

Again, supporters of nuclear power point out that other forms of alternative energy do not have the same benefits. They agree that solar power and wind power are cleaner forms of energy, but they require huge “farms” of solar panels or windmills to produce significant amounts of electricity. Some argue that wind farms hurt an area’s bird populations because the birds become almost hypnotized by the turning blades and fly right into them, where they are killed. By reducing an area’s bird populations, the rodents that birds eat can multiply freely and cause rodent infestations.

Nuclear power protects land and animal habitats. Per unit of electricity, nuclear power plants take up far less land than other types of power-generating stations. For example, assume a plant that produces 1,000 megawatts of power (a megawatt is a million watts, so a thousand megawatts is 1 billion watts). To produce the same amount of power, a solar "farm" would need 35,000 acres of solar panels. A wind farm would require 135,000 acres devoted to windmills. In contrast, a typical nuclear power plant takes up only about 500 acres of land.

Further, the fuel nuclear power plants use, uranium, is very energy dense. This means that a pound of the fuel produces far more energy than a pound of coal. For example, one metric ton of uranium, or about 2,200 pounds (998 kilograms), will power a 1,000-megawatt nuclear power plant for two weeks. This fuel would come from about nine metric tons of mined uranium oxide. The same amount of energy from coal would require about 160,000 metric tons, or almost 353 million pounds. Thus, mining nuclear fuel has much less impact on the environment.

With regard to energy output, some nuclear power opponents say that these figures are misleading. They point out that conventional fuels like coal have to be burned to process uranium for use as fuel. They are correct, but the amount of conventional energy that has to be burned to do so is about 2 percent of the amount of energy the uranium will produce.

## ECONOMIC IMPACT

In examining the cost of nuclear energy, many factors have to be taken into account. Some of these are obvious, such as construction costs and the cost of mining uranium. Others are more hidden and include taxes, licensing fees, interest payments on debt, and the like. Thus, any examination of the economic costs and benefits of nuclear energy involves complex calculations.

The first cost comparison involves the fuel itself. Uranium has to be mined, converted, enriched, and loaded into fuel rods. Coal has to be mined, but it can be used as is. On the other hand, the cost of transporting nuclear fuel is low because of its energy density. The cost of transporting coal is high because large volumes have to be shipped.

Per unit of energy, the cost of a nuclear power plant is generally higher than that of a conventional power plant. Nuclear power plants have to be built to the highest standards. Many of their systems are redundant, or repetitive, for safety reasons. On the


The Pacific Pintail, transporting 140 kg of weapons-grade plutonium, docks at Cherbourg, France after arriving from the United States on October 6, 2004. The nuclear waste will be conditioned here before being transported from this northwestern French port some 745 miles (1,200 kilometers) by road to a plutonium fuel fabrication facility in Cadarache, southern France. ©*Jacky Naegelen/Reuters/Corbis.*

other hand, coal-fired plants have additional costs because of requirements that they have pollution-control devices, such as scrubbers that remove particles from their emissions. Debt also increases the cost of nuclear plants. Because building these plants is so expensive, power companies have to borrow large sums of money, and they have to pay interest on that debt. Thus, high interest payments have added to their costs.

Nuclear power plants have higher maintenance costs than do conventional power plants. For example, corrosion and cracking are common problems in the water pipes in boiling water reactors. These components have to be replaced at great cost. In the meantime, the reactor is shut down. It is not producing energy, but workers still have to be paid and debt still has to be financed.

Both conventional and nuclear power plants have normal day-to-day costs. Nuclear facilities require highly trained technicians, engineers, safety inspectors, health workers, and the like, increasing labor costs. Conventional plants are relatively simple to operate, so they do not require as many highly trained workers. However, they require a larger labor force because of the amount of labor involved in running the plant's operations.

Nuclear plants face other charges as well. The license fee for a nuclear reactor is almost $3 million. The license for nuclear fuel use is over $2.5 million. Many nuclear plants pay $15 to $20 million in local property taxes. In addition, the Nuclear Regulatory Commission requires nuclear plant operators to take on expenses for other specialized needs, including, for example, radiographers who measure radiation in the plant. Producing nuclear energy does not come cheap.

On top of all these expenses, the nuclear industry spends many dollars for nuclear waste disposal. Coal-fired plants have only to dispose of ash. Further, the cost of decommissioning a nuclear power plant is high, often 4 percent of the initial cost of construction. A coal-fired plant that is put out of commission essentially just has to be knocked down and carted away. Yet most costs are comparable. The end result is that nuclear power is slightly more expensive than coal.

## SOCIETAL IMPACT

The societal impact of nuclear power tends to be a matter more of perceptions and public sentiment than facts. Opinions about nuclear power are likely to depend on opinions about science. On the one hand, many people place a great deal of faith in science. They believe that science can solve many of the world's ills. Science, for example, can increase crop yields in poorer nations. It can reduce and eventually eliminate many diseases. And it can provide for the energy needs of the six billion people who live on Earth—a number that is likely to grow significantly as the twenty-first century progresses. Scientists, with their specialized knowledge, have become almost like magicians who solve the world's problems.

As the sheer volume of scientific information grows each year, however, the public feels disconnected from scientists and their magic. Few people know how a toaster works, let alone something as complex as a nuclear power plant. Further, they believe that while science can solve problems, it has also caused problems. In their view, the Earth and its resources have been exploited in the name of science. The atmosphere and bodies of water have been polluted because of scientific and technological advancement. Some of the people who feel this way yearn for a simpler time, when people (in their view) lived in harmony with the natural world. They were attuned to the cycles of the natural world and accepted them rather than trying to conquer them through science.

Nuclear energy stands at the center of this dilemma. Supporters of nuclear energy point to its clear benefits. It provides large amounts of power. It does not release pollution into the atmosphere. It does not consume resources whose supply will eventually run out. It does not make countries such as the United States dependent on foreign sources of fuel. It has an exemplary safety record, and improvements in the design of nuclear power plants make them safer than ever. Perhaps most importantly, nuclear power is the best hope for developing nations such as India and China. These and other countries are attempting to find a place for their large populations among the developed nations of the world. To do so, they need energy.

This point of view is not shared by all people. Many environmentalists believe that nuclear power plants are a disaster waiting to happen. Their views are sometimes supported by the mass media, which tends to focus on bad news rather than good. A documentary prepared by the Public Broadcasting Service (PBS) is a case in point. The documentary was titled “Meltdown at Three Mile Island.” This title is dramatic, but it is false. No “meltdown” occurred at Three Mile Island.

## BARRIERS TO IMPLEMENTATION OR ACCEPTANCE

The popular culture adds to the climate of distrust and emotional debate surrounding nuclear energy. Movies routinely depict scientists as “mad,” as people bent on making scientific discoveries no matter what effects those discoveries might have on the human community. Cable-television science fiction channels routinely run movies about creatures that have been mutated into killer beasts because of science, especially nuclear science. At best, the stereotype of the scientist is one of an unappealing, slightly eccentric person. In this climate, the mysteries of nuclear power become an easy target for people’s fears and uncertainties about the future.

During the first years of the twenty-first century, nuclear energy development was very much on hold, particularly in Western nations such as those in North America and Europe, as well as Australia. Public sentiment in the West favors other alternatives, such as solar, wind, and hydrogen. Less developed nations, though, do not have the luxury of picking and choosing, and many are going ahead with plans for nuclear power plants.

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# Solar Energy

## INTRODUCTION: WHAT IS SOLAR ENERGY?

Solar energy is energy made from sunlight. Light from the sun may be used to make electricity, to provide heating and cooling for buildings, and to heat water. Solar energy has been used for thousands of years in other ways as well.

Most life on Earth could not exist without the sun. Most plants produce their food via a chemical process called photosynthesis that begins with sunlight. Many animals include plants as part of their diet, making solar energy an indirect source of food for them. People can eat both plants and animals in a food chain providing one example of the importance of the sun's energy.

In direct or indirect fashion, the sun is responsible for nearly all the energy sources to be found on Earth. All the coal, oil, and natural gas were produced by decaying plants millions of years ago. In other words, the primary fossil fuels used today are really stored solar energy.

The heat from the sun also drives the wind, which is another renewable source of energy. Wind arises because Earth's atmosphere is heated unevenly by the sun. The only power sources that do not come from the sun's heat are the heat produced by radioactive decay at Earth's core; ocean tides, which are influenced by the moon's gravitational force; and nuclear fusion and fission.

### Historical overview: Notable discoveries and the people who made them

Ancient peoples did not just use solar energy; many of them worshipped gods based on the sun. More than 5,000 years ago ancient Egyptians worshipped a sun god named Ra as the first ruler of Egypt. Two ancient Greek gods, Apollo and Helios, were

## Words to Know

**Attenuator** A device that reduces the strength of an energy wave, such as sunlight.

**Convection** The circulation movement of a substance resulting from areas of different temperatures and/or densities.

**Current** The flow of electricity.

**Distillation** A process of separating or purifying a liquid by boiling the substance and then condensing the product.

**Heliostat** A mirror that reflects the sun in a constant direction.

**Hybridized** The bringing together of two different types of technology.

**Modular** An object which can be easily arranged, rearranged, replaced, or interchanged with similar objects.

**Passive** A device that does not use a source of energy.

likewise identified with the sun. Shamash was a sun god worshipped in Mesopotamia.

### *Ancient uses of solar energy*

Since at least the time when these gods were worshipped, the rays of the sun were used to dry things such as clothes, crops, and food. For centuries people who lived in the desert made homes from adobe, a type of brick made from sun-dried earth and straw. Adobe stores and absorbs the sun's heat during the day, which keeps the home cool. Then it releases heat at night to warm the home.

Ancient Greeks were aware of an early form of passive solar heating and cooling for homes. Passive solar heating and cooling use the sun's energy without help from any machines or devices. In one of his works, the philosopher Socrates (470–399 BCE [before the common era]) described how a home should be placed in relation to the sun so that it would be warmed in the winter and cooled in the summer. Ancient Romans and Chinese also designed and placed homes based on the principles of passive solar heating and cooling.

One famous Roman, Pliny the Younger (c. 61–c. 112), built a home in northern Italy that used this concept. In one room, he placed thin sheets of transparent mica (a mineral) in the window opening. That room was kept warmer than the others in the home. Because of the position of his house, Pliny was able to use less wood, which was used for heat and was in short supply.

Another way that ancient Romans used the principles behind passive solar energy was in the heating of water. In the public baths that were common at the time, black tiles were used in designs on the floors and walls. These tiles were set so they would be heated

## Polar Bears and Solar Energy

Scientists have discovered that the fur and skin of polar bears are very effective at converting sunshine into heat energy. Researchers became interested in learning more about this effect when Canadian scientists found that polar bears could not be seen through infrared photography equipment. Infrared cameras are supposed to be able to detect anything that gives off heat, including all warm-blooded animals. But such cameras cannot see polar bears because their fur keeps the body heat inside so well that it cannot be detected on the outside of their bodies. A polar bear's white fur even converts more than 95 percent of the sun's ultraviolet rays into heat. This amount is larger than any solar technology that scientists and researchers have devised (come up with).

A polar bear's white fur converts more than 95 percent of the sun's ultraviolet rays into heat. *JLM Visuals. Reproduced by permission.*

Scientists have studied polar bear fur to determine why it is so efficient at drawing in and holding heat. There are several reasons why they think the fur works this way. Each piece of hair in polar bear fur is really not white, but transparent or clear. And each hair is hollow at its inner core. Because each hair is hollow, the light that hits the fur travels from the hair's tip to the skin of the polar bear. Though polar bear fur is white, the skin is black. So when the sunlight reaches the skin, it is converted into heat. Some researchers believe that this is because the hairs work the way fiber optic cable works when it transmits telephone calls. The hairs send the heat from the sun down the hair to the skin of the polar bear, like fiber optic cables transmit light from one point to another. However, other researchers do not agree and are unsure of the process by which polar bears retain their heat so effectively.

Scientists have used their findings on polar bear fur to improve flat plate collectors, photovoltaic (PV) cells, and other solar technologies. They have applied it to reduce heat loss in flat plate collectors. They are hoping that other applications outside of solar energy might be possible.

by sunlight. The water that ran to the baths would pour over the tiles and become warmed. A Roman architect named Vitruvius (died c. 25 BCE) drew up plans for a bathhouse that used passive solar design to heat the building. He oriented the building so that it would be warmed by sunlight in the late afternoon, especially during the winter.

There are also ancient examples of concentrated solar power. In the ruins of Ninevah in ancient Assyria, burning glasses were found. Burning glasses are like magnifying lenses. They could be used to start a fire by concentrating light from the sun into a beam.

### *Modern solar developments*

Solar energy has been used for scientific purposes for several centuries. One scientist, Joseph Priestly (1733–1804), used sunlight to accomplish his discovery and isolation of oxygen in the 1770s. He heated and broke down mercuric oxide using heat created by concentrated sunlight.

An early nineteenth-century development was the greenhouse. Greenhouses are essentially passive solar energy collectors that collect the sun's energy to help grow plants. They capture light energy and retain heat while holding in humidity, which is used to water the plants. Greenhouses make it possible to grow plants even in winter.

Significant discoveries that advanced the use and efficiency of solar technology occurred in the nineteenth and twentieth centuries: photovoltaic cells and solar collectors, dish systems and trough systems, and power towers.

### *Photovoltaic cells*

The idea behind the photovoltaic cell was described by Alexandre-Edmond Becquerel in 1839. This scientist discovered the photovoltaic effect (also known as the photoelectric effect). He made his findings while conducting an experiment on an electrolytic cell. This cell was made of photosensitive materials and consisted of two metal electrodes placed in an electricity-conducting solution. When this cell was exposed to sunlight, an electric current was created.

Becquerel's experiments inspired other scientists to continue to work on the photovoltaic effect. Another discovery came in 1873 when Willoughby Smith (1828–1891) discovered the photoconductivity of the element selenium. Four years later two other scientists, William G. Adams and R. E. Day, learned that solid selenium could be used in the photovoltaic effect. They developed the first photovoltaic cell made with selenium. Their cell had limited power: It could convert less than 1 percent of the energy of the sun into electricity.

Though the photovoltaic cell designed by Adams and Day was not very powerful, another inventor was able to improve on their design. In 1883 the American scientist Charles Fritts came up with his own photovoltaic cell, which was made from selenium wafers. While work continued on photovoltaic cells in the late nineteenth and early twentieth centuries, it was not until 1954 that the first practical version of photovoltaic cells was created.

This cell was made in Bell Laboratories by three scientists: Calvin Fuller, Daryl Chapin, and Gerald Person. In the early 1950s they created a photovoltaic cell that was made from crystalline silicon. When exposed to light, their creation produced a significant amount of electricity. The 1954 version of the photovoltaic cell has proved to be the basis of all future photovoltaic cells. It was patented in 1957 and called a "Solar Energy Converting Apparatus." It has since been used on nearly all space satellites since that time.

The first satellite to use photovoltaic cells was the Vanguard 1, launched in 1958. The success of the Vanguard 1 led the National Aeronautics and Space Administration (NASA) to use photovoltaic cells as the normal way of powering satellites in the Earth's orbit. Even the Hubble Space Telescope, which was launched in 1990, uses photovoltaic cells to produce electric power. Such cells are also used to power the international space station.

#### *Dish systems, trough systems, and power towers*

In the mid-1800s a French engineer and math instructor named Auguste Mouchout was granted a patent for solar technology that used the sun to make steam. Mouchout used a dish to concentrate the sun's rays. His invention was an early version of the dish system. He began working on the project in 1860 in part because he was concerned that his country was too dependent on coal as an energy source.

Mouchout's design featured a cauldron filled with water. It was surrounded by a polished metal dish that focused the sunlight on the cauldron. This focused sunlight created steam that powered an engine. Mouchout's original engine generated one-half horsepower.

Over the next twenty years Mouchout continued to improve on his design. He replaced the cauldron with a multi-tubed boiler. This boiler made the engine run even better. Mouchout also made his overall design bigger. However, Mouchout's invention only found limited applications. It was used in the French protectorate of Algeria as a source of power for a time. Even this utilization was only short-lived, as coal transportation to Algeria improved and coal remained a much cheaper source of energy. Despite this situation, Mouchout was well known in France in his time, had the backing of the French government, and won a medal for his work.

Mouchout's invention led to innovations on the dish system by other scientists. One of them was John Ericsson (1803–1889), an engineer who was a native of Sweden but who lived in the United States. In the 1870s Ericsson came up with a different version of Mouchout's means of using the sun to make power. Ericsson attempted to improve on Mouchout's design. He first replaced the dish with a reflector shaped like a combination of a cone and a dish.

Ericsson later replaced this conical dish shape with a parabolic trough. This trough looked like an oil drum cut in half lengthwise. The trough reflected the sun's radiation in a line across the open side of the reflector. What Ericsson came up with evolved into the trough system that is currently used to convert solar energy into electricity.

Ericsson's creation was simple to make. It tracked the sun in a single direction: either north to south or east to west. The trough could not produce the same temperatures or work as efficiently as the dish-shaped reflector. However, Ericsson's design was functional from the beginning. Until his death, he continued to try to improve his design with lighter materials for the reflector.

Another scientist worked with Mouchout's basic design to create a new technology that became important in the late twentieth century. In 1878 William Adams, an English scientist, came up with a solar technology design that would become the basis for power towers. Adams set up flat, silvered mirrors in a semicircle around a cauldron. The mirrors were erected this way so that sunlight could be continuously focused on the cauldron. The mirrors were also placed on a rack that moved along a semicircular track so they could be moved throughout the day around the boiler by an attendant. Most modern solar power towers also use mirrors placed in a semicircle that reflect sunlight onto a boiler that generates steam to run a heat engine. Adams was able to run a small engine with his invention, though it never moved beyond the experimentation stage.

The American scientist Aubrey Eneas worked with both dishes and troughs, as well as with other solar technologies, in the late nineteenth and early twentieth centuries. Eneas first began experimenting with solar-driven motors. He formed the first solar company, the Solar Motor Company, in 1900 and spent the next five years working on his idea. Eneas first made a reflector similar to Ericsson's, but he could not make it work.

Then Eneas focused on making a reflector more like Mouchout's. Eneas improved on Mouchout's design to make the dish larger by increasing the sides to be more upright. The dish focused the sunlight on a boiler that was 50 percent bigger than earlier versions. Eneas exhibited his design at a Pasadena, California, ostrich farm. His demonstration model had a 33-foot diameter reflector with 1,788 mirrors. The boiler could hold 100 gallons (378 liters) of water and was 13 feet (3.9 meters) long. While Eneas received some attention in the press and sold a few of his systems, none could withstand bad weather. His idea failed to catch on.

***Solar collectors***

In the 1880s a French engineer named Charles Tellier (1828–1913) made significant strides in the development of the solar collector. He designed the first nonreflecting (that is, nonconcentrating) solar motor. His work in this area led to research for which he was better known: refrigeration.

Tellier's solar collector was made up of ten plates. Each plate consisted of two iron sheets that were riveted (joined) together so they had a watertight seal. The plates were connected by tubes to form a solar collector. Inside the collector, Tellier placed ammonia instead of water because ammonia has a lower boiling point than water. In 1885 he put such solar collectors on the roof of his home. When the collector was exposed to the sun, each plate released ammonia gas.

Tellier's solar collector worked well. The pressurized ammonia gas powered a water pump. This water pump was put in a well and was able to pump about 300 gallons per hour during daytime hours. Tellier was able to increase the efficiency of his collectors by covering the top with glass and by putting insulation on the bottom.

Tellier believed that his solar collectors would work for anyone in the Northern Hemisphere that had a south-facing roof. He also was certain that his system could be used industrially if more plates were added to the collectors to make the system bigger. Tellier hoped his invention would be used in Africa to provide power and to manufacture ice. But while he realized that he had a good idea, Tellier decided to focus on developing refrigeration technologies.

Other inventors improved on Tellier's design. In the first decades of the twentieth century American scientists such as Henry Willsie and Frank Shuman came up with their own solar collector designs. Their inventions failed to catch on at the time but continued to improve the technology.

## The Million Solar Roofs Initiative

Announced by the U.S. government in June 1997, the Million Solar Roofs Initiative called for one million homes and businesses in the United States to install solar energy technologies such as PV cells for electricity, solar collectors, and solar water heaters by 2010. The initiative had several goals. The federal government hoped to increase the market for solar energy and keep it viable. It was also hoped to spur job creation in the solar industry in the United States. One study showed that each solar roof could stop thirty-four tons of greenhouse gases from reaching the atmosphere over its lifetime of use. There was widespread support for the initiative. At least eighty-nine different partnerships formed to help achieve this goal, with both state and local governments as well as private businesses and community organizations. Financial incentives were given by the U.S. Department of Energy and by agencies on the state and local levels. By 2002 nearly 350,000 roofs had been installed as part of the program.

### *Government-supported developments*

Government support of solar energy helped move the industry forward in the 1970s and early 1980s. Many homes were built that featured solar technologies. Although government support decreased in the 1980s and early 1990s, some progress continued on alternative energy research. By the mid-1990s there was renewed interest in the United States in building homes and businesses that used solar technologies.

In 2004 only six percent of U.S. energy came from renewable sources, and only three percent of that six percent came from solar energy. However, many experts believe that solar power will be the most important alternative energy source in the future.

## How solar energy works

Solar energy technologies use the energy that comes from the sun. Inside the sun, hydrogen atoms combine to make helium, and the process produces the extreme amount of heat that is felt on Earth. The core of the sun has a temperature of 36,000,000°F (20,000,000°C). The surface of the sun, called the photosphere, has a temperature of 10,000°F (5,538°C). The energy that the sun creates has to travel 93,000,000 miles (150,000,000 kilometers) to reach the surface of Earth.

People on Earth do not feel the full force of the sun, because Earth's upper atmosphere blocks out much of the sun's thermal power. This power, sometimes called radiation, is spread out when it hits the water vapor, molecules of gas, and clouds that surround Earth. The sunlight that does reach the ground is called direct radiation or beam radiation. If the sunlight hits something before reaching the ground, it is called diffuse radiation.

The amount of solar radiation that reaches the surface of Earth is more than ten thousand times the amount of energy used by the world already. A significant amount of the sun's radiant energy, about 69 percent, is reflected back into space by such things as clouds, ice found on the ice caps, land, and bodies of water. Of the energy that is absorbed by Earth, about 70 percent of the absorption is done by the oceans. Solar energy helps keep the oceans from freezing and pushes their currents. It also prevents Earth's atmosphere from freezing.

## Current solar technology

Solar technologies can be divided into passive systems or active systems. Passive solar energy projects only employ the sunlight; no other forms of energy are used. Active solar energy systems employ additional mechanisms such as pumps, blowers, or generators to apply or add to the solar energy created. Active systems often make electricity or heat. Solar water heating systems can be either active or passive.

### *Passive solar systems*

Passive solar systems are primarily concerned with the design of buildings, homes, and lighting. Passive solar design focuses on the placement of the home or building and on windows, ventilation, and insulation to cut down on the need for electricity by using the sun. The home or building is designed to maximize the potential of solar energy for heating and cooling. In northern countries such as Canada, where sunshine is not as strong as it is in locations to the south, passive solar heating is one of the easiest forms of solar technology to use.

One important form of passive solar design is known as "daylighting." In daylighting the placement and design of windows is used to encourage natural sunlight to light the inside of a building instead of electric lights. Daylighting helps cut down on lighting costs, and many experts believe that exposure to natural rather than artificial light sources provides health benefits to humans.

Another type of passive solar system is the transpired solar collector. This is a relatively new passive solar technology made of dark perforated metal. Transpired solar collectors are used to heat buildings by heating the air. They can also cool buildings in summertime.

#### *Active solar systems*

Active systems include solar collectors (also known as solar panels), which are primarily used on solar hot water heaters; photovoltaic (PV) cells, which make electricity; and concentrated solar power systems (also known as solar thermal systems), which also make electricity but on a larger scale than PV cells.

Solar collectors are used primarily to capture solar energy for use in solar hot water heaters. However, they can also be used to provide heat in a building and even to make the energy to cool a building. While not all solar collectors are used in active solar energy systems, it is more common for solar collectors to be used in an active system than a passive system.

Photovoltaic (PV) cells convert sunlight directly into electricity inside the cell. They are more adaptable than many other types of solar energy technology. In addition to powering satellites, PV cells can be put on buildings to provide electricity for any number of uses. They do not require direct sun to convert sunlight into electricity.

There are at least five types of concentrated solar power systems that focus the sun's power to make electricity on a larger scale than PV cells. They include solar ponds, parabolic trough systems, dish systems and dish-engine systems, solar power towers, and solar furnaces. Mirrors or other reflective devices draw in as much sunlight as possible to these systems. They often track the sun as it moves through the sky in order to capture the most sunlight.

Concentrated solar power systems usually heat water, or another fluid that is connected to a source of water, to make steam. The steam is used to drive turbines that create electricity. Concentrated solar power systems are primarily used for industrial applications and to make electricity for consumers and businesses on a wide scale.

### Emerging solar technologies

There are several technologies being developed that bypass mirrors and collectors to capture the sun. Solar paints contain conductive polymers, extremely small semiconducting wires, or quantum dots. Such paints could be used to coat any surface and turn it into an electrical generator. Other companies are working on similar technologies for plastics. Rolls of plastic are coated with an electricity-generating film. The plastic could be spread over roofs or other surfaces to convert sunlight into electricity.

The use of solar energy to cool homes and buildings is another area under more development. Such systems use solar panels to produce electricity. These panels power a pump connected to an absorber machine. This machine works something like a refrigerator. The absorber employs hot air to compress a gas. When this gas expands, it causes a reaction that cools the air. Solar thermal coolers are expected to reach the commercial market in the early twenty-first century.

Many new solar technologies are still in the experimental stage. One possibility is solar-powered air flights. Another is a different kind of solar lighting, in which a building's interior is lit by a parabolic collector on the roof. This collector is connected to the interior by fiber optic light pipes. Such a system would make its own electricity to power the lights.

### Benefits and drawbacks to solar energy

One of the primary benefits to solar energy is that it is a renewable resource. Sunshine is available everywhere free. There is no limit to its renewability, at least not until the sun burns itself out billions of years from now. Solar energy also does not contribute to pollution and thus is considered a "clean" energy source. Using it produces no greenhouse gases and thus does not contribute to global warming.

The biggest drawback to using solar energy is the cost of the technology. Solar photovoltaic cells and solar collectors are still very expensive. While the technology may become cheaper over time, it is still costly when compared to the amount of energy it will produce over its use cycle. Similarly, it is very expensive to build solar power towers and furnaces. Using such technology to generate power on a wide scale is too expensive to be used realistically, at least as of the early twenty-first century.

Another major problem with solar technology is that solar energy is not available on demand in every location on Earth. Heavy cloud cover can limit the use of some solar energy systems. Some systems cannot be used at all if direct sunlight is not available. In most areas of the world, only low-power solar energy applications can be used because of the lack of direct sunlight.

## Japan and Germany Lead the Way

No two nations have invested more heavily in solar power than Japan and Germany. By 2001 Japan was able to produce up to 671 megawatts of solar-generated power at peak conditions. The country was also a leader in the number of solar water heating units being used. As of 2005 there were more solar hot water heaters being used just in the city of Tokyo than in the whole of the United States.

As of the early 2000s Germany was number two in the world with 260.6 megawatts of solar-generated power being produced at peak conditions. By this point the German city of Freiberg had more solar projects than any other city on the continent of Europe. It was home to the headquarters of the International Solar Energy society, and the city also featured parking meters powered by solar power.

For large-scale projects such as solar power towers and solar furnaces, or even smaller-scale projects such as solar ponds, dish systems, and trough systems, large areas of land are needed. In the desert, where a number of these systems are currently located, the solar technology that is put there to capture the intense sunshine is considered unsightly by some people.

### Environmental impact of solar energy

Solar energy can have both positive and negative effects on the environment. On the positive side, most solar technologies are environmentally friendly. They do not pollute the atmosphere by emitting (giving off) greenhouse gases, they do not produce radioactive waste like nuclear energy reactors, and they do not contribute to global warming or acid rain. Most solar energy systems are silent or quiet when they operate, which cuts down on noise pollution. If solar technologies that make electricity on a significant scale can be adopted, many countries can lessen their dependence on electricity produced by fossil fuels. This change could decrease the amount of environmental pollution in the world.

However, solar energy technologies are not perfect. In addition to large-scale projects negatively affecting the landscape, these solar technologies can negatively affect the animal life around them. Big dish systems, trough systems, and power towers take up land that animals live on and affect their habitats. The very building of these projects can pollute otherwise pristine (clean) lands, even if the solar technology itself does not. Also, while the use of solar technology does not pollute the environment, the manufacture of certain types of solar technology can.

### Economic impact of solar energy

The adoption of solar energy technologies can have a profound impact on the economies of individual communities, states, and countries. When renewable energy sources such as solar energy are used in a community in the United States, more of the money spent on that energy stays at least in the same area, if not within the country. Most of the cost of solar energy implementation comes from materials and installation, not buying the actual fuel source as is the case with oil. The materials can be local, and the installation is often done by local companies.

The use of solar energy can also make countries more energy independent. Currently many countries rely on foreign oil for nearly all their energy needs. Because a few countries hold most of the oil resources in the world, they have a lot of control over the pricing and distribution of that oil. If nations are able to augment the imported oil with solar energy, they will be better able to govern their future energy supply.

### Societal impact of solar energy

The spread of solar energy technologies could lead to electrical power being available where it was not available before. People who live in rural areas are often not connected to an electrical power grid; this is especially true in poorer, less developed countries. In 2000 more than two billion people worldwide did not have access to electricity. Solar technologies could provide energy to these communities.

### Barriers to implementation or acceptance

There are two main barriers to implementation of solar energy on a larger scale: efficiency of the technology and cost of the technology. As of 2005 the existing solar technology was still too inefficient to make it a viable energy source on a large scale. The existing PV cells, for instance, do not convert enough sunlight into energy.

The other main barrier is cost. Over the years many researchers and companies have announced that solar technologies will be ready and/or profitable by a certain date, but this promise has not been kept. Even if the technology has become available, it has not been developed as cheaply as promised. Some critics believe that solar energy, as well as other alternative energy sources, will never live up to the promises made by its supporters; they feel that the energy produced by solar power will never be enough to make up for the high cost of producing it. Increased tax breaks for solar technology on the federal, state, and local levels could help build the marketplace for the technology and drive down the production and implementation cost.

Another barrier to implementation is that solar technology has not yet been applied on a widespread basis and thus remains unproven on a large scale. The technology has done well in small, specialty markets, proving that it can work, at least on this scale. More large-scale success would increase the perception of solar energy as a useful technology for the future.

## PASSIVE SOLAR DESIGN

Passive solar design focuses on the construction of the building, the way its site is set up, the environment around it, and its orientation to the sun to make the best use of the amount of sunlight to which it is exposed. These choices can cut down on electricity costs for the building while also helping to light, heat, and cool it.

Passive solar design can be used on many types of buildings, including homes, businesses, industrial sites, schools, and shopping facilities. In the Northern Hemisphere, buildings created on the principles of passive solar design usually have the longest walls running from east to west. This orientation allows heating from the sun in the winter and much less sun exposure in the summer. Such buildings also feature large south-facing windows, which are often insulated. Building materials that absorb and slowly release the heat of the sun are used in the flooring and walls. Such building materials include rocks, stone, or concrete; some even contain saltwater, which can collect the solar energy as heat.

Another key facet of passive solar building design is a roof overhang. Such overhangs are designed to allow sunlight to stream inside during the winter and shade windows from the higher sun in the summer. In areas where summer temperatures are high, especially in the South, putting roof overhangs on buildings can help keep buildings much cooler than they otherwise would be.

Some passive solar-designed buildings can be located underground or built into the side of a hill. Because the temperatures found a few feet below ground are steady, this allows the building


Passive solar design focuses on the placement of the home or building and on windows, ventilation, and insulation to cut down on the need for electricity by using the sun. © *Joel W. Rogers/ Corbis.*

to be cool in the summer and warm in the winter. Another passive solar concept is landscaping, or the design and placement of trees and shrubs around a building. For example, deciduous trees, which lose their leaves in the winter, can be planted around the building to keep it cool during the summer by providing shade. During the winter, when the trees are bare, more sunlight reaches the building.

There are five basic types of passive solar design systems:

1. Direct Gain. Direct gain is the simplest type of passive solar design. In this system a large number of windows in a building are set up to face south (in the Northern Hemisphere). The glass is usually double-paned or even triple-paned. That is, the glass consists of two to three panes of glass with a pocket of air in between each pane. These panes are sealed inside one frame. Materials that can absorb and store the sun's heat can be incorporated into the floors and walls that are hit by the sun. These floors and walls release the heat at night, when it is needed the most to heat the building.

Adobe house with passive solar power. © *Michael Freeman/Corbis.*

2. Thermal Storage. Thermal storage is very similar to direct gain. In this system, there is also a large wall oriented to the south in the Northern Hemisphere. This wall is placed behind double-glazed windows so that it can absorb sunlight. In some of these thermal storage systems, the wall contains a storage medium such as masonry or perhaps water. The solar energy that is collected is stored during daylight hours so that it can be released when there is no sun.
3. Solar Greenhouse. Solar greenhouses are also known as sunspaces. They are a combination of both direct gain and thermal storage but are located in a greenhouse. The wall of the thermal storage system is placed next to the greenhouse and the home to which it is attached. This system primarily heats the greenhouse but also can provide heat to the house itself.
4. Roof Pond. As its name implies, the roof pond system consists of ponds of water placed on a roof. These ponds, which are exposed to the sun, collect the radiation from the sun and store it. The heat that is produced is controlled by

insulating panels that are movable. During the winter these panels are open during daylight hours so that sunlight can be collected. During nighttime hours the panels are closed so that little or no heat is lost. The heat that is collected is released into the building to warm it. During the summer roof ponds are used in the opposite way. The panels are closed during the day to block the heat of the sun. At night they are opened to allow cooling of the building.

5. Convective Loop. The convective loop is also known as a natural convective loop. In this system, a collector is located below the building's living space. The hot air that is created from solar energy rises to heat this living space when needed.

### Current uses of passive solar design

Passive solar design is primarily used in the planning of homes, offices, schools, and any other type of building. In 2001 about one million U.S. homes and twenty thousand buildings used only for commercial purposes employed the principles of passive solar design.

### Benefits and drawbacks of passive solar design

What makes passive solar design so simple is that it has no moving parts or working parts. Buildings made using passive solar design do not need to be maintained any differently than any other type of building.

Buildings created with passive solar design in mind are more effective in sunny environments, though buildings in any environment benefit from passive solar design. Sometimes these buildings can become overheated in the summer. However, design changes can address this issue. Nevertheless, it would be difficult to retrofit a home or building with passive solar design principles unless it sat on its lot in the correct orientation to the sun.

### Impact of passive solar design

Passive solar design has no real negative effects on the environment, other than what would happen when any building is constructed. The principles of passive solar design often incorporate trees, resulting in more trees being planted in an area.

Economically, passive solar–designed buildings can produce heating bills that are 50 percent less than buildings without any passive solar design principles, a significant savings in energy costs. The increased use of passive solar design can bring business to builders specializing in this discipline. However, unlike other solar technologies, passive solar design does not afford any tax breaks from the U.S. government.

#### Issues, challenges, and obstacles of passive solar design

One potential issue related to the use of passive solar design is that not every architect accepts and employs these principles. There are only a limited number of professionals who design such buildings. There is currently a limited market for passive solar design because many people do not know about it. However, the popularity of passive solar design is poised to grow as consumers look for ways to battle higher heating and cooling bills caused by the increase in the cost of electricity and natural gas.

### DAYLIGHTING

Daylighting, also known as passive lighting, is a form of passive solar design. Daylighting involves the use of sunlight to light up the inside of a building. Daylighting can fully replace electric lights, or it can be used to cut down on electrical costs by supplementing electrical lighting already being used. Daylighting can also be used to heat a building.

Daylighting primarily occurs through a building's windows, though other kinds of openings on buildings, such as skylights, can also be used. The windows are often large and, in the Northern Hemisphere, face south. Buildings and homes that use daylighting have specific placement and spacing of windows. For example, windows that are higher up on a wall distribute sunlight better. Windows called clerestory windows (a row of windows located at the top of a wall, near the roof) are an important part of daylighting in museums and churches. Skylights, when combined with sensors and other lighting elements, can ensure that lighting inside a building stays even.

Windows used in daylighting absorb sunlight and release it slowly to light up a building. One way to regulate the amount of sunlight and/or heat is through window shades or curtains that are insulating. Light shelves can also be used. They are placed so that the sunlight drawn in by the windows is reflected and lights a room from top to bottom. These shelves can bring natural light deeper into a room.

Chemical compounds in windows for daylighting can be made part of window glass or placed between the panes of double- and triple-paned windows. These compounds can boost how much solar energy a window can store. They can also increase the insulating capacity of windows. In addition, coatings and glazings on the windows can control the amount of light or heat. The heating effect of daylighting can be increased by window coatings that are anti-reflective. Some window coatings can carry an electric current that can moderate how much light or heat is let in based on current weather conditions. One type of glazing can allow a measured amount of light to pass through a window while keeping heat out.

In daylighting systems where natural light is used with electrical lighting, there is need for a control system. This control system regulates the amount of electric light used based on how much daylighting is available. The types of controls include photocell sensors, infrared receivers, occupant sensors, dimming control systems, and wall-station controls.

Building materials and interior design can enhance the effectiveness of daylighting. Walls that are white or brightly colored reflect the light that is drawn inside. In office buildings, cubicle walls kept under a certain height will allow the sunlight to spread over the office.

New technologies are being developed to increase the effect of daylighting. Some buildings are incorporating heliostats, which are the same mirrors used in solar power towers. The heliostats can track the movement of the sun during the day and reflect the sunshine into windows. Another device that is being worked on employs fiber optics to take the sunlight collected on the roof inside the building.

### Benefits and drawbacks of daylighting

As daylighting provides light during the day, the amount of heat gain from electric lighting is reduced significantly. Daylighting also makes homes and buildings less gloomy. However, homes and buildings that use daylighting often have to deal with issues such as heat and glare. If the natural lighting is not regulated, the system is not properly designed, or the correct type of window for the local environment is not used, homes and buildings can become hotter than they would were daylighting not used. Daylighting can potentially increase cooling costs during the summer because there is more natural light inside. Daylighting will not work everywhere because there is not enough sunshine in some locations.

Daylighting is difficult to incorporate into buildings that have already been constructed. Even if daylighting is built into a new building, the controls needed to regulate the natural light and electric lights are expensive and require a significant investment. After the system is installed, it must be operated and maintained. People must be trained to deal with the sensors and computer systems that come with many daylighting systems.

### Impact of daylighting

There is little to no negative environmental impact with daylighting as an energy system. The only effect on the environment comes from the production of the windows, coatings, controlling systems, and buildings. Using daylighting ensures that fewer fossil fuels are burned, cutting down on pollution.

For consumers and businesses, the use of daylighting can cut electric bills significantly, perhaps up to one-half. It can also cut down on energy costs for buildings. If daylighting is done correctly, less air conditioning is needed during the summer months.

Because of daylighting's positive effects on people, workers in offices with daylighting are more productive. There are fewer absences and errors by such workers. When workers' productivity is increased, businesses can become more successful. Daylighting can even affect shoppers. Shopping centers and malls that incorporate daylighting into their design find that more natural light may lead to increased sales.

### Issues, challenges, and obstacles of daylighting

Though daylighting is simple and the principles behind it show evidence of success, there is still a reluctance to embrace this solar energy system. The reasons vary. Adjusting building plans in order to place windows to save on electrical costs may increase the price of the building and thus affect its appeal to potential buyers. Also, daylighting is difficult to incorporate into existing buildings, so its growth may be limited solely to the new construction industry.

## TRANSPIRED SOLAR COLLECTORS

A transpired solar collector, sometimes known under the brand name Solarwall, is used to heat what will become ventilated air as it enters a building. This relatively new technology was developed with the support of the U.S. Department of Energy and has won several awards.

The transpired solar collector is very simple. It is a metal panel that is dark colored and has perforations (lines of holes). The metal is usually corrugated steel or aluminum. The piece of metal is formed to fit and mounted on the outside of a south-facing building wall. The collector is not fully attached to the inside wall; instead, a gap is left between the metal panel and the interior wall of the building. There are ventilation fans at the top of the space and the interior wall. These fans draw in the air through the holes in the metal panel. After the air enters the space between the walls, it rises to the top of the panel. The air becomes heated as it passes near the hot metal panel and continues to rise to the ventilation fans, where it is sucked into the building. This hot air is circulated through the building via its air ducts.

A transpired solar collector does not just heat the air for a building. It can help cool the building as well. During summer months the ventilation fans draw in the hot air. Instead of bringing this hot air into the building, bypass dampers are used to move the hot air back outside. This hot air then does not come in direct contact with the inner wall, thus making the building cooler.

### Current uses of transpired solar collectors

Transpired solar collectors are primarily used to heat air for office buildings, schools, homes, and industrial facilities. While the technology can be used in most buildings, it is really useful for buildings that are used by industry, commercial interests, and institutional interests. Such buildings usually need a lot of ventilation, and this technology can be extremely helpful in such circumstances. Transpired solar collectors can be used to preheat combustion air for industrial furnaces. In an agricultural setting this technology can be used to create hot air for crop drying.

### Benefits and drawbacks of transpired solar collectors

As a means of heating air, transpired solar collectors are very inexpensive to make and very efficient. They preheat air twice as effectively as any other type of solar heater. Transpired solar collectors can use as much as 80 percent of the solar energy that comes into contact with the collector. The use of a transpired solar collector can result in much lower energy costs for the building to which it is attached.

Transpired solar collectors can be used in parts of the world where there is not a significant amount of direct sunlight. For example, this solar technology can be used in Canada and the northern United States. Snowfall can actually make the transpired solar collector heat better. When snow covers the ground, it can reflect as much as 70 percent more solar radiation onto the transpired solar collector. More reflected solar radiation results in more heat produced. In addition, transpired solar collectors do not need as much additional heating as other solar heating systems when there is no sunlight. The heat that is collected during the day can be retained and used after dark.

On the other hand, only buildings that have a south-facing wall, at least in the Northern Hemisphere, can effectively use a transpired solar collector. Because of this requirement, it can be difficult to retrofit certain homes and buildings with this solar technology.

### Impact of transpired solar collectors

The use of transpired solar collectors has no real negative environmental impact. There is a chance that the manufacture of the metal or other pieces needed for the collector can negatively affect the environment. But by using a transpired solar collector, fossil fuel use can be lessened because the solar technology cuts down on energy costs.

Many states offer consumers and businesses tax credits and incentives for the installation and use of transpired solar collectors. In new construction projects, when the transpired solar collector begins to operate to both heat and cool homes and buildings, consumers and businesses save money. The technology can reduce annual heating costs by about two to eight dollars per square foot because it can increase the temperature of incoming air by 54°F (12°C). For new construction, transpired solar collectors can pay for themselves in three years. If the technology is put on an already existing building, the transpired solar collectors pay for themselves in seven years. The cost savings depends on how long the heating season is and what kind of air ventilation is needed.

### Issues, challenges, and obstacles of transpired solar collectors

Transpired solar collectors have not yet been widely embraced because the technology is relatively new. The collectors were not invented until the 1990s, and the general public only has minimal knowledge of the technology.

Another obstacle is that transpired solar collectors are most often large and very noticeable on a building. Because they need a dark color, they do not always blend in with their surroundings. Certain types of businesses might be reluctant to put something so large on their building if the owners or operators feel the collector will detract from the way their building looks.

## SOLAR WATER HEATING SYSTEMS

A solar water heating system uses the sun's power to heat water. The water can be used in homes, businesses, swimming pools, hot tubs, and spas. On a larger scale, water can be heated for industrial processes.

While there are many different types of solar water heating systems, there is a common method to how they work. Most are simple in design and inexpensive to install, even in older homes. In general, the sunlight passes through a collector. The radiation that is absorbed by the collector is usually converted to heat in a liquid-transfer medium or through the air. The radiation can also be used to heat the water directly.

Solar collectors are used primarily to capture solar energy for use in solar hot water heaters. However, they can also be used to provide heat in a building and even to make the energy to cool a building. © *Dietrich Rose/ zefa/Corbis.*

Solar water heating systems can be active or passive to transfer the heat. An active solar water heating system uses pumps to transfer heat from the collector to the storage tank. Active systems can use a PV module to produce the electricity to run an electric pump motor. In a passive system, the system does not use pumps or control mechanisms to transfer the heat created to the storage tank. Instead, passive systems use natural forces such as gravity to circulate the water. There is also an exchange/storage tank of some kind. When such systems are used for bigger buildings that house businesses or offices, there is often more than one storage tank for the water.

There are at least six types of solar water heating systems:

1. Direct Systems. Direct systems use a pump to circulate the water. The water moves from the home into a water storage tank and passes through the solar collectors for heating.

After it leaves the collector, the water returns to a tank. From there, it is pumped back into the house as hot water. The pump can be powered by a PV cell or by an electronic controller or appliance timer. Direct systems are usually used in warm climates with few or no days in which the temperature dips below freezing. Because of this requirement, there is a very limited area where direct systems can be used, at least in the United States.

2. Indirect Systems. Indirect systems use a heat exchanger that is separate from the solar collector. The collector contains an antifreeze solution instead of the water to be heated. The heat exchanger transfers the heat from the collector's antifreeze solution to the water located in the water storage tank. The heat exchanger can either be inside the storage tank or outside the storage tank. One advantage to this system is that it can be used in areas where the temperature falls below the freezing point.
3. Thermosyphons. A thermosyphon solar water heating system features an insulated storage tank that is placed above the solar collector, usually a flat-plate collector. When the sun hits the collector, it warms the water located in the tubes that pass through the collector. This water travels up through the top of the storage tank, which is insulated, and out through a hot water pipe. At the bottom of the storage tank is the cold water, which travels down through a pipe and into the collector. Sometimes, a small pump can be added to this system if it is not possible to place the tank on the same level or below the collectors. This system is more common outside of the United States and can only be used in warmer climates where temperatures remain above freezing. Locations in the Caribbean, Middle East, Mediterranean, Australia, and Asia use this system.
4. Draindown/Drainback Systems. Draindown systems are often used in cold climates. In this system, water passes through the collector to be heated. Draindown systems prevent water from freezing inside the collector by the use of electric valves. These valves automatically remove the water from the collector if the temperature gets too cold. The drainback system is very similar to the draindown system. When the circulating pump that is part of the drainback system stops as a result of cold temperatures, the collector is automatically drained.

5. Integral Collector Storage (ICS) Systems. These types of systems are also known as integrated collector systems, batch heaters, bulk storage systems, or breadbox heaters. Whatever the name, the ICS system features a collector and 40-gallon (151-liter) insulated storage tank that are part of one unit. The tank is lined inside with glass and painted black to draw in the sun's heat. The ICS system is usually placed on a roof or in a place on the ground where there is sunlight. Cold water comes into the ICS system from the plumbing in the house. The inlet inside the tank pushes the water to the bottom of the tank. The hot water rises in the tank and goes into the building through an outlet. There can also be a backup tank below the ICS unit that transfers water to be heated when the already heated water is taken from the primary storage tank. One drawback to this system is that the hot water created by the ICS system should be used during the afternoon or evening hours. If it is not, it should be transferred into another storage tank before nightfall. Otherwise, the water in the primary storage tank might lose much of its heat overnight, especially in cold weather.
6. Swimming Pool Systems. The solar energy systems used to heat swimming pools and hot tubs are usually simpler than other kinds of solar water heaters, but just as effective. The use of a solar water heater can allow an outdoor pool or hot tub to be used for at least four months longer than a pool or hot tub without a heater. The system usually consists only of a temperature sensor, an electronic controller, a pumping system, and solar collectors. The collectors can be mounted on the pool's deck, on the ground, or on a roof. Most collectors used for pools or hot tubs usually have no glass covering or insulation. They are also usually lower-temperature collectors. That is, they usually are designed only to raise the temperature of the pool's water to about 80 to 100°F (26 to 37°C). This system does not need a storage tank since the pool or hot tub serves as the storage medium.

There are also pumped systems intended for bigger buildings, such as hotels and gymnasiums. In this type of system the storage tank is located inside the building and uses a pump to transfer water between the collectors and the tank. In addition, a controller is needed that detects when the water in the panels is hotter than the water in the tanks. The controller regulates the pump so that the temperatures remain correct. If the outside temperature gets below freezing, the pump starts running to prevent the water from freezing.

#### *Flat plate collectors*

The most common type of energy collector, the flat plate collector, is a rectangular-shaped box that is put on the roof of the home or building where the solar water heating system is located. Inside the box is a thin absorber sheet, usually black in color and made of either copper or aluminum. Behind the sheet is a tubing system in the form of a grid or coils. The collector and tubing system are put inside an insulated casing. The cover is usually glass and transparent. This glass is often black or a dark color that draws in the sunlight.

As the sun shines, the heat builds up in the collector and heats the fluid that is inside the tubes. If it is water, it is heated and passes through a storage tank. If the fluid inside is antifreeze, the water is heated by circulating the heated solution through a tube inside the storage tank in which the water is located.

#### *Evacuated tube collectors*

This type of collector features rows of glass tubes placed parallel to each other with a vacuum between them that insulates the tubes and helps hold on to the heat. The tubes are also transparent and covered with a coating. Inside each tube is an absorber with liquid inside it. When light from the sun hits the tube and its radiation is absorbed by the absorber, the liquid inside is heated. Because of the vacuum between the tubes, this liquid can be heated to very high temperatures, up to 350°F (176°C). Though the evacuated tube collectors can achieve high temperatures, they are more fragile than other types of solar collectors and more expensive.

### Current use of solar water heating systems

Solar water heating systems have existed for many years. They are used in homes, businesses, schools, office buildings, prisons, military bases, and industrial settings. Solar water heating systems can be used to power irrigation systems, and they can also be used to provide water for livestock on farms and ranches. Solar hot water heating systems are often used where natural gas or electricity cannot be used to heat water.

For a typical household, solar water heating systems can provide from 70 to 90 percent of the hot water needed for bathing and laundry. In a common single family home in the United States, about

25 percent of the energy is used to heat water. As of 2001 about 1.5 million solar water heating systems were being used in the United States in both commercial businesses and homes. About 300,000 swimming pools were being heated the same way. By 2005 at least 500,000 homes in California alone used solar water heating systems.

### Benefits and drawbacks of solar water heating systems

One of the biggest benefits to solar water heating systems is their practicality. They are relatively easy to install in both new and existing homes and buildings. Because of the variety of systems available, at least one type will work in most locations. The systems are long-lasting, with most systems lasting a minimum of fifteen to twenty years. Passive solar water heating systems in particular are very inexpensive because of the limited equipment involved and the little maintenance required.

However, certain types of solar water heating systems cannot be used in freezing temperatures, limiting the area in which solar technology can be used. Some types of solar water heaters cannot work as well or at all when it is cloudy. Because of the variations in temperatures and sunlight in most parts of the world, solar water heating systems sometimes need a backup water heating system to ensure the availability of hot water at all times. For many consumers, businesses, and institutions, this situation often means the purchase or use of a whole other hot water heater or water storage system with a means of keeping the water warm.

### Impact of solar water heating systems

The use of a solar hot water heating system is positive for the environment. Using these systems reduces the amount of oil-based electricity used, resulting in fewer pollutants and lower greenhouse gas emissions. The manufacture of the elements in a solar water heating system can potentially affect the environment negatively, since most manufacturing processes require fossil fuels.

On an economic level, the installation and use of a solar water heating system can immediately save a consumer, business, or institution money in electricity costs. It only takes a few years for the system to pay for itself through energy cost savings. For example, a swimming pool solar water heater can pay for itself in about three years. However, some solar water heating systems, primarily those that heat swimming pools, are usually not eligible for any type of tax credit, rebate, or incentive for use.

**Issues, challenges, and obstacles of solar water heating systems**

Solar water heating systems can save money and are widely available. There are even "do it yourself" kits that allow the average home owner to add a solar hot water heater to his or her home. These kits are usually for batch solar water heaters. Despite this wide availability, these systems are not yet commonly used. In general, solar water heating systems can be expensive when compared to conventional water heating systems.

Advances in other water heating technologies also have drawn consumers away. There are new technologies that use natural gas to both heat water and spaces inside a home very efficiently. Such developments can potentially lengthen the payback time of a solar water heating system, making them less attractive to consumers and businesses.

## PHOTOVOLTAIC CELLS

Photovoltaic cells, also known as solar cells, photoelectric cells, or just PV cells, are a type of solar technology that takes the energy found in light and directly converts it to electrical energy. PV cells are modular. That is, one can be used to make a very small amount of electricity, or many can be used together to make a large amount of electricity. A 3.9-inch (10-centimeter) diameter PV cell can make about one watt of power if the sun is directly overhead and the conditions are clear.

Because each photovoltaic cell produces only about one-half volt of electricity, cells are often mounted together in groups called modules. Each module holds about forty photovoltaic cells. By being put into modules, the current from a number of cells can be combined. PV cells can be strung together in a series of modules or strung together in a parallel placement to increase the electrical output.

When ten PV cell modules are put together, they can form an arrangement called an array or array field. Like modules, arrays can also be organized in a series or placed in parallel fashion. Arrays can be used to make electricity for a building or home. If many arrays are combined, they can create enough power to power a power plant. Some arrays are combined with a sun tracking device to ensure the sun hits the PV cell arrays throughout the day.

Even with photovoltaic cells, concentrating systems can be used to get more sunlight on the actual cells and help them produce more power. Such systems use mirrors or lenses to focus more sunlight on the PV cells. They also must be able to track the sun and be able to remove excess heat. If the temperature is too high in the PV cells, the amount of power each cell puts out is decreased.

Inside a photovoltaic cell are thin layers of a semiconductor material. Most commonly, these materials are silicon (melted sand) or cadmium telluride. The layers have a tiny amount of doping agent. Doping agents are impurities intentionally introduced in a chemical manner. Germanium and boron are examples of one type of doping agent that is used. The doping agents are important because they give the semiconductor materials the ability to make an electric current when exposed to light. These layers are stacked together. Each PV cell converts about 5 to 15 percent of the sunlight that hits it into electrical current.

***Types of photovoltaic cells***

There are several types of PV cells. A monocrystalline PV cell is blue or gray-black in color. At the rounded corner of each cell is a white backing. This backing shows through and makes a pattern that is easy to see. Some people do not use monocrystalline PV cells on their home or businesses because of their appearance. A module of PV cells is usually covered with tempered glass and surrounded by an aluminum frame.

A polycrystalline PV cell looks a little different than a monocrystalline PV cell. Polycrystalline PV cells are shaped like rectangles and colored sparkling blue. There is no white background showing. Thus, these PV cells look more uniform in appearance. Like monocrystalline cells, they are often covered in tempered glass and placed in an aluminum frame.

Another type is the amorphous or thin-film cell. However, this type of PV cell is less durable, not as efficient for the conversion of sunlight into power, and not as commonly used at this time. However, many experts believe that thin-film cells are the future of PV cell technology because they use less semiconductor material, do not need as much energy to manufacture, and are easier to mass produce than other PV cells.

Sometimes, photovoltaic systems have other components to make them useful for providing electricity. Two such components are an inverter and a storage device. The inverter helps change the DC power (direct current) produced by the cells to the AC (alternating current) used by most equipment, homes, and businesses that run on electricity in the United States.

The storage unit stores the energy created by the photovoltaic cells for use when there is little or no sun. One storage unit that

## Solar Races and Other Contests

To encourage the development of solar energy and related technologies in the United States and around the world, there are a number of solar energy contests and competitions for students of many ages. Arguably the best-known solar energy competitions are the long-running solar car races. There is a World Solar Challenge, as well as smaller competitions such as the North American Solar Challenge. Sometimes cars compete in both races.

These solar cars are designed, built, and raced by college students who represent their school in the race. Students are trying to build the car that most effectively converts sunlight into energy and can travel the fastest on the route, but also last the longest in the race. They use solar collectors or PV cells to power the cars. Mechanical failures are common and have to be fixed on site. Students must also attract corporate sponsors to help pay for the cars and the travel involved in getting to and from the races.

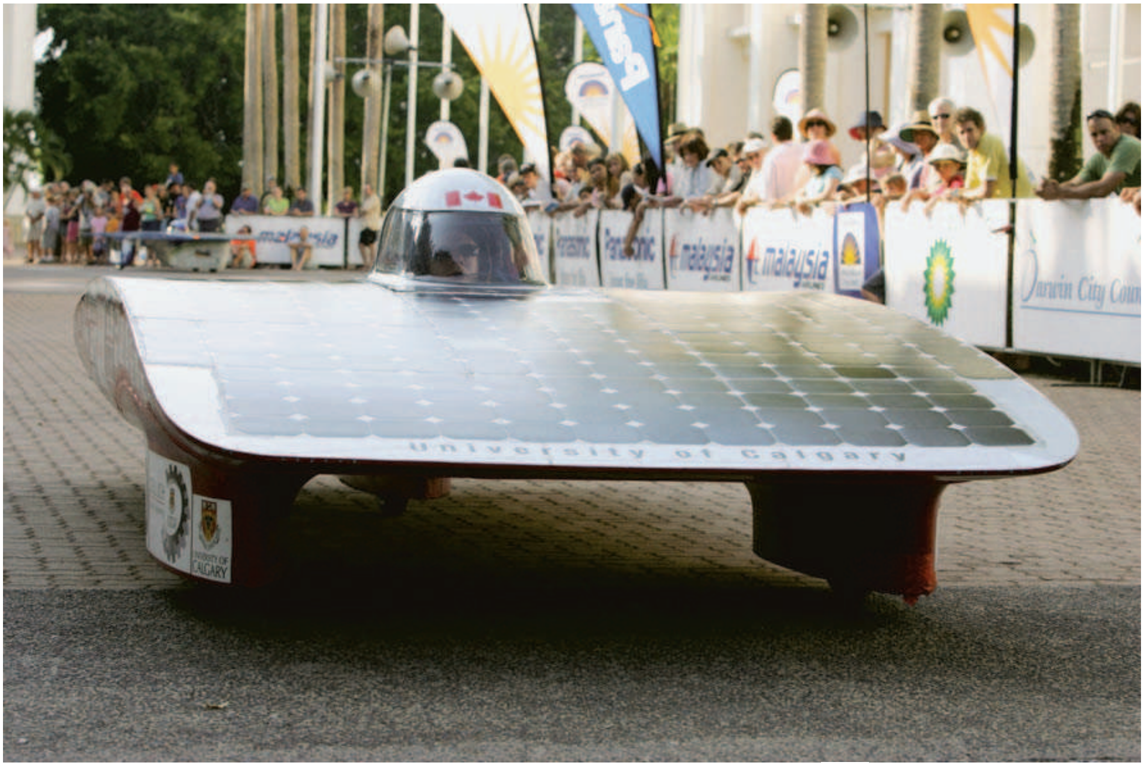
These solar races have been held for a number of years. The first World Solar Challenge was held in 1987 in Australia. The North American Solar Challenge began in 2001. In 2005 twenty-eight teams competed in the North American Solar Challenge. That race ran from Austin, Texas, to Calgary, Alberta, Canada. The route was over 2,500 miles (4,100 kilometers) and took two weeks to complete. The route differs year to year. The University of Michigan won the 2005 North American Solar Challenge with a time of 53 hours, 59 minutes, and 43 seconds. The car averaged a speed of 46.2 miles (74.3 kilometers) per hour. Each year the speed the cars in the contest can achieve increases.

There are other solar contests. In 2005 the second annual Solar Decathlon was held on the National Mall and other locations in Washington, D.C. This contest is sponsored by the U.S. Department of Energy, the National Renewable Energy Laboratory, and private sponsors such as Home Depot. Groups of college students compete in events such as building the best solar house.

works well with photovoltaic cells is a battery, which stores the energy created electrochemically. The energy created by PV cells can also be stored as potential energy. Pumped water and compressed air are two types of potential energy. All of these storage types are used where the PV cells are located.

### Current and future uses of photovoltaic cells

The first use for the first practical PV cell was a source of electricity for satellites orbiting Earth. PV cells were chosen because they were considered safer than nuclear power, another option being considered. On Earth, photovoltaic cells are used to



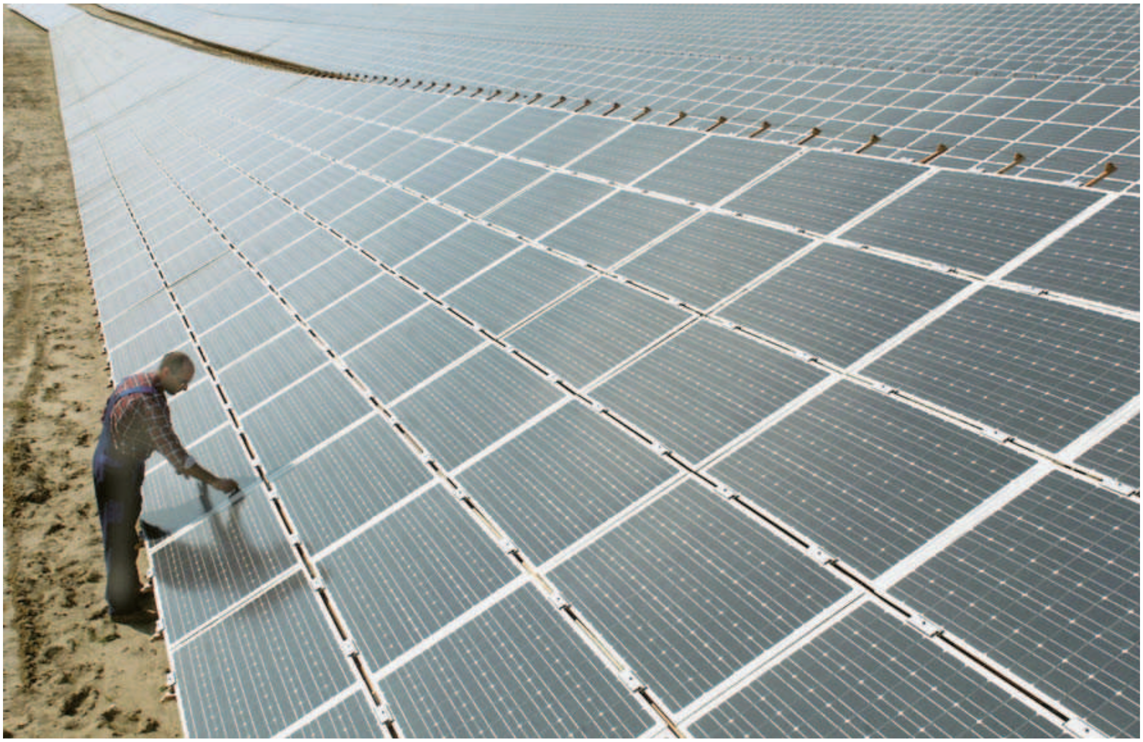

The solar car from The University of Calgary, Canada, leaves the starting point in Darwin on Sunday, September 25, 2005, in the 8th World Solar Challenge. Twenty-two solar-powered cars from the United States, France, Japan, and Canada will be trying to beat the Dutch team, which has won the last two events, in the 1,877 mile (3,021 kilometer) journey to Adelaide. © *David Hancock/Handout/EPA/ Corbis.*

make electricity in places not connected to the power grid or where it is too costly to use electricity produced by the grid. This often happens in remote areas.

People who live in isolated houses or who want to be independent of the power grid use PV cells to provide electricity for their homes because of their adaptability. PV cells can power most household appliances, such as televisions, refrigerators, and computers, and they can also power electric fences and feeders for livestock. Photovoltaic systems can be used on farms to power pumps that provide water for livestock on grazing areas that are far away from the main farm.

Other independent, often isolated, objects use PV cells in similar ways. Navigation beacons can be powered by PV cells, as can remote monitoring equipment stations for pipeline systems, water quality systems, and meteorological information. Many traffic signals, street signs, billboards, bus stop lights, highway signs, security lighting, and roadside emergency telephones also use this technology.

Photovoltaic cells and modules are being integrated into buildings and homes to provide power. They usually supplement other



A man tends to one of the world's largest solar power plants. Each panel measures 80 by 160 centmeters and is part of 33,500 modules that form a solar power station providing five megawatts of electricity for about 2,000 households. *©Waltraud Grubitzsch/EPA/Corbis.*

forms of power. There are incentives that will increase over time in many parts of the United States to use this technology. PV cells can also be used on the electrical grid in a supporting role for the transmission and distribution of power.

There are large photovoltaic systems that allow certain companies to avoid the electrical grid entirely. There have also been experiments to make large central power plants based on PV cells. However, PV cells have not yet proven to be cost effective in these situations. They are not yet efficient enough to justify the high cost of putting the project together and getting it started. If PV cells continue to become less expensive, such projects might become more practical.

In the future, the idea of building integrated photovoltaics (BIPV) might catch on. In this system, PV cells would be integrated into building materials such as shingles on roofs, windows, skylights, and the covers of insulation materials to provide a source of electricity for the home or building constructed with them. PV cells might also provide auxiliary power to automobiles.

Though PV cells are being installed for home or business use, they are not expected to be used on a widespread basis until 2010 at the earliest. By that time the cost of the technology is expected to be similar to the cost of electricity from the grid.

### Benefits and drawbacks of photovoltaic cells

The use of photovoltaic cells has many positive aspects. They make no noise, require little to no maintenance, and are reliable. No special training is needed to operate a PV cell system. In addition, PV cells can be made a variety of sizes from very small to very large, providing flexibility in use. Moreover, many PV cells can be used anywhere because they can use both direct sunlight and diffuse sunlight. Finally, PV cell systems are long-lasting, maintaining their effectiveness for twenty to thirty years. Thus, they produce much more energy through their operation over their lifetime than is used to manufacture them.

Like many solar energy technologies, however, one major drawback to photovoltaic cells is that no power is produced when there is no sunshine. If the weather is poor and the sun is blocked, as when it rains or snows, these cells do not produce power. Photovoltaic cells also do not produce power at night. Because of this situation, some sort of backup system or alternate power supply is needed.

While the PV cells are very efficient producers of power, the manufacture of these cells does come at a significant energy cost. Also, over time the PV cells slowly become less efficient. At some point the cells lose most of their ability to be conductive. The costs of PV cells have remained high, though the prices have gone down over time. But because of the cost, the electricity PV cells produces costs more than electricity from the power grid in most areas.

### Environmental impact of photovoltaic cells

While the widespread use of PV cells will reduce global warming by helping to cut down on the use of fossil fuel-created electricity, the manufacture of this solar technology can be polluting. Most manufacturers use mercury to construct solar cells. This is toxic waste that must be disposed of during their manufacture and after PV cells have reached the end of their usefulness.

### Economic impact of photovoltaic cells

On a house-by-house level, photovoltaic cell systems are currently only cost-effective if the home is far away from power lines or if it is too costly to bring power lines to the house. The technology is still too expensive to be used everywhere on this level.

## Solar Electric Light Fund

Founded in 1990, the Solar Electric Light Fund (SELF) strives to ''promote, develop, and facilitate solar rural electrification and energy SELF-sufficiency in developing countries.'' By 2005 the fund had completed six separate projects on four continents and was working on several others. One such project in northern Nigeria used solar power to generate electricity for essential services such as water pumps to supply rural villages with fresh drinking water, lights for medical clinics and schools, and streetlights. All of the SELF projects used PV cell technology.

Though PV cells are costly, many governments and companies believe in the technology. Much money has been spent on research from the early 1990s to early 2000s. For instance, although BP Amoco is an oil company, it has invested in producing PV technology. By 2000 its goal was to become the biggest producer of PV cells in the world. Amoco has already put some PV cells in its gas stations.

Because of this economic support of PV cell research, an industry has grown up around them. In 2004 the production worldwide of photovoltaic cells increased by 60 percent, and this growth is expected to continue. Manufacturing costs have declined every year for several years. By 2010 it is expected that the PV market may be $30 billion worldwide, perhaps making it one of the big growth industries in the world. As the market expands and research into better technology grows, prices will likely come down. Thus, the future of PV cells is extremely promising.

### Societal impact of photovoltaic cells

The use of PV cells can increase the availability of electricity around the world. Photovoltaic cells have brought power to parts of the world that did not have power before, except from generators powered by diesel fuel. Developing countries can best benefit from PV cell technology. The World Bank has installed PV systems in developing countries to provide a source of electricity. By 2001 at least 500,000 of the systems have been put in countries such as Sri Lanka, Indonesia, Kenya, Mexico, and China. China has 100,000 of the systems, while Kenya has 150,000. These numbers are expected to increase.

PV cells are also making an impact in developed countries such as the United States and Japan. By 1995 photovoltaic cells and modules added a capacity supply of 4.6 megawatts to the U.S. power grid. As of 2001 at least 200,000 residences in the United States used PV technology in some form.

### Issues, challenges, and obstacles of photovoltaic cells

The use of photovoltaic cells can be challenging. Since the electricity they produce is DC and most applications of electric power use AC, a power conditioning system is needed to ensure that the DC is converted to AC and is safe to use.

Another factor that has limited the widespread use of PV cells, especially to make large amounts of electricity, is the PV cell system's efficiency. PV cells are not particularly efficient in the amount of sunlight that is converted to electricity. If PV cells can turn more than 15 percent of the sunlight's energy into electricity, they will become an even more attractive alternative to electricity created by fossil fuels.

## DISH SYSTEMS

The dish system is also known as the distributed-point-focus system. Dish systems feature small, parabolic mirrors that are dish-shaped. They reflect the sunshine onto a receiver. A two-axis tracking system is employed to move the mirrors to ensure that as much solar energy reflected by the mirrors is captured as possible. The receiver is usually mounted above the mirrors at the center of the dish, its focal point. Inside the receiver is a fluid, which transfers the intense heat created by focusing the sunlight on the receiver. This makes electricity. Each dish can produce from 5 to 50 kilowatts of electricity. The dishes can be used singly or linked together.

Dish systems can be part of another solar technology called a dish-engine system. The dish part of the system is similar to the one described above. But the dish-engine system also includes an engine. The receiver in this system transfers the sunlight's energy to the engine. The engine, often one that can be driven by an external heat source, converts the energy to heat. The heat is then made into mechanical power. This happens by the compression of the working fluid, like steam, with the heat. It is then expanded via a turbine or piston. After mechanical power is produced, an electric generator or alternator turns the mechanical power into electrical power.

A dish-engine system can also be linked. If they are linked, they can potentially produce a significant amount of electricity. Ten

Tracking parabolic solar dishes concentrate incoming solar radiation to a central point, where a thermal collector captures the heat and transforms it into energy. © *Otto Rogge/Corbis.*

25-kilowatt dish-engine systems can produce 250 kilowatts of power. This would only require an acre of land.

**Current uses of dish systems**

Dish systems and dish-engine systems are used to generate electric power. However, they are still in the experimental and demonstration phases. The most electricity that has been produced from a single dish-engine system is about 50 kilowatts. More commonly, as of 2005 each system generates about 25 kilowatts.

It is believed that linked dish-engine systems will be a significant electricity producer of the future. Dish-engine systems can also be hybrids. That is, they might be combined with natural gas into a hybrid that can ensure the constant production of electricity.

Because of the size of the dishes involved, they must be used on a significant scale. They are not made for just one home. In 2004 a dish made by Stirling Energy that could produce 25 kilowatts of electricity was 38 feet (11.5 meters) across and 40 feet (12 meters) tall. It is expected that such systems will be produced on a commercial scale. The Arizona Public Service Company has already agreed to buy ten such systems to make power. Other southwestern states in the United States are also considering purchasing them.

### Benefits and drawbacks of dish systems

Dish systems and dish-engine systems are efficient producers of electricity. When they are linked together, they can produce more energy per acre than any other kind of solar energy technology. As the technology improves, they may be able to provide electricity for areas off the electricity grid or as an alternative to the electricity grid. Using technologies such as the dish system and dish-engine system can lead to less dependence on fossil fuels to make electricity.

To use the dish system and dish-engine system, however, very intense sunshine is needed. In the United States, the kind of sunshine needed can only be found in the southwestern part of the country. Key to the use of dish-engine systems is space. If such systems are going to be used on any type of scale, large amounts of empty space are needed for the many dishes to operate.

Dish systems and dish-engine systems also need more maintenance than other types of solar energy technologies. There are many moving parts, especially if a generator or motor is attached, which could break down and disrupt the flow of electricity.

### Impact of dish systems

No matter if one or many dish systems and dish-engine systems are being used, the environment where they are placed will be affected. In the United States, the systems will most likely be placed in deserts, which means that previously barren deserts will be covered with technology. Wildlife and plant life in the area could be negatively affected. If dish-engine systems reach a commercial scale, this impact could be devastating. The very environmentalists who support solar energy might find themselves at odds with the reality of the technology.

Economically, if this technology reaches maturity, it will provide a potentially cheap alternative source of power. This could affect how electric companies and energy providers run their businesses. It could also result in lower energy costs for consumers.

On a societal level, dish systems and dish-engine systems could provide a source of electricity for developing countries located in extremely sunny environments. The availability of such electricity could improve quality of life there.

### Issues, challenges, and obstacles of dish systems

It is unclear if the environmental issues related to the use of the dish system and dish-engine system will negatively affect the use of these systems as a widespread source of electricity. A balance must be created between the effect on the environment and the creation of electricity by such alternative forms of energy.

## TROUGH SYSTEMS

The trough system, also called the line-focus collector, focuses sunlight to create electricity. The trough system has its name because each collector is shaped like a trough that is parabolic (curved) in shape. There is a tube running down the middle of the trough with fluid inside. Mirrors inside the trough concentrate sunlight on that tube and heat the fluid inside it. The fluid is usually dark oil, but other substances can be used. The oil can get as hot as 752°F (400°C). The heat from the oil is transferred to water, which turns into steam. The steam can be used to power a turbine-generator or other machinery to produce the electricity.

Trough systems are modular. That means they can be linked together to make a larger amount of electricity than can be created by an individual trough. Many troughs together form a collector field when they are put in parallel rows. In a collector field the troughs are set in a certain way, usually aligned in an axis running from north to south. This allows the troughs to track the sun from east to west, the direction the sunlight moves during the day. An individual trough system can produce up to 80 megawatts of electricity.

There are several ways to make sure trough systems produce electricity after the sun goes down. Some trough systems have a means of thermal storage. That is, they can save the heat transfer fluid while still hot. By doing so, the troughs can still power the turbines after the sun goes down. However, trough systems are usually hybridized, meaning they are combined with a fossil fuel system for supplying electricity. Usually, the heat is created by natural gas. Using a gas-powered steam boiler is also possible. If trough systems are hybridized, they can produce power at all times. Coal-powered plants can also be supplemented by the trough system.

### Current uses of trough systems

The trough system is already being used to make electricity around the world. As of 2001 these types of systems accounted for 90 percent of the solar energy-produced electricity in the

Parabolic trough mirrors at a solar power plant. 

world. Since the early 1990s troughs have been operating in Southern California's Mojave Desert. These troughs have provided as much as 354 megawatts of electricity for the power grid in the Southern California area.

### Benefits and drawbacks of trough systems

Trough systems have many benefits, which is why they have been so widely adopted. Except for the generator, trough systems require minimal maintenance. They are also very flexible in terms of how many or few troughs can be linked together. The energy they produce is not quite on the price level of fossil fuel-produced electricity, but the figure is often very close.

As with all solar energy technologies, the fact that the sun does not shine at all times is a major drawback. For trough systems to operate to capacity, they need intense, direct sunshine. Such sunshine can only be found in the United States in the desert Southwest. Trough systems also take up a significant amount of space when they are linked together to provide power on a widespread scale.

### Impact of trough systems

While the trough system produces pollutant-free energy, many systems used together can take up much land. They are often placed in a desert that had previously been free of buildings or other structures. Placing a collector farm or any significant number of trough systems may litter this landscape and potentially destroy it. Animals and plants in the area could be negatively affected by the presence of this technology.

Despite the environmental costs, many governments support the use of trough systems to generate power. There are federal tax incentives for the use of trough systems. The State of California, for example, has mandated that power made by renewable energy sources must be purchased, and this is one technology the state has encouraged. If trough systems are ever used on a widespread basis, they could provide a cheap alternative source of power.

### Issues, challenges, and obstacles of trough systems

Because the trough system is a more commonly used technology than other types of solar energy, there is a familiarity with it in the energy industry. This awareness makes it more appealing. If trough systems can spread to all sunny parts of the world, solar energy in general technology could become more accepted. However, the space requirement of the trough system will limit the growth of this industry.

## SOLAR PONDS

A solar pond is a large, controlled body of water that collects and stores solar energy. Solar ponds do not use tracking systems such as mirrors, nor do they concentrate the sun's rays like many other solar energy technologies.

There are two types of convecting solar ponds. (Convection is a process in which a fluid such as water circulates, and in so doing the circulation causes a transfer of heat.) One is called a salt-gradient pond. At the very bottom of the pond is a dark layer that can absorb heat. This is usually a liner made of butyl rubber or other dark material. In addition to helping the water absorb the heat, it helps protect the nearby soil and groundwater from being contaminated by the saltwater from the solar pond.

In the pond, there is a significant amount of salt located near the bottom. The types of salt commonly used are sodium chloride or magnesium chloride. The water is saturated (filled entirely) or almost saturated with salt. The closer to the surface, the less salt is found in the water. At the very top of the pond is a layer of

Salt evaporation ponds at Shark Bay, Western Australia. © *Sergio Pitamitz/ Corbis.*

freshwater (that is, water without salt). This change in saltiness forms layers in the pond. The gradual change in the amount of salt is called a salt-density gradient.

The layers of saltwater stop the natural tendency of hot water to rise to the surface. Thus, the water that is heated by the sun stays at the bottom of a solar pond. The layers that are close to the surface remain cool. There is a significant temperature difference between the top and the bottom of a solar pond, though some heat can be stored on every layer. Temperatures as high as 179 to 199°F (82 to 93°C) can be found at the bottom.

The heat is extracted by a heat exchanger at the bottom of the pond. This heat energy can power an engine, provide space heating, or produce electricity via a low-pressure steam turbine. The heated saltwater can be pumped to the location where the heat is needed. After the heat is used, the water can be returned to the solar pond and heated again.

The second type of convecting pond is a membrane pond. A membrane pond is similar to the salt-gradient pond except the

## Ocean Thermal Energy Conversion

The concept behind solar ponds can be applied in the ocean in ocean thermal energy conversion (OTEC). In the ocean the water has different temperatures at different depths. It is often warm on the surface and colder the farther from the surface it is. If the temperature difference is at least 68°F (20°C), such as in tropical areas where the ocean is deep, then OTEC could be used to create energy.

To take advantage of OTEC, a pipe would be used to pump a significant amount of water to the surface. There, it would be run through a heat exchanger to capture the energy. In addition to providing electricity, the system could be adapted to produce freshwater. It could also be used to provide water full of nutrients in which such food items as fish and vegetables could be raised.

A prototype of OTEC was used in Hawaii in the mid-1990s. In the future, developing countries in coastal tropical areas could employ the technology.

layers of water are physically divided. They are separated by membranes that are thin and transparent. The separation of layers physically prevents convection (circulating movement). With a membrane pond the heat that is created is also removed from the bottom layer of the pond as in a salt-gradient pond.

There are also two types of nonconvecting ponds. One is called a shallow solar pond. This pond has no saltwater. Pure freshwater is kept inside a large bag. The bag allows convection to take place but limits the amount of water that can be evaporated. At the bottom of the bag is a black area. Foam insulation can also be found near the bottom. On top of the bag are two types of glazing. These glazings are usually sheets of plastic or glass.

In a shallow solar pond, the sunshine heats the bag and the water inside during the day. The heat energy is extracted at night. The heated water is pumped into a large heat storage tank. This process can be difficult because heat loss is possible. The problems with heat loss have meant that shallow solar ponds have not been fully developed as a technology.

The other type of nonconvecting pond is the deep, saltless pond. The primary difference between this pond and the shallow solar pond is that the water is not pumped in and out of its storage medium. This limits the amount of heat that can be lost.

### Current and future uses of solar ponds

Solar ponds can be used in a number of ways. They can make electricity or be used to provide heating for community, residential, and commercial purposes. They can also provide low-temperature heat for certain industrial and agricultural purposes, and they can also be used in preheating applications for industrial processes that require higher temperatures. In addition, solar ponds can be used to desalinate (remove the salt from) water. In Australia a pond at the Pyramid Hill salt works in Northern Victoria is used by the company to help make salt.

Solar ponds have been used for several decades. In the 1970s in Israel, a salt-gradient pond was created near the Dead Sea. Until 1989 it generated 5 megawatts of electricity. The project ended because of the high costs involved. Similar systems were built in California and other locations in the United States as well as India and Australia, though they were on a smaller scale. Several shallow solar ponds were built by the Tennessee Valley Authority.

There are a number of potential applications for solar ponds. Such ponds might be used to grow and farm brine shrimp or other sea creatures that are used as feed for livestock. In Australia solar pond projects are planned that would dry fruit and grain. Some researchers hope to use solar ponds in the production of dairy products.

### Benefits and drawbacks of solar ponds

Solar ponds are very versatile. They can use both direct sunlight as well as diffuse radiation on cloudy days. They can store the heat they collect during the daytime hours for use at night. A separate thermal storage unit is not always needed.

Another benefit is that solar ponds can be used in nearly any climate. They can even be used in winter when the top layer of a salt-gradient pond becomes covered in ice. They are also reusable: The water from which the heat is removed can be returned to the pond.

Finally, solar ponds do not always cost much to construct. There is no solar collector that needs to be cleaned. Because the solar pond can be built to be big, large amounts of power can be produced.

One drawback is that solar ponds require a very large area of flat land. It can be difficult to find the empty land needed to make the pond big enough to be used. In addition, lots of salt is also needed.

## Make Your Own Solar Pond

A small solar pond is easy to make at home with an aquarium, some food coloring, a lamp with a 100-watt light bulb, some salted water, and a few other items. First, set up a small five-gallon aquarium. Take two gallons of warm water and mix in one cup of salt. Mix until all the salt is dissolved. Then add in another one-third cup of salt. Let the mixture cool. Mix in a little red food coloring and put the mixture in the aquarium.

Take a very small funnel and a foot-long piece of hose. Attach the hose to the bottom of the funnel. Put the hose about half way into the water in the tank. Slowly add a gallon of freshwater. After the water is added, move the hose up toward the top of the tank without moving the hose above the water level. This step helps to create a gradient.

Now something small that can float is needed. Such items could be a plastic coffee can lid or a very thin wooden block. Put this item on the water. Pour water slowly onto the floating object. Leave the aquarium alone for one hour.

After one hour, put a few drops of blue food coloring onto the floating object. Then put the lamp over the tank and turn it on so the light is shining down. Put a thermometer that can go as high as 120 degrees Fahrenheit (48 degrees Celsius) in the water. Monitor the aquarium for the next twenty-four hours. The temperature will rise over that time period. As this solar pond heats up, three different colors will appear representing the three different levels of salty water that would be found in a solar pond.

**Impact of solar ponds**

Some of these ponds are very large, which can affect the environment around them. Measures must be taken to ensure that the salt from the solar ponds does not contaminate the soil. This contamination could very negatively affect the environment. Solar ponds can also have a positive environmental impact, however. When combined with desalting units, solar ponds can be used to purify water that is contaminated. Solar ponds make heat energy without burning any fuels and save conventional energy resources.

Despite the fact that solar ponds are not particularly efficient in their production of energy, they are inexpensive. However, they are not seen as economically advisable in the long term. As a result, there is very little commercial interest in them in most parts of the world.

Solar ponds can be a source of cheap salt in some countries. In Australia, for example, solar ponds can productively use lands that have too much salt in them to be used for anything else. All over Australia there are a number of underground sources of saltwater.

This water can be turned into freshwater using solar ponds in a profitable fashion. These uses could be positive for Australian society, resulting in the creation of new jobs, industries, and sources of water.

### Issues, challenges, and obstacles of solar ponds

While solar ponds have much potential, there has not been very much investment in the technology behind them. Yet the solar ponds could provide freshwater and electricity in coastal desert regions and islands. However, such applications have not yet been realized.

## SOLAR TOWERS

Solar towers, also known as power towers, central receivers, or heliostat mirror power plants, use solar energy to generate enough power to provide electricity over a large area. In this system the sun's power is collected by a large field of flat, movable mirrors. Sometimes there are thousands of mirrors. The mirrors, called heliostats, move so they can track the sun. They are focused on one single, fixed receiver that is located on top of a tall, central tower. Temperatures can be produced from 1,022 to 2,732°F (550 to 1,500°C) at the receiver.

The receiver collects all the energy and heat into a heat-transfer fluid that is flowing through it. In early power towers, this fluid was plain water. However, more recent models usually use molten salt, though liquid sodium, nitrate salt, and oil are also used. The heat energy held in the salt is used to boil water and make steam. This steam is used to generate electricity in a steam generator, usually located at the foot of the tower.

Molten salt can act as an efficient thermal storage medium for the heat collected in the solar tower. The heat can be stored for many hours or several days in this fashion. This storage medium is very important. It allows the solar towers to be operational for up to 65 percent of the year. The rest of the time, a backup fuel source is used. When there is no energy storage medium, solar towers can only be used for about 25 percent of the year.

### Current and future uses of solar towers

In the 1970s supporters believed that solar tower technology would take off. A number of solar tower technologies were implemented in the successive decades. In California there have been several solar tower projects. Solar One, which operated from 1982 to 1988, used water as a heat-transfer fluid in the receiver. It used 1,818 mirrors placed in semicircles around a tower that was 255 feet (78 meters) high. The mirrors focused the sunlight onto a boiler at the top. The use of water created problems for storage of the heat created and for running the turbine. Solar One was remade in 1992 to replace the water with molten salt. Despite this change, Solar One only functioned for a short time longer.

California funded another solar tower project that required an initial investment of $150 million. Solar Two operated from 1996 to 1999, had 10 megawatts of capacity, and also used molten salt. The success of Solar Two showed that the technology could work on a commercial basis. Solar towers were built in other countries as well. In Spain a solar tower was built that was smaller than the power towers built in California. It was constructed in 1982 south of Madrid and could produce up to 50 kilowatts of power. It was only used on an experimental basis to heat air.

Despite this early promise, as of 2001 there were no commercial solar towers in operation anywhere in the world. But more projects are being planned. In the future it is believed that solar towers will be built that can provide power for from 100,000 to 200,000 homes. Future projects might include a project in Spain called Solar Tres ("Solar Three") that will also use molten salt. Solar Tres was not seen as a short-term experiment but a long-term source of power. South Africa is planning on building a solar tower plant as well.

The most ambitious solar tower project was planned in Australia. In the early 2000s the country talked about building a giant solar tower, one of the tallest structures in the world, out in the desert near Mildura, Victoria, Australia. It would be 0.62 miles (0.9 kilometers) high and would produce 650 gigawatts of electricity each year at its peak to serve 70,000 consumers or 200,000 homes. This tower would be connected to thirty-two turbines. The tower would cost at least US$720 million to build. Australia hopes to have the tower actually working in 2008, if funding and logistics can be worked out. It is unclear how it would be built. There were other issues such as how to protect it from high winds, if it would be commercially workable, and if it would be technologically out of date by the time it was completed.

#### Benefits and drawbacks of solar towers

Solar towers have one important advantage over other types of solar power: They continually generate electricity as long as they have a means of heat storage such as molten salt. This means that they can be used to provide reliable power for customers over a long period of time. However, there are many drawbacks to solar towers as well. The technology is currently very costly. It might cost too much to make the power when considering the cost of building the tower itself. Also, solar towers are not particularly efficient means of converting sunshine into electricity. Only about 1 percent of the sunlight that hits the tower is actually made into electricity. Moreover, the size of the tower makes it difficult to place.

### Impact of solar towers

Solar towers take up a lot of space and are usually put in the desert or on empty land. The construction of such a large project could negatively affect the environment. The size and scope of what a solar tower looks like—the field of mirrors, the high tower, and the generator—could also negatively affect the location in which the tower is placed.

On the other hand, if this technology reaches maturity, solar towers could provide a cheap alternative source of power in the future. Although at present solar towers produce power that costs more than current electricity made with fossil fuels, as fossil fuels run out, the electricity made with fossil fuels will become more expensive and solar towers will become comparatively cheaper.

### Issues, challenges, and obstacles of solar towers

Solar towers have many positive aspects. They can run for long periods of time on stored energy, which comes from the sun. This makes solar towers different from many other renewable energy technologies. Yet solar towers have not caught on as a power-producing technology. Perception of the potential of solar towers needs to change for it to be considered a viable electric-producing source in the future. As long as the technology continues to develop, solar towers have a chance to be an important source of renewable energy in the future.

## SOLAR FURNACES

Like solar power towers, solar furnaces use mirrors to concentrate sunlight onto one point to achieve high temperatures. The solar energy is collected from over a wide area. Solar furnaces can create higher temperatures than solar towers. There are several types of solar furnaces, each of which produces a different wattage of power.

The best known solar furnace is called a high-flux solar furnace. It uses just one flat mirror or heliostat that is very large in size. It tracks the sun to ensure the greatest reflection of sunlight onto the primary concentrator. The concentrator consists of twenty-five or so individual curved mirrors. These mirrors focus the light, called a solar flux, at a target inside the building.

The large parabolic mirror, target area, and tower of the solar furnace in Odeillo, France. © *Paul Almasy/ Corbis.*

The light from the concentrator is focused on a circle or target inside the furnace. The focused beam of light created by the concentrator is much, much stronger than normal sunlight. At its focal point it can produce the energy of 2,500 suns. There can also be a reflective secondary concentrator added to the focus. The equivalent of up 20,000 suns can then be produced. When a refractive concentrator is added to the system to focus even more light on the beam, the intensity can equal an amazing 50,000 suns. Temperatures rise very rapidly in a solar furnace, more than 1,832°F (1,000°C) per second. The power level inside the furnace is adjustable by a device called an attenuator, which works like pulling down blinds over a window.

### Current and future uses of solar furnaces

Solar furnaces are primarily used to generate heat or steam to make electricity and for industrial use. Steam created by solar furnaces can be used to run generators and industrial equipment. An advantage of using solar-created heat in such industrial processes is that the heat is clean, meaning that it produces no harmful emissions. The first solar furnace was designed in Germany in 1921. It used a parabolic concentrator and lenses. Several more were built in Germany, France, and the United States between the 1930s and 1950s. One built in France in 1952 could produce 50 kilowatt hours of electricity.

In 1970 one of the most powerful solar furnaces built was constructed. It was located in Odeillo, France, at one of the sunniest points in Europe. It can produce about 100 kilowatt hours of electricity and has the capability of making heat as hot as 59,432°F (33,000°C). On the hillside opposite the furnace are 9,600 to 11,000 flat mirrors over 1,860 square miles (4,817 square kilometers) that track the sun and reflect sunlight onto one side of the furnace. On this side of the ten-story furnace are curved mirrors that cover its face. These mirrors are joined together to act as one large mirror. They focus the sun's energy onto an area that is less than 10 square feet (1 square meter) in order to create the high temperatures. This solar furnace is primarily used for scientific experiments on high temperature applications.

As of 2005 there are only a few solar furnaces in working order. Besides the one in Odeillo, France, they include smaller ones in China and the United States. The solar furnace in the United States is located at the National Renewable Energy Laboratory's CSR (Concentrated Solar Radiation) User Facility in Golden, Colorado. A high-flux solar furnace, it was built in 1990 and puts out 10 kilowatts of power. It is used to experiment on how solar furnaces can be used in industry.

The future uses of solar furnaces are being determined by furnaces such as the one at the CSR User Facility. There, experiments are being conducted with ceramics, surface hardening, coatings, and processes related to the processing of silicon. It is believed that solar furnaces can be used in manufacturing in the production of aerospace products, defense products, and in electronics. Solar furnaces also could be used to break down and destroy toxic waste. In these uses the high-flux solar furnace would replace laser furnaces and furnaces using fossil fuels.

Solar furnaces also have the potential to be used in materials processing and materials manufacturing that require high temperatures. The furnaces can quicken the pace of weathering for studying of future materials and how they will change over time. The CSR furnace can weatherize an object the equivalent of twenty years in only two-and-one-half months.

### Benefits and drawbacks of solar furnaces

A solar furnace can produce very high temperatures for industrial processes without the environmental costs and economic costs related to fossil fuels. Because some scientific experiments need a more pure fuel than is possible with fossil fuels, solar furnaces could be used because of the purity of sunlight. One drawback of solar furnaces is that they are very large and costly to build. They require a large amount of land in a sunny area to be effective.

### Impact of solar furnaces

Constructing a solar furnace has a profound effect on the environment in which it is placed. Acres, if not many square miles, of land are needed to place mirrors and a furnace, as well as any related industrial equipment. The building and operation of a solar furnace affects the local wildlife and local plant life.

On an economic level, it is unclear if the cost of building a solar furnace is cost-effective based on how much energy is produced by such furnaces. However, if solar furnaces prove to be cost-effective and feasible in more than a few areas, they could provide an alternative heat and electricity source for many types of industry. The growth in the use of solar furnaces could be an ideal way for industry to convert to solar energy and use less fossil fuels.

### Issues, challenges, and obstacles of solar furnaces

Solar furnace technology has existed for many years but never has been fully explored or used on a widespread commercial basis. It is unclear if solar furnaces will ever be used on any type of scale because of the limitations in their placement and use. However, the research happening at the CSR User Facility and others like it could lead to breakthroughs that improve the technology and/or lower the cost.

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# Alternative Energy

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## Volume 3

**Neil Schlager and Jayne Weisblatt, editors**

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# Contents

# Introduction

*Alternative Energy* offers readers comprehensive and easy-to-use information on the development of alternative energy sources. Although the set focuses on new or emerging energy sources, such as geothermal power and solar energy, it also discusses existing energy sources such as those that rely on fossil fuels. Each volume begins with a general overview that presents the complex issues surrounding existing and potential energy sources. These include the increasing need for energy, the world's current dependence on nonrenewable sources of energy, the impact on the environment of current energy sources, and implications for the future. The overview will help readers place the new and alternative energy sources in perspective.

Each of the first eight chapters in the set covers a different energy source. These chapters each begin with an overview that defines the source, discusses its history and the scientists who developed it, and outlines the applications and technologies for using the source. Following the chapter overview, readers will find information about specific technologies in use and potential uses as well. Two additional chapters explore the need for conservation and the move toward more energy-efficient tools, building materials, and vehicles and the more theoretical (and even imaginary) energy sources that might become reality in the future.

## ADDITIONAL FEATURES

Each volume of *Alternative Energy* includes the overview, a glossary called "Words to Know," a list of sources for more information, and an index. The set has 100 photos, charts, and illustrations to

enliven the text, and sidebars provide additional facts and related information.

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## COMMENTS AND SUGGESTIONS

We welcome your comments on *Alternative Energy* and suggestions for future editions of this work. Please write: Editors, *Alternative Energy*, U•X•L, 27500 Drake Rd., Farmington Hills, Michigan 48331-3535; call toll free: 1-800-877-4253; fax: 248-699-8097; or send e-mail via www.gale.com.

# Words to Know

## A

**acid rain:** Rain with a high concentration of sulfuric acid, which can damage cars, buildings, plants, and water supplies where it falls.

**adobe:** Bricks that are made from clay or earth, water, and straw, and dried in the sun.

**alkane:** A kind of hydrocarbon in which the molecules have the maximum possible number of hydrogen atoms and no double bonds.

**anaerobic:** Without air; in the absence of air or oxygen.

**anemometer:** A device used to measure wind speed.

**anthracite:** A hard, black coal that burns with little smoke.

**aquaculture:** The formal cultivation of fish or other aquatic life forms.

**atomic number:** The number of protons in the nucleus of an atom.

**atomic weight:** The combined number of an atom's protons and neutrons.

**attenuator:** A device that reduces the strength of an energy wave, such as sunlight.

## B

**balneology:** The science of bathing in hot water.

**barrel:** A common unit of measurement of crude oil, equivalent to 42 U.S. gallons; barrels of oil per day, or BOPD, is a standard measurement of how much crude oil a well produces.

**biodiesel:** Diesel fuel made from vegetable oil.

**bioenergy:** Energy produced through the combustion of organic materials that are constantly being created, such as plants.

**biofuel:** A fuel made from organic materials that are constantly being created.

**biomass:** Organic materials that are constantly being created, such as plants.

**bitumen:** A black, viscous (oily) hydrocarbon substance left over from petroleum refining, often used to pave roads.

**bituminous coal:** Mid-grade coal that burns with a relatively high flame and smoke.

**brine:** Water that is very salty, such as the water found in the ocean.

**British thermal unit (Btu or BTU):** A measure of heat energy, equivalent to the amount of energy it takes to raise the temperature of one pound of water by one degree Fahrenheit.

**butyl rubber:** A synthetic rubber that does not easily tear. It is often used in hoses and inner tubes.

## C

**carbon sequestration:** Storing the carbon emissions produced by coal-burning power plants so that pollutants are not released in the atmosphere.

**catalyst:** A substance that speeds up a chemical reaction or allows it to occur under different conditions than otherwise possible.

**cauldron:** A large metal pot.

**CFC (chlorofluorocarbon):** A chemical compound used as a refrigerant and propellant before being banned for fear it was destroying the ozone layer.

**Clean Air Act:** A U.S. law intended to reduce and control air pollution by setting emissions limits for utilities.

**climate-responsive building:** A building, or the process of constructing a building, using materials and techniques that take advantage of natural conditions to heat, cool, and light the building.

**coal:** A solid hydrocarbon found in the ground and formed from plant matter compressed for millions of years.

**coke:** A solid organic fuel made by burning off the volatile components of coal in the absence of air.

**cold fusion**: Nuclear fusion that occurs without high heat; also referred to as low energy nuclear reactions.

**combustion**: Burning.

**compact fluorescent bulb**: A lightbulb that saves energy as conventional fluorescent bulbs do, but that can be used in fixtures that normally take incandescent lightbulbs.

**compressed:** To make more dense so that a substance takes up less space.

**conductive:** A material that can transmit electrical energy.

**convection:** The circulation movement of a substance resulting from areas of different temperatures and/or densities.

**core:** The center of the Earth.

**coriolis force:** The movement of air currents to the right or left caused by Earth's rotation.

**corrugated steel:** Steel pieces that have parallel ridges and troughs.

**critical mass:** An amount of fissile material needed to produce an ongoing nuclear chain reaction.

**criticality:** The point at which a nuclear fission reaction is in controlled balance.

**crude oil:** The unrefined petroleum removed from an oil well.

**crust**: The outermost layer of the Earth.

**curie**: A unit of measurement that measures an amount of radiation.

**current**: The flow of electricity.

## D

**decay:** The breakdown of a radioactive substance over time as its atoms spontaneously give off neutrons.

**deciduous trees:** Trees that shed their leaves in the fall and grow them in the spring. Such trees include maples and oaks.

**decommission:** To take a nuclear power plant out of operation.

**dependent**: To be reliant on something.

**distillation:** A process of separating or purifying a liquid by boiling the substance and then condensing the product.

**distiller's grain**: Grain left over from the process of distilling ethanol, which can be used as inexpensive high-protein animal feed.

**drag:** The slowing force of the wind as it strikes an object.

**drag coefficient:** A measurement of the drag produced when an object such as a car pushes its way through the air.

## E

**E85:** A blend of 15 percent ethanol and 85 percent gasoline.

**efficient:** To get a task done without much waste.

**electrolysis:** A method of producing chemical energy by passing an electric current through a type of liquid.

**electromagnetism:** Magnetism developed by a current of electricity.

**electron:** A negatively charged particle that revolves around the nucleus in an atom.

**embargo:** Preventing the trade of a certain type of commodity.

**emission:** The release of substances into the atmosphere. These substances can be gases or particles.

**emulsion:** A liquid that contains many small droplets of a substance that cannot dissolve in the liquid, such as oil and water shaken together.

**enrichment:** The process of increasing the purity of a radioactive element such as uranium to make it suitable as nuclear fuel.

**ethanol:** An alcohol made from plant materials such as corn or sugar cane that can be used as fuel.

**experimentation:** Scientific tests, sometimes of a new idea.

## F

**feasible:** To be possible; able to be accomplished or brought about.

**feedstock:** A substance used as a raw material in the creation of another substance.

**field:** An area that contains many underground reservoirs of petroleum or natural gas.

**fissile:** Term used to describe any radioactive material that can be used as fuel because its atoms can be split.

**fission:** Splitting of an atom.

**flexible fuel vehicle (FFV):** A vehicle that can run on a variety of fuel types without modification of the engine.

**flow:** The volume of water in a river or stream, usually expressed as gallons or cubic meters per unit of time, such as a minute or second.

**fluorescent lightbulb:** A lightbulb that produces light not with intense heat but by exciting the atoms in a phosphor coating inside the bulb.

**fossil fuel:** An organic fuel made through the compression and heating of plant matter over millions of years, such as coal, petroleum, and natural gas.

**fusion:** The process by which the nuclei of light atoms join, releasing energy.

## G

**gas:** An air-like substance that expands to fill whatever container holds it, including natural gas and other gases commonly found with liquid petroleum.

**gasification:** A process of converting the energy from a solid, such as coal, into gas.

**gasohol:** A blend of gasoline and ethanol.

**gasoline:** Refined liquid petroleum most commonly used as fuel in internal combustion engines.

**geothermal:** Describing energy that is found in the hot spots under the Earth; describing energy that is made from heat.

**geothermal reservoir:** A pocket of hot water contained within the Earth's mantle.

**global warming:** A phenomenon in which the average temperature of the Earth rises, melting icecaps, raising sea levels, and causing other environmental problems.

**gradient:** A gradual change in something over a specific distance.

**green building:** Any building constructed with materials that require less energy to produce and that save energy during the building's operation.

**greenhouse effect:** A phenomenon in which gases in the Earth's atmosphere prevent the sun's radiation from being reflected back into space, raising the surface temperature of the Earth.

**greenhouse gas:** A gas, such as carbon dioxide or methane, that is added to the Earth's atmosphere by human actions. These gases trap heat and contribute to global warming.

## H

**halogen lamp:** An incandescent lightbulb that produces more light because it produces more heat, but lasts longer because the filament is enclosed in quartz.

**Heisenberg uncertainty principle:** The principle that it is impossible to know simultaneously both the location and momentum of a subatomic particle.

**heliostat:** A mirror that reflects the sun in a constant direction.

**hybrid vehicle:** Any vehicle that is powered in a combination of two ways; usually refers to vehicles powered by an internal combustion engine and an electric motor.

**hybridized:** The bringing together of two different types of technology.

**hydraulic energy:** The kinetic energy contained in water.

**hydrocarbon:** A substance composed of the elements hydrogen and carbon, such as coal, petroleum, and natural gas.

**hydroelectric:** Describing electric energy made by the movement of water.

**hydropower:** Any form of power derived from water.

## I

**implement:** To put something into practice.

**incandescent lightbulb:** A conventional lightbulb that produces light by heating a filament to high temperatures.

**infrastructure:** The framework that is necessary to the functioning of a structure; for example, roads and power lines form part of the infrastructure of a city.

**inlet:** An opening through which liquid enters a device, or place.

**internal combustion engine:** The type of engine in which the burning that generates power takes place inside the engine.

**isotope:** A "species" of an element whose nucleus contains more neutrons than other species of the same element.

## K

**kilowatt-hour:** One kilowatt of electricity consumed over a one-hour period.

**kinetic energy:** The energy associated with movement, such as water that is in motion.

**Kyoto Protocol:** An international agreement among many nations setting limits on emissions of greenhouse gases; intended to slow or prevent global warming.

## L

**lava:** Molten rock contained within the Earth that emerges from cracks in the Earth's crust, such as volcanoes.

**lift:** The aerodynamic force that operates perpendicular to the wind, owing to differences in air pressure on either side of a turbine blade.

**lignite:** A soft brown coal with visible traces of plant matter in it that burns with a great deal of smoke and produces less heat than anthracite or bituminous coal.

**liquefaction:** The process of turning a gas or solid into a liquid.

**LNG (liquefied natural gas):** Gas that has been turned into liquid through the application of pressure and cold.

**LPG (liquefied petroleum gas):** A gas, mainly propane or butane, that has been turned into liquid through the use of pressure and cold.

**lumen:** A measure of the amount of light, defined as the amount of light produced by one candle.

## M

**magma:** Liquid rock within the mantle.

**magnetic levitation:** The process of using the attractive and repulsive forces of magnetism to move objects such as trains.

**mantle:** The layer of the Earth between the core and the crust.

**mechanical energy:** The energy output of tools or machinery.

**meltdown:** Term used to refer to the possibility that a nuclear reactor could become so overheated that it would melt into the earth below.

**mica:** A type of shiny silica mineral usually found in certain types of rocks.

**modular:** An object which can be easily arranged, rearranged, replaced, or interchanged with similar objects.

**mousse:** A frothy mixture of oil and seawater in the area where an oil spill has occurred.

## N

**nacelle:** The part of a wind turbine that houses the gearbox, generator, and other components.

**natural gas:** A gaseous hydrocarbon commonly found with petroleum.

**negligible:** To be so small as to be insignificant.

**neutron:** A particle with no electrical charge found in the nucleus of most atoms.

NGL (**natural gas liquid**): The liquid form of gases commonly found with natural gas, such as propane, butane, and ethane.

**nonrenewable:** To be limited in quantity and unable to be replaced.

**nucleus:** The center of an atom, containing protons and in the case of most elements, neutrons.

## O

**ocean thermal energy conversion** (OTEC): The process of converting the heat contained in the oceans' water into electrical energy.

**octane rating:** The measure of how much a fuel can be compressed before it spontaneously ignites.

**off-peak:** Describing period of time when energy is being delivered at well below the maximum amount of demand, often nighttime.

**oil:** Liquid petroleum; a substance refined from petroleum used as a lubricant.

**organic:** Related to or derived from living matter, such as plants or animals; composed mainly of carbon atoms.

**overburden:** The dirt and rocks covering a deposit of coal or other fossil fuel.

**oxygenate:** A substance that increases the oxygen level in another substance.

**ozone:** A molecule consisting of three atoms of oxygen, naturally produced in the Earth's atmosphere; ozone is toxic to humans.

## P

**parabolic:** Shaped like a parabola, which is a certain type of curve.

**paraffin:** A kind of alkane hydrocarbon that exists as a white, waxy solid at room temperature and can be used as fuel or as a wax for purposes such as sealing jars or making candles.

**passive:** A device that takes advantage of the sun's heat but does not use an additional source of energy.

**peat:** A brown substance composed of compressed plant matter and found in boggy areas; peat can be used as fuel itself, or turns into coal if compressed for long enough.

**perpetual motion:** The power of a machine to run indefinitely without any energy input.

**petrochemicals:** Chemical compounds that form in rocks, such as petroleum and coal.

**petrodiesel:** Diesel fuel made from petroleum.

**petroleum:** Liquid hydrocarbon found underground that can be refined into gasoline, diesel fuel, oils, kerosene, and other products.

**pile:** A mass of radioactive material in a nuclear reactor.

**plutonium:** A highly toxic element that can be used as fuel in nuclear reactors.

**polymer:** A compound, either synthetic or natural, that is made of many large molecules. These molecules are made from smaller, identical molecules that are chemically bonded.

**pristine:** Not changed by human hands; in its original condition.

**productivity:** The output of labor per amount of work.

**proponent:** Someone who supports an idea or cause.

**proton:** A positively charged particle found in the nucleus of an atom.

## R

**radioactive:** Term used to describe any substance that decays over time by giving off subatomic particles such as neutrons.

**RFG (reformulated gasoline):** Gasoline that has an oxygenate or other additive added to it to decrease emissions and improve performance.

**rem:** An abbreviation for "roentgen equivalent man," referring to a dose of radiation that will cause the same biological effect (on a "man") as one roentgen of X-rays or gamma rays.

**reservoir:** A geologic formation that can contain liquid petroleum and natural gas.

**reservoir rock:** Porous rock, such as limestone or sandstone, that can hold accumulations of petroleum or natural gas.

**retrofit:** To change something, like a home, after it is built.

**rotor:** The hub to which the blades of a wind turbine are connected; sometimes used to refer to the rotor itself and the blades as a single unit.

## S

**scupper:** An opening that allows a liquid to drain.

**seam:** A deposit of coal in the ground.

**sedimentary rock:** A rock formed through years of minerals accumulating and being compressed.

**seismology:** The study of movement within the earth, such as earthquakes and the eruption of volcanoes.

**sick building syndrome:** The tendency of buildings that are poorly ventilated, lighted, and humidified, and that are made with certain synthetic materials to cause the occupants to feel ill.

**smog:** Air pollution composed of particles mixed with smoke, fog, or haze in the air.

**stall:** The loss of lift that occurs when a wing presents too steep an angle to the wind and low pressure along the upper surface of the wing decreases.

**strip mining:** A form of mining that involves removing earth and rocks by bulldozer to retrieve the minerals beneath them.

**stored energy:** The energy contained in water that is stored in a tank or held back behind a dam in a reservoir.

**subsidence:** The collapse of earth above an empty mine, resulting in a damaged landscape.

**surcharge:** An additional charge over and above the original cost.

**superconductivity:** The disappearance of electrical resistance in a substance such as some metals at very low temperatures.

## T

**thermal energy:** Any form of energy in the form of heat; used in reference to heat in the oceans' waters.

**thermal gradient:** The differences in temperature between different layers of the oceans.

**thermal mass:** The measure of the amount of heat a substance can hold.

**thermodynamics:** The branch of physics that deals with the mechanical actions or relations of heat.

**tokamak:** An acronym for the Russian-built toroidal magnetic chamber, a device for containing a fusion reaction.

**transitioning:** Changing from one position or state to another.

**transparent:** So clear that light can pass through without distortion.

**trap:** A reservoir or area within Earth's crust made of nonporous rock that can contain liquids or gases, such as water, petroleum, and natural gas.

**trawler:** A large commercial fishing boat.

**Trombé wall:** An exterior wall that conserves energy by trapping heat between glazing and a thermal mass, then venting it into the living area.

**turbine:** A device that spins to produce electricity.

## U

**uranium:** A heavy element that is the chief source of fuel for nuclear reactors.

## V

**viable:** To be possible; to be able to grow or develop.

**voltage:** Electric potential that is measured in volts.

## W

**wind farm:** A group of wind turbines that provide electricity for commercial uses.

**work:** The conversion of one form of energy into another, such as the conversion of the kinetic energy of water into mechanical energy used to perform a task.

## Z

**zero point energy:** The energy contained in electromagnetic fluctuations that remains in a vacuum, even when the temperature has been reduced to very low levels.

# Overview

In the technological world of the twenty-first century, few people can truly imagine the challenges faced by prehistoric people as they tried to cope with their natural environment. Thousands of years ago life was a daily struggle to find, store, and cook food, stay warm and clothed, and generally survive to an “old age” equal to that of most of today’s college students. A common image of prehistoric life is that of dirty and ill-clad people huddled around a smoky campfire outside a cave in an ongoing effort to stay warm and dry and to stop the rumbling in their bellies.

The “caves” of the twenty-first century are a little cozier. The typical person, at least in more developed countries, wakes up each morning in a reasonably comfortable house because the gas, propane, or electric heating system (or electric air-conditioner) has operated automatically overnight. A warm shower awaits because of hot water heaters powered by electricity or natural gas, and hair dries quickly (and stylishly) under an electric hair dryer. An electric iron takes the wrinkles out of the clean shirt that sat overnight in the electric clothes dryer. Milk for a morning bowl of cereal remains fresh in an electric refrigerator, and it costs pennies per bowl thanks to electrically powered milking operations on modern dairy farms. The person then goes to the garage (after turning off all the electric lights in the house), hits the electric garage door opener, and gets into his or her gasoline-powered car for the drive to work—perhaps in an office building that consumes power for lighting, heating and air-conditioning, copiers, coffeemakers, and computers. Later, an electric, propane, or natural gas stove is used to cook dinner. Later still, an electric

popcorn popper provides a snack as the person watches an electric television or reads under the warm glow of electric light bulbs—after perhaps turning up the heat because the house is a little chilly.

## CATASTROPHE AHEAD?

Most people take these modern conveniences for granted. Few people give much thought to them, at least until there is a power outage or prices rise sharply, as they did for gasoline in the United States in the summer and fall of 2005. Many scientists, environmentalists, and concerned members of the public, though, believe that these conveniences have been taken too much for granted. Some believe that the modern reliance on fossil fuels—fuels such as natural gas, gasoline, propane, and coal that are processed from materials mined from the earth—has set the Earth on a collision course with disaster in the twenty-first century. Their belief is that the human community is simply burning too much fuel and that the consequences of doing so will be dire (terrible). Some of their concerns include the following:

- Too much money is spent on fossil fuels. In the United States, over $1 billion is spent every day to power the country's cars and trucks.
- Much of the supply of fossil fuels, particularly petroleum, comes from areas of the world that may be unstable. The U.S. fuel supply could be cut off without warning by a foreign government. Many nations that import all or most of their petroleum feel as if they are hostages to the nations that control the world's petroleum supplies.
- Drilling for oil and mining coal can do damage to the landscape that is impossible to repair.
- Reserves of coals and especially oil are limited, and eventually supplies will run out. In the meantime, the cost of such fuels will rise dramatically as it becomes more and more difficult to find and extract them.
- Transporting petroleum in massive tankers at sea heightens the risk of oil spills, causing damage to the marine and coastal environments.

Furthermore, to provide heat and electricity, fossil fuels have to be burned, and this burning gives rise to a host of problems. It releases pollutants in the form of carbon dioxide and sulfur into the air, fouling the atmosphere and causing "brown clouds" over cities. These pollutants can increase health problems such as lung

disease. They may also contribute to a phenomenon called "global warming." This term refers to the theory that average temperatures across the globe will increase as "greenhouse gases" such as carbon dioxide trap the sun's heat (as a greenhouse does) in the atmosphere and warm it. Global warming, in turn, can melt glaciers and the polar ice caps, raising sea levels with damaging effects on coastal cities and small island nations. It may also cause climate changes, crop failures, and more unpredictable weather patterns.

Some scientists do not believe that global warming even exists or that its consequences will be catastrophic. Some note that throughout history, the world's average temperatures have risen and fallen. Some do not find the scientific data about temperature, glacial melting, rising sea levels, and unpredictable weather totally believable. While the debate continues, scientists struggle to learn more about the effects of human activity on the environment. At the same time, governments struggle to maintain a balance between economic development and its possible effects on the environment.

## WHAT TO DO?

These problems began to become more serious after the Industrial Revolution of the nineteenth century. Until that time people depended on other sources of power. Of course, they burned coal or wood in fireplaces and stoves, but they also relied on the power of the sun, the wind, and river currents to accomplish much of their work. The Industrial Revolution changed that. Now, coal was being burned in vast amounts to power factories and steam engines as the economies of Europe and North America grew and developed. Later, more efficient electricity became the preferred power source, but coal still had to be burned to produce electricity in large power plants. Then in 1886 the first internal combustion engine was developed and used in an automobile. Within a few decades there was a demand for gasoline to power these engines. By 1929 the number of cars in the United States had grown to twenty-three million, and in the quarter-century between 1904 and 1929, the number of trucks grew from just seven hundred to 3.4 million.

At the same time technological advances improved life in the home. In 1920, for example, the United States produced a total of five thousand refrigerators. Just ten years later the number had grown to one million per year. These and many other industrial and consumer developments required vast and growing amounts of

fuel. Compounding the problem in the twenty-first century is that other nations of the world, such as China and India, have started to develop more modern industrialized economies powered by fossil fuels.

By the end of World War II in 1945, scientists were beginning to imagine a world powered by fuel that was cheap, clean, and inexhaustible (unable to be used up). During the war the United States had unleashed the power of the atom to create the atomic bomb. Scientists believed that the atom could be used for peaceful purposes in nuclear power plants. They even envisioned (imagined) a day when homes could be powered by their own tiny nuclear power generators. This dream proved to be just that. While some four hundred nuclear power plants worldwide provide about 16 percent of the world's electricity, building such plants is an enormously expensive technical feat. Moreover, nuclear power plants produce spent fuel that is dangerous and not easily disposed of. The public fears that an accident at such a plant could release deadly radiation that would have disastrous effects on the surrounding area. Nuclear power has strong defenders, but it is not cheap, and safety concerns sometimes make it unpopular.

The dream of a fuel source that is safe, plentiful, clean, and inexpensive, however, lives on. The awareness of the need for such alternative fuel sources became greater in the 1970s, when the oil-exporting countries of the Middle East stopped shipments of oil to the United States and its allies. This situation (an embargo) caused fuel shortages and rapidly rising prices at the gas pump. In the decades that followed, gasoline again became plentiful and relatively inexpensive, but the oil embargo served as a wakeup call for many people. In addition, during these years people worldwide grew concerned about pollution, industrialization, and damage to the environment. Accordingly, efforts were intensified to find and develop alternative sources of energy.

## ALTERNATIVE ENERGY: BACK TO THE FUTURE

Some of these alternative fuel sources are by no means new. For centuries people have harnessed the power of running water for a variety of needs, particularly for agriculture (farming). Water wheels were constructed in the Middle East, Greece, and China thousands of years ago, and they were common fixtures on the farms of Europe by the Middle Ages. In the early twenty-first century hydroelectric dams, which generate electricity from the power of rivers, provide about 9 percent of the electricity in the

United States. Worldwide, there are about 40,000 such dams. In some countries, such as Norway, hydroelectric dams provide virtually 100 percent of the nation's electrical needs. Scientists, though, express concerns about the impact such dams have on the natural environment.

Water can provide power in other ways. Scientists have been attempting to harness the enormous power contained in ocean waves, tides, and currents. Furthermore, they note that the oceans absorb enormous amounts of energy from the sun, and they hope someday to be able to tap into that energy for human needs. Technical problems continue to occur. It remains likely that ocean power will serve only to supplement (add to) existing power sources in the near future.

Another source of energy that is not new is solar power. For centuries, people have used the heat of the sun to warm houses, dry laundry, and preserve food. In the twenty-first century such "passive" uses of the sun's rays have been supplemented with photovoltaic devices that convert the energy of the sun into electricity. Solar power, though, is limited geographically to regions of the Earth where sunshine is plentiful.

Another old source of heat is geothermal power, referring to the heat that seeps out of the earth in places such as hot springs. In the past this heat was used directly, but in the modern world it is also used indirectly to produce electricity. In 1999 over 8,000 megawatts (that is, 8,000 million watts) of electricity were produced by about 250 geothermal power plants in twenty-two countries around the world. That same year the United States produced nearly 3,000 megawatts of geothermal electricity, more than twice the amount of power generated by wind and solar power. Geothermal power, though, is restricted by the limited number of suitable sites for tapping it.

Finally, wind power is getting a closer look. For centuries people have harnessed the power of the wind to turn windmills, using the energy to accomplish work. In the United States, wind-operated turbines produce just 0.4 percent of the nation's energy needs. However, wind experts believe that a realistic goal is for wind to supply 20 percent of the nation's electricity requirements by 2020. Worldwide, wind supplies enough power for about nine million homes. Its future development, though, is hampered by limitations on the number of sites with enough wind and by concerns about large numbers of unsightly wind turbines marring the landscape.

## ALTERNATIVE ENERGY: FORWARD TO THE FUTURE

While some forms of modern alternative energy sources are really developments of long-existing technologies, others are genuinely new, though scientists have been exploring even some of these for up to hundreds of years. One, called bioenergy, refers to the burning of biological materials that otherwise might have just been thrown away or never grown in the first place. These include animal waste, garbage, straw, wood by-products, charcoal, dried plants, nutshells, and the material left over after the processing of certain foods, such as sugar and orange juice. Bioenergy also includes methane gas given off by garbage as it decomposes or rots. Fuels made from vegetable oils can be used to power engines, such as those in cars and trucks. Biofuels are generally cleaner than fossil fuels, so they do not pollute as much, and they are renewable. They remain expensive, and amassing significant amounts of biofuels requires a large commitment of agricultural resources such as farmland.

Nothing is sophisticated about burning garbage. A more sophisticated modern alternative is hydrogen, the most abundant element in the universe. Hydrogen in its pure form is extremely flammable. The problem with using hydrogen as a fuel is separating hydrogen molecules from the other elements to which it readily bonds, such as oxygen (hydrogen and oxygen combine to form water). Hydrogen can be used in fuel cells, where water is broken down into its elements. The hydrogen becomes fuel, while the "waste product" is oxygen. Many scientists regard hydrogen fuel cells as the "fuel of the future," believing that it will provide clean, safe, renewable fuel to power homes, office buildings, and even cars and trucks. However, fuel cells are expensive. As of 2002 a fuel cell could cost anywhere from $500 to $2,500 per kilowatt produced. Engines that burn gasoline cost only about $30 to $35 for the same amount of energy.

All of these power sources have high costs, both for the fuel and for the technology needed to use it. The real dreamers among energy researchers are those who envision a future powered by a fuel that is not only clean, safe, and renewable but essentially free. Many scientists believe that such fuel alternatives are impossible, at least for the foreseeable future. Others, though, work in laboratories around the world to harness more theoretical sources of energy. Some of their work has a "science fiction" quality, but these scientists point out that a few hundred years ago the airplane was science fiction.

One of these energy sources is magnetism, already used to power magnetic levitation ("maglev") trains in Japan and Germany. Another is perpetual motion, the movement of a machine that produces energy without requiring energy to be put into the system. Most scientists, though, dismiss perpetual motion as a violation of the laws of physics. Other scientists are investigating so-called zero-point energy, or the energy that surrounds all matter and can even be found in the vacuum of space. But perhaps the most sought-after source of energy for investigators is cold fusion, a nuclear reaction using "heavy hydrogen," an abundant element in seawater, as fuel. With cold fusion, power could be produced literally from a bucket of water. So far, no one has been able to produce it, though some scientists claim to have come very close.

None of these energy sources is a complete cure for the world's energy woes. Most will continue to serve as supplements to conventional fossil fuel burning for decades to come. But with the commitment of research dollars, it is possible that future generations will be able to generate all their power needs in ways that scientists have not even yet imagined. The first step begins with understanding fossil fuels, the energy they provide, the problems they cause, and what it may take to replace them.

# Water Energy

## INTRODUCTION: WHAT IS WATER ENERGY?

Water energy is energy derived from the power of water, most often its motion. Energy sources using water have been around for thousands of years in the form of water clocks and waterwheels. A more recent innovation has been hydroelectricity, or the electricity produced by the flow of water over dams. In the twenty-first century scientists are developing water-based applications ranging from tidal power to thermal power.

### Historical overview

The history of water energy is almost as old as the history of human civilization itself, making it the first form of "alternative energy" people employed. Many centuries ago the ancient Egyptians devised water clocks, whose wheels were turned by the flow of water. The Egyptians and Syrians also used a device called a *noria,* a waterwheel with buckets attached, that was used to raise water out of the Nile River for use on their crops. Two thousand years ago the ancient Greeks built waterwheels to crush grapes and grind grains. At roughly the same time, the Chinese were using waterwheels to operate bellows used in the casting of iron tools such as farm implements.

The ancient Romans were especially skilled at managing water. In fact, the English word *plumber* comes from the Latin word *plumbum,* meaning "lead," referring to the lead pipes used in plumbing and reflected in the symbol for lead in the periodic table of elements, Pb. The Romans built water-carrying structures called aqueducts to channel water from natural sources to canals, where the water's energy could be harnessed by waterwheels. Near Arles in what is now southern France, for example, the

## Words to Know

**Flow** The volume of water in a river or stream, usually expressed as gallons or cubic meters per unit of time, such as a minute or second.

**Hydraulic energy** The kinetic energy contained in water.

**Hydropower** Any form of power derived from water.

**Kinetic energy** The energy contained in any fluid mass, such as water, that is in motion.

**Mechanical energy** The energy output of tools or machinery.

**Ocean thermal energy conversion (OTEC)** The process of converting the heat contained in the oceans' water into electrical energy.

**Stored energy** The energy contained in water that is stored in a tank or held back behind a dam in a reservoir.

**Thermal energy** Any form of energy in the form of heat; used in reference to heat in the oceans' waters.

**Thermal gradient** The differences in temperature between different layers of the oceans.

**Work** The conversion of one form of energy into another, such as the conversion of the kinetic energy of water into mechanical energy used to perform a task.

Romans built a massive grain mill powered by sixteen waterwheels.

In the centuries that followed, until fossil fuels became the preferred power source during the industrial revolution of the nineteenth century, farmers continued to take advantage of the currents in rivers and streams for a variety of agricultural purposes, including grinding grain and pumping water for irrigation (watering crops). An English manuscript called the *Domesday Book,* written in 1086, listed 5,624 waterwheel-driven mills south of the Trent River in England, one mill for every four hundred people.

Farmers, though, were not the only ones to use waterwheels. Early factories, especially in Great Britain and in the American Northeast, relied heavily on water power as well because of the large number of rivers and streams in the British Isles and in such states as Massachusetts, Connecticut, and New York. In these examples, rivers often powered such enterprises as sawmills, but the textile industry, in particular, used water to power the "Spinning Jenny," a cotton-spinning machine for making cloth. In 1769 English inventor and industrialist Richard Arkwright (1732–1792) patented a water-powered textile loom for spinning cotton (originally meant to be powered by horses) that revolutionized the textile industry.

The city of Hama in Syria is famous for its ancient water wheels, or *noria*, on the Orontes River. © *Elio Ciol/ Corbis.*

The result over the next half-century was a boom in the textile industry, both in Britain and, later, in the United States. One of the pioneers in this effort was a New England businessman, Francis Cabot Lowell (1775–1817). In the early nineteenth century Lowell imported British technology to the Charles River in Waltham, Massachusetts, where he and other business owners built textile mills powered by the river. Later, Waltham's mill owners, needing more power than the Charles could supply, moved to an area north of Boston. Here they created the industrial town of Lowell, Massachusetts, almost entirely around water power. Soon, textile mills were able to produce millions of yards of cloth, thanks largely to water power.

The major problem with early waterwheels, though, was that they could not store power for later use, nor could they easily distribute power to several users. This disadvantage was overcome by the development of hydroelectricity (though modern waterwheels can also produce electricity). Hydroelectric dams, unlike waterwheels, do not depend entirely on the rate of flow of the water in a river or stream. Moreover, by producing electricity, power can be stored and distributed to more than one user in a community.

This is a traditional horizontal *noria* water wheel. The water comes out of the well on a wheel carrying pitchers, which then supplies the irrigation network. © *Marc Garanger/Corbis.*

Hydroelectricity was first used in 1880, when the Wolverine Chair Factory began producing hydroelectric power for its own use in its Grand Rapids, Michigan, plant (perhaps it is no accident that the city had the word *Rapids* in its name). The first hydroelectric plant whose power went to multiple customers began operation on September 30, 1882, on the Fox River near Appleton, Wisconsin. Major improvements in hydroelectric power generation were made by Lester Allan Pelton (1829–1908), an inventor who is sometimes called the "father of hydroelectric energy." Sometime in the late 1870s Pelton developed the Pelton wheel, a new, more efficient design for turbines that powered hydroelectric plants. A later design, developed by Eric Crewdson in 1920 and called the turgo impulse wheel, improved on the efficiency of Pelton's design. Because of these improvements, more and more electrical needs in the United States were being met by hydroelectric power.

The water in rivers and streams, though, is not the only water in motion. The oceans move too, and in the late twentieth and early twenty-first century, efforts have been launched to tap the power contained in the oceans' tides, waves, and currents. Fundamentally,

## Richard Arkwright

Richard Arkwright, the youngest of thirteen children, began his career as a barber's apprentice. He wanted to run his own company, so he decided to become a wig maker. He spent the early part of his career traveling through England collecting discarded hair he could use to make wigs.

After Arkwright became involved in the textile industry in the 1760s, he built many profitable mills in England, Wales, and Scotland. When he died, he was worth nearly a million dollars, an enormous fortune in the late eighteenth century. In 1786 he was knighted by England's King George III.

But like many industrialists of the time, Arkwright built his fortune on the backs of his workers, who toiled from 6:00 in the morning to 7:00 in the evening. Among his 1,900 employees, two-thirds were children. While many other mill owners employed children as young as five, Arkwright was slightly enlightened for his time: he did not hire children under the age of six. Nor would he hire anyone over the age of forty.

though, these sources of power are little different from the power provided by rivers and streams. The water is moving, so the challenge for engineers is to devise ways to convert that motion into electricity. While strides have been made, the practical use of these power sources is still in the beginning stages.

Tidal power for electrical generation is relatively new. Currently, only one tidal power-generating station has been built and is in use. This plant is located at the mouth of the La Rance River along France's northern coast. The plant was built in 1966 and provides 240 megawatts, or 240 million watts, of electricity. There is a 20-megawatt experimental station in Nova Scotia, Canada, and Russia has a 0.4-megawatt station near the city of Murmansk. Other promising sites include the Severn River in western England, Cook Inlet in Alaska, and the White Sea in Russia.

Waves and ocean currents, like the tides, contain enormous amounts of energy, as any swimmer who has been pelted by a wave or swept along on an ocean current knows. The first patent for a wave power machine that would function much like a waterwheel in powering grain mills and sawmills was filed in France in 1799, although there is no evidence that the device was ever built.

## The Pelton Wheel

Lester Allan Pelton (1829–1908) was born in Ohio but migrated to California during the gold rush of the late 1840s. In the 1870s he conceived the design for the Pelton wheel. He tested a prototype in 1879 and received a patent for the design in 1889.

Before the Pelton wheel, the most common type of turbine was the reaction turbine, which came equipped either with flat paddles or with cups or buckets. In either case, the water came straight at the paddle or bucket. As the water struck it, it pushed the paddle or bucket, thus turning the wheel. The Pelton wheel was the result of an accident. Pelton was watching a spinning water turbine. The key that held the wheel onto the shaft slipped out of place so that the wheel tilted. Instead of hitting the paddles on the waterwheel directly in the center, the water hit near the edge and was diverted to flow in a half-circle. To Pelton's surprise, the wheel actually began to spin faster.

The turgo turbine was developed in 1919 and represented an improvement in the Pelton wheel. It is less expensive to make and can handle a greater flow of water, so a smaller turgo turbine can generate the same amount of power as a larger Pelton wheel.

One of the first important developments for harnessing this power took place in 1974, when a British engineer named Stephen Salter invented a device called a "duck." This was a hydraulic mechanism that converted wave power into electricity, but this is only one of many ingenious innovations that scientists and engineers have developed. In the years that followed, scientists and engineers sought ways to transform innovations like the duck into a working wave power-generating station. Their efforts were finally successful in 2000, when the United Kingdom opened the first such station on the island of Islay, off the coast of Scotland. This station is called the Limpet 500, which stands for Land-Installed Marine-Powered Energy Transformer. The number 500 refers to the 500 kilowatts of electricity it feeds into the United Kingdom's power grid.

The world's oceans are also the source of thermal energy, or the heat that oceans absorb from the sun. The word *thermal* comes

## Georges Claude

Georges Claude (1870–1960) may have built the first system for harnessing the thermal energy in oceans, but his impact as a scientist was probably much greater in a way that is glaringly obvious every day (or every night) in just about every city and town throughout the developed world.

As a young engineer, chemist, and inventor, Claude turned his attention to the inert gases. He discovered that passing an electrical current through cylinders filled with inert gases such as neon produces colored light. In other words, Claude was the inventor of the neon sign, which he first demonstrated in Paris in 1910. The first neon signs arrived in the United States when he sold two of them to a Packard automobile dealership in Los Angeles in 1923.

from a Greek word, *therme,* meaning "heat," and is related to another Greek word, *thermos,* meaning "hot."

The first scientist to propose that the thermal energy of the oceans could be tapped for human needs was a French physicist named Jacques Arsene d'Arsonval (1851–1940) in 1881. D'Arsonval may very well have gotten the idea, though, from author Jules Verne (1828–1905), who imagined the use of ocean temperature differences to produce electricity in his novel *Twenty Thousand Leagues under the Sea* in 1870. In 1930 one of d'Arsonval's students, Georges Claude, built the first-ever system for doing so off the coast of Cuba. The system he built generated 22 kilowatts, or 22,000 watts, of electricity. However, this it represented a net power loss, because it actually took more power to run the system than it was able to generate. Then in 1974 the Natural Energy Laboratory of Hawaii Authority (NELHA) was formed. In 1979 NELHA successfully demonstrated a plant that produced more energy than it consumed (50-kilowatts gross; 15-kilowatts net). In 1981 Japan built a system that produced 31.5 kilowatts of net power. In 1993 NELHA set a record when it produced a net power of 50 kilowatts in a demonstration.

### How water energy works

To understand fully the nature of water energy, two terms have to be defined more precisely: energy and work. In everyday use, the word energy often refers to a substance, such as gasoline, coal, or natural gas. Strictly speaking, though, these substances are not energy; they are just chemical substances. Their energy is locked inside their chemical bonds, and it has to be released by burning them. What makes these substances useful is that they contain a lot of energy that can easily be released through combustion (burning).

Put differently, these substances can do a great deal of work, but scientists define work in their own peculiar way. To most people, "work" means something like a chore or job, such as mowing the lawn. To a scientist, though, "work" refers to the process of converting one form of energy into another, such as converting the chemical energy of natural gas into heat used to boil water or heat a house. Scientists usually measure energy output in terms of the amount of work that can be done with it. For example, the calorie, used most often in discussions of diet, exercise, and weight, is actually a unit that measures a form of work. A more commonly used unit of work among scientists is the joule. The joule is part of the metric system units, and it is used to measure heat, electric energy, and the energy of motion.

To produce energy, though, it is not always necessary to burn something. When cleaning up after dinner, a family's first task is to rinse off the dishes, pots, and pans, using water from the kitchen faucet. What rinses the dishes, though, is not the water from the faucet by itself so much as it is the energy contained in the running water. This type of energy is called kinetic energy. The word *kinetic* comes from a Greek word, *kinesis,* which means "motion," so kinetic energy is the energy contained in a body of water when it is in motion. In discussions of water energy, sometimes the term *hydraulic energy* is used instead of kinetic energy. The word *hydraulic* is derived from *hydro,* the Greek word for "water." In this context, kinetic energy and hydraulic energy refer to the same thing.

To put water to work, then, the water has to be in motion. The best way to put large amounts of water in motion is to let gravity do the work. Streams and rivers, for example, flow because the water in them is moving downhill, even if only slightly, following the downward pull of gravity. In a home, water flows "downhill" because a city's water is stored in large elevated tanks, where it contains stored energy. When a homeowner opens a faucet, the water flows in a downward direction from the tank through the city's water pipes and out the faucet, where it carries enough kinetic energy to knock food remnants off dirty dinner dishes. Helping out is the sheer weight of the water, which pushes it down through the city's water pipes.

Scientists measure how much work a body of water can do using flow, which is simply the volume of water measured in, for example, gallons or liters per second or minute. This is just common sense. A homeowner who wants to rinse off a dirty porch uses a hose, not a squirt gun, because the flow from the hose is much greater than the flow from a squirt gun, so the water can do more work in a given period of time. A squirt gun might work, but the job would take a very long time.

This, then, is the basic science behind kinetic energy. Water flowing downhill, pulled by gravity, contains kinetic energy. A tool such as a waterwheel can be used to convert this kinetic energy into mechanical energy, which can then be harnessed to perform a task, such as grinding grain, sawing lumber, or running a textile loom. Or the kinetic energy can be transformed into electricity, which can be stored and distributed to many different users.

### Current and future technology

The moon in large part is responsible for another type of energy that water can provide: tidal power. Every day, the moon (and, to a lesser extent, the sun), exerts gravitational pull on the Earth, causing the Earth's oceans to bulge outward. At the same time, the Earth rotates beneath this water, so twice each day, the Earth's coastlines experience high and low tides. These tides, just like rivers and streams, are water in motion. This motion, driven by the pull of gravity, imparts kinetic energy to the oceans. The ebb and flow of the tides along a coast, or perhaps into and out of an inlet or bay, are little different from the flow of water in a river, and they can be harnessed using technology similar to that used on rivers. Because the water flows in two directions, though, the system can generate power when water is flowing in and when it is ebbing out. However, a tidal power-generating station can operate only about ten hours a day, during the times when the tides are in motion.

The oceans' waves are yet another potential source of kinetic energy. Waves, which average about 12 feet (almost 4 meters) in height in the oceans, are caused by wind blowing across the surface of the water, just as tiny ripples are created when a person blows across the surface of a cup of hot chocolate to cool it. The height of a wave—from its peak, or crest, to its bottom, or trough—is determined by how fast the wind is blowing, the length of time it has blown in the same direction, and the width of the open water over which it is blowing. The steepest and most powerful waves are caused by winds that blow strongly in the same direction across oceans, such as the trade winds.

Waves move across the waters of the open ocean with little change. But as they approach the shore and the water gets shallower, they begin to release their enormous energy. First, the ocean's floor causes the wave to slow and to increase in height. Then, the front of the wave "breaks," or collapses, hurling tons of water at the coastline. The force of this wave power is so great that it continues to wash away the coastlines. It is estimated, for example, that parts of Cape Cod are eroding at a rate of 3 feet (0.9 meter) per year. Like the water in rivers and streams, these waves could potentially be used for their kinetic energy.

A final source of kinetic energy in the oceans is their currents. Currents, like waves, are usually propelled by the wind blowing across the surface. The wind has to be strong and consistent. But other currents are formed by differences in water temperature and salinity (salt content) and even by slight differences in the elevation of the sea's surface. The currents follow paths determined by the Coriolis effect, or the effect of the Earth's rotation. In the Northern Hemisphere, the Earth's rotation deflects the currents into a clockwise rotation; in the Southern Hemisphere, the currents flow counterclockwise.

One of the most studied and well-known ocean currents is the Gulf Stream, which originates near Florida, crosses the Atlantic Ocean, and warms much of northern Europe. The Gulf Stream is 50 miles (80 kilometers) wide, and an estimated 10 cubic miles (16 cubic kilometers) of water move through it every hour. It moves so fast that its warm waters do not mix with the colder water that surrounds it. The Gulf Stream is, in effect, a river. The water is in motion, so it contains vast amounts of kinetic energy that could be tapped for human use.

There is also thermal energy, or the heat contained in the world's oceans. Tapping the oceans' thermal energy, though, is not just a matter of somehow going out and piping in the heat. The process, called ocean thermal energy conversion (OTEC), is driven by the ocean's thermal gradient, which refers to the differences in temperature between the ocean's layers of water. Power can be produced when the difference between the warmer surface waters and the colder deep waters is at least 36°F (20°C). Energy-producing systems for tapping the ocean's thermal energy rely on a system of condensers, evaporators, and turbines to generate electricity. OTEC could provide electricity, especially to many tropical nations that currently have to import all their fuel.

### Benefits of water energy

The major benefit that all forms of water energy have is that they provide power without burning fossil fuels. Energy can be provided for human use without having to tear up the land to mine coal or disrupt ecosystems to drill for oil. The power they provide is clean—it does not release particulate matter, carbon dioxide, or sulfur dioxide into the air, contributing to smog and the ill health effects that smog can cause, such as lung disease. Also, because water energy does not depend on the burning of fossil fuels, it does not contribute to global warming, caused by the buildup of gases such as carbon dioxide in the atmosphere. Nor does it contribute to acid rain, or precipitation that is more acidic than normal because it contains such substances as sulfur dioxide. Acid rain, like any acidic substance, can have harmful effects on forests, wildlife, and even structures built by people.

Another major benefit of water energy is that it is virtually inexhaustible. Once fossil fuels run out, they are gone. There is no way to somehow manufacture more oil or natural gas. However, the energy provided by water will be there as long as the sun shines and as long as the Earth contains oceans and rivers. Further, the energy provided by water is essentially free—once, of course, the technology is put in place to extract the energy. While money would continue to have to be spent to build plants, maintain them, and distribute the power they produce, a major benefit is that power providers would not have to buy fuel for them. The potential savings is huge. As of mid-2005 the cost of a barrel of oil was hovering around $60. The United States uses about twenty million barrels of oil each day. That means about $1.2 billion per day is spent for just that one form of fuel. Replacing that fuel with water energy would result in enormous savings for consumers.

### Drawbacks of water energy

These energy sources, though, are not without their drawbacks. While hydroelectric dams have been around for well over a century, stations for harvesting tidal, wave, ocean current, and ocean thermal power are still in the developmental stages. Exploiting these forms of power would require a huge investment. The cost of building a tidal power-generating station, for example, could run as high as $15 billion.

A second drawback is that water energy is not totally reliable. In an energy plant that burns fossil fuels, the fuel can be fed into the system at a constant rate. As a result, the energy output of the system can be predicted and maintained at a steady pace. Water energy can be a little more variable. In a dry season, the water in a river may not run as fast. The level of the water in the reservoir behind a hydroelectric dam may fall so far that the dam's operators have to slow the flow of water over the dam, cutting power output. In the case of ocean energy, plant operators have no control over the water. Tidal power, for example, can vary from day to day, depending on the alignment of the Earth with the sun and the moon. Wave power could be highly variable, depending on prevailing winds. While the power in ocean currents and in the ocean's thermal gradient is more predictable, the chief obstacle is getting to it. Creating a power plant in the middle of the Gulf Stream would be no easy feat.

A related problem is that water energy is not evenly distributed across the Earth. Providing tidal power to the residents of Nebraska would be impractical because Nebraska is nowhere near an ocean. While tides operate throughout the world, not every coastal region can produce tidal power very efficiently. Some coastal regions have higher tides than others, usually because of some geographical feature, such as bays and inlets that push the water to a higher level than it would otherwise reach. To be practical, efforts to harness tidal power require a difference of about 16 feet (5 meters) between high and low tide. This difference can be found at only about forty places around the world. As the water flows in, and then as it flows out, it can be harnessed in much the same way that the water in any river can be harnessed. However, tidal power stations would be possible only in a limited number of locations.

The use of river power, too, is highly variable. While hydroelectric power provides 24 percent of the electricity used worldwide and 9 to 10 percent used in the United States, much of that hydroelectric power is concentrated in regions with several rivers. In the United States, for example, 14 percent of the power used in the Rocky Mountain states comes from hydroelectric dams; in the Pacific Northwest, in contrast, some 65 percent of power demand is filled by 58 hydroelectric dams. While hydroelectric dams provide almost all of the electricity in Norway, 83 percent in Iceland, 67 percent in Austria, and 60 percent in Canada, they can provide little or none in the desert countries of the Middle East or in most of Africa. This suggests that no one source can magically solve any nation's energy problems.

A final drawback is that a fossil fuel-fired plant can be built essentially anywhere because the fuel is brought to the plant. With water energy, the plant has to be brought to the fuel, meaning that plants have to be built on rivers, along shorelines, and in bays, where they disrupt the natural environment.

### Environmental impacts of water energy

A major drawback to the use of water energy is the potential environmental impact. On one level, using water energy would have benefits for the environment, including cleaner air and reduced global warming, compared to the use of fossil fuels. However, the power plants themselves could potentially have a devastating effect on local ecosystems.

Hydroelectric dams are a good example. Throughout the world, about 40,000 large dams are in use to provide hydroelectric power. Most of these dams were built with little regard to the environmental impact they would have. Dams, for example, require reservoirs. In effect, they turn a river ecosystem into a lake ecosystem, at the same time gobbling up large tracts of land. Moreover, they block the migration of fish, such as salmon in the Pacific Northwest. They also prevent the downstream movement of silt, which is often rich in nutrients.

Such facilities as tidal power-generating stations could have similar environmental impacts. The construction and operation of such facilities could have a serious impact on marine and coastal ecosystems, fisheries, and the like. They could disturb the silt on the ocean bed, with unintended consequences. Further, they could convert beautiful natural areas into eyesores.

Another potential drawback to hydroelectric dams—or any water energy project—concerns ownership rights. Rivers usually flow through more than one country. In Southeast Asia, for example, six countries make up the Mekong River's watershed. During rainy seasons this would not be a problem, for the Mekong flows at a rate of 31 cubic miles (50,000 cubic meters) per second. During the dry season, however, the river flows at a rate of only about 1.2 cubic miles (2,000 cubic meters) per second, seriously reducing the amount of power that could be produced. This would provide an upriver country with an incentive to block the flow of the river, denying water and power to the downriver countries. The result could be serious regional conflict over water rights. A similar problem could occur in the oceans. It is an established principle that no country owns the oceans in its vicinity, other than a narrow strip along the coastline. Any type of power-generating station that lies outside of a nation's coastal waters would run into serious legal difficulties if it used international seas to provide power for just one nation.

### Economic impact of water energy

The economic impact of water energy has always been great, but new forms have the potential to dwarf the impact that has been felt throughout human history. While water power has been used throughout much of history, its economic impact began to be felt more fully in the late eighteenth and early nineteenth centuries. The town of Lowell, Massachusetts, which grew as textile firms built up around the availability of water power, by the mid-1830s boasted 20 textile mills employing 8,000 people and producing 50 million yards (46 million meters) of cloth per year.

Hydroelectricity had an even larger impact. In the early twenty-first century hydroelectric dams provide about 9 to 10 percent of the electricity used in the United States. Worldwide, though, hydroelectric plants provide about 24 percent of electricity, serving a billion people. Together, they annually produce about 675,000 megawatts (*mega-*, meaning "million"), the equivalent of about 3.6 billion barrels of oil. That represents a savings of about $180 billion that might otherwise be spent on oil. These hydroelectric plants are the world's single largest source of renewable energy.

Other sources of water energy hold even greater promise. Just over 70 percent of the Earth's surface is covered by oceans. The amount of water they contain is staggering: 328 million cubic miles (527 million cubic kilometers), or 361.2 quintillion gallons (1,367.3 quintillion liters). (A quintillion is 1,000,000,000,000,000,000.) Every day the sun shines on these oceans, and every day they absorb a great deal of thermal energy. In fact, the oceans can be thought of as the world's single largest solar panel. It is estimated that on a typical day, about 23 million square miles (60 million square kilometers) of the world's tropical oceans absorb an amount of energy from the sun equal to about 250 billion barrels of oil.

To put that figure in perspective, the total amount of oil produced in the world each day in 2005 was about 76 million barrels. That means that each day, the tropical oceans absorb three thousand times more energy than that provided by oil. This is an enormous amount of energy. Some experts estimate that the amount of power that could potentially be produced from heat in the oceans is 10 trillion watts. Just 1/200th of one percent of this thermal energy—absorbed by the tropical oceans in just one day—could provide all the electricity consumed in the entire United States. This energy would be clean and endlessly renewable. The problem, of course, is finding ways to capture that energy.

### Societal impact of water energy

The societal impact of water energy is essentially the same as the impact of any alternative energy. Clean, renewable energy would lessen the adverse health effects of fossil fuel burning. Because the fuel itself is essentially free, more reliance on water power would free up billions of dollars that could be used for other human needs. Using water power would also benefit the environment, reducing the need for environmentally disruptive coal mining and oil drilling, along with the regular oil spills that spoil many nations' coastlines. Water power could also have a major impact on poorer nations, which lack the resources to import fossil fuels for economic development. Water energy could provide these nations with a clean, relatively inexpensive way to develop and provide a richer economic, social, educational, and cultural future for their peoples.

## HYDROPOWER

The term *hydropower* is a general one that can be used to refer to any type of water energy. Here, though, the term will be used to refer to the earliest form of hydropower, the kind used in primitive waterwheels, though modern waterwheels are not as primitive as those of the past. In the early 2000s waterwheels continue to be used for low-level electrical power generation.

A waterwheel is a paddlewheel attached to a fixed rotor, or axle, and placed in the current of a river or stream. The wheel is actually a pair of parallel wheels connected to the rotor by radial spokes. Between the two wheels is an arrangement of paddles. As the water passes, the kinetic energy of the water pushes against the paddles, turning the wheel and producing mechanical energy, which in turn is transferred through gears to machinery that accomplishes the task at hand. In the past this machinery was very often a large stone used to grind grain, but could also consist of saws in a sawmill, bellows in a foundry, looms in a textile mill, abrasive tools for polishing metal, pumps for removing water from a mine, and many other applications. Some wheels, rather than using paddles, used buckets. The weight of the water in the buckets helped to propel the wheel around.

Early waterwheel users were creative with the placement of waterwheels. While the wheels were often inserted directly into a stream or river and connected to a facility on the riverbank, often they were placed on barges and boats (called ship mills), sometimes suspended between two barges or boats. Others were attached to the abutments of stone bridges over rivers.

The John Cable Mill in Cades Cove, Tennessee, was in operation up to the mid-1900s to grind corn and saw logs. Two streams were used to provide adequate water flow to the waterwheel in order to generate power. *James Steinberg/Photo Researchers, Inc.*

Historically, three different types of waterwheels were used. The first was the horizontal waterwheel. This type of wheel was lowered horizontally into the water, where it was totally submerged. Attached to the wheel were veins, which were somewhat like the veins on a pinwheel that turns when air blows over it. This type of wheel was attached to a rotor that protruded up out of the water and connected directly to something like a millstone. Horizontal waterwheels are still in use in India and Nepal.

A more efficient and powerful design is the vertical waterwheel. Vertical waterwheels came in two types, the undershot and the overshot, both of which required a system of gears to turn the machinery. An undershot wheel was lowered vertically into the water of a river. The water passed by the lower portion of the wheel, pushing on the paddles to turn it. A major disadvantage of this type of wheel was the variability in the river's water level. During dry spells, the water level in the river would fall, diminishing the wheel's power. Sometimes the water level would fall so much that the wheel was entirely out of the water, making it useless.

With an overshot wheel, the water flowed from above. These types of wheels were sometimes positioned underneath waterfalls so that the water struck the paddles as it fell, or alternatively poured into buckets so that the weight propelled the bucket forward, turning the wheel. More commonly, the source of the water was an artificial channel that flowed to a position above the waterwheel.

### Current uses of hydropower

Although waterwheels are thought of as a feature of earlier societies, in fact they are still widely used for irrigation, pumping water, and even occasionally still to power machinery such as sawmills. These types of wheels can be found in many areas of the world. In Turkey and Afghanistan, waterwheels are still used to grind grain. In the United States, a company called Equality Mills in West Virginia still manufactures waterwheels, and one of the first wheels the company ever produced, in 1852 (under earlier owners), is still in operation at the Tuscorora Iron Works just across the creek.

Companies in the United States and Germany also manufacture waterwheels for electrical power generation, and the British Hydropower Association provides detailed information about building small waterwheel power plants. Typically, such a plant would involve the following:

- A water intake from a river or stream
- A small canal to channel the water
- A forebay tank, where the water is slowed so that debris can settle out, along with a trash rack to filter out debris
- A penstock, which shoots the water downward to the turbine
- A powerhouse, which contains a turbine where the power is actually generated
- A tailrace, which channels the water back into the river or stream

### Benefits of hydropower

Prior to the industrial revolution, waterwheels were essentially the only form of alternative energy available. In Europe, the rapid spread of waterwheels may have been a function of the Black Death, the plague that wiped out large portions of the population in the late Middle Ages. Waterwheel use expanded rapidly in England, France, and other European nations as a way to replace lost labor.

In modern times waterwheels are used primarily for low-level electrical power generation. The British Hydropower Association notes that small-scale hydropower generation is highly efficient, between 70 and 90 percent (meaning that 70 to 90 percent of the available power can actually be generated).

### Drawbacks of hydropower

Historically, waterwheels had two primary drawbacks. The first was that they required a great deal of maintenance. Because they were constructed mostly of wood, they tended to break down over time. Further, water is not very friendly to wood, causing it to deteriorate and rot. The second problem was that in northern climates, waterwheels were of limited usefulness in cold weather, when the water froze.

The primary drawback of modern waterwheels is that building such a power plant is expensive for the amount of energy it can produce. The bulk of the expense lies in the turbines needed to generate the power, gearboxes needed to convert kinetic energy into mechanical energy, and generators needed to convert mechanical energy into electrical energy. The extent to which this is a drawback depends on the amount of available energy. When flow is high, the amount of power generated is more likely to justify the cost; when it is low, the amount of power generated may not be worth the cost. The British Hydropower Association estimates that the total cost of building a 100-kilowatt (kW) power plant could range from roughly $150,000 to $470,000. Adding to the cost is the need to acquire rights to use the land.

Another potential drawback of waterwheel power plants is safety. Such plants, including the wheel itself, have to be fenced off so that they do not injure curious people who get too close. This fencing, combined with the plant itself, has the potential to become an eyesore, though manufacturers attempt to make the equipment as visually attractive as possible.

A final drawback stems from the variability of water flow. During spring runoff, when snow is melting and rivers run rapidly, the amount of power generated is much higher than in, say, August, when rivers are running low, providing less flow.

### Issues, challenges, and obstacles of hydropower

The primary issue surrounding the use of waterwheels is ownership rights. Any stream or river almost certainly flows through property owned by many people. The river itself is common property; no one individual owns it. If one property owner builds a waterwheel, other property owners along the river might object, particularly if they are uncertain about the effects the wheel might have downstream.

Another challenge concerns distribution of the power. One property owner might build a waterwheel for personal use, but larger waterwheels in high flow streams might generate enough electricity for multiple users. The questions then become how that power is going to be distributed and how its users will divide the cost of constructing the waterwheel.

## HYDROELECTRICITY

Hydroelectricity is any electricity generated by the energy contained in water, but most often the word is used to refer to the electricity generated by hydroelectric dams. These dams harness the kinetic energy contained in the moving water of a river and convert it to mechanical energy by means of a turbine. In turn, the turbine converts the energy into electrical energy that can be distributed to thousands, even millions, of users.

One of the most prominent hydroelectric dams in the United States is the Hoover Dam on the Colorado River along the border between Arizona and Nevada. Construction on the dam began in 1931; it was completed five years later, under budget, for $165 million. Behind the dam is a reservoir, Lake Mead, containing about 1.24 trillion gallons of water. The dam is 726 feet (221 meters) tall, and at its base is 660 feet (201 meters) thick. Its 4.5 million cubic yards of concrete would be enough to build a two-lane highway from Seattle, Washington, to Miami, Florida. Each year, the dam produces 4 billion kilowatt-hours of electricity, enough to serve 1.3 million people.

The largest hydroelectric dam in the United States is the Grand Coulee Dam on the Columbia River in Washington State. Construction began on the dam in 1933 and was completed in 1942. The original purpose of the dam, however, was not to generate electricity but to irrigate one-half million acres of agricultural land. From 1966 to 1974 the power-producing ability of the dam was expanded with the addition of six new electrical generators. The scope of the Grand Coulee Dam amazes visitors. It is the largest concrete structure in the United States, at 11,975,521 cubic yards. At its widest point, it is almost exactly a mile (1.6 kilometers) long. At 550 feet (167 meters) tall, it is twice the height of the Statue of Liberty and more than twice the height of Niagara Falls. Its reservoir, Roosevelt Lake, contains up to 421 billion cubic feet of water. Its four power plants and 33 generators produce 6,809 megawatts of power annually.

Huge turbine engines inside the Hoover Dam in Black Canyon, Nevada, supply electricity and water to California, Nevada, and Arizona. © *James Leynse/ Corbis.*

A hydroelectric dam consists of the following components:

- Dam: The dam is built to hold back water, which is contained in a reservoir. This water is regarded as stored energy, which is then released as kinetic energy when the dam operators allow water to flow. Sometimes these reservoirs, such as Lake Mead, are used as recreational lakes.
- Intake: Gates open to allow the water in the reservoir to flow into a penstock, which is a pipeline that leads to the turbine.

Aerial view of Hoover Dam, Nevada, which was built between 1931 and 1936 to harness the Colorado River, creating the reservoir Lake Mead. © *Lester Lefkowitz/ Corbis.*

The water gathers kinetic energy as it flows downward through the penstock, which serves to "shoot" the water at the turbine.

- Turbine: A turbine is in many ways like the blades of a windmill or the veins of a pinwheel. The water flows past the turbine, striking its blades and turning it. The most common turbine design used in large, modern hydroelectric power plants is the Francis turbine, which is a disc with curved blades. The Francis turbine was developed by British-American engineer James B. Francis (1815–1892), who began and ended his professional career in the United States as an engineer at the Locks and Canal Company in Lowell, Massachusetts. In the largest hydroelectric plants, these turbines are enormous, weighing up to 170 tons or more. The largest ones turn at a rate of about 90 revolutions per minute.
- Generator: The turbine is attached by a shaft to the generator, which actually produces the electricity. Generators are based on the principle of electromagnetic induction, discovered by

## Roll on, Columbia

In the 1940s folk singer Woodie Guthrie (1912–1967) was hired by the Bonneville Power Administration to write folk songs about the dams being built on the Columbia River. Over a period of about a month, Guthrie wrote twenty-six folk songs under the general title *Columbia River Ballads*. One of the most popular of these songs was ''Roll on, Columbia,'' which the state of Washington adopted as its official folk song in 1987.

British scientist Michael Faraday (1791–1867) in 1831. Faraday discovered that as a metal that conducts electricity, such as copper wire, moves through a magnetic field, an electrical current can be induced, or created, in the wire from the flow of electrons. The mechanical energy of the moving wire is therefore converted into electrical energy. In a hydroelectric plant, the mechanical energy is supplied by the turbine, which in turn is powered by the kinetic energy of moving water.

- Transformer: A transformer converts the alternating current produced by the generator and converts it into a higher voltage current.
- Power lines: Power lines transmit the power out of the power plant to the electrical grid, where it can be used by consumers.
- Outflow: Pipes called tailraces channel the water back into the river downstream.

Hydroelectric power plants come in three basic types:

- High head: "Head" refers to the difference in level between the source of the water and the point at which energy is extracted from it. Assuming other things are equal, the higher the head, the more power is generated. A high head hydroelectric plant is one that uses a dam and a reservoir to provide the kinetic energy that powers the plant. Most major hydroelectric plants are of this type.
- Run-of-the-river: In contrast, a run-of-the-river plant requires either no dam or a very low dam. It operates entirely, or almost entirely, from the flow of the river's current. No energy is stored in a reservoir. These hydroelectric plants are generally small, producing less than about 25 kilowatts.

### The World's Biggest Hydroelectric Power Plant

The world's biggest hydroelectric power plant is in South America. From 1975 to 1991 the Itaipú Dam was built across the Paraná River as a joint project by Brazil and Paraguay. The plant has eighteen generating units that can provide 12,600 megawatts of power, or 75 million megawatt-hours per year, enough wattage to power most of California. By 1995 the dam was providing 25 percent of Brazil's energy and 78 percent of Paraguay's.

The dam, called one of the ''Seven Wonders of the Modern World'' by the American Society of Civil Engineers, is enormous. The amount of iron and steel used in its construction could have built 380 Eiffel Towers (the famous landmark in Paris). The volume of concrete used to construct it is equal to fifteen times the volume used to construct the tunnel under the English Channel that connects France and England. To build the dam, workers had to rechannel the seventh largest river in the world and remove 50 million tons of earth and rock.

- Pumped-storage: Some hydroelectric plants rely on a system of two reservoirs. The upper reservoir operates exactly as the reservoir does in a high head plant: Water from the reservoir flows through the plant to turn the turbines, then exits the plant and reenters the river downstream. In a pumped-storage plant, the water exiting the plant is stored in a lower reservoir rather than reentering the river. Using a reversible turbine, normally during off-peak hours (or hours when power usage is low, usually at night), water is then pumped from the lower to the higher reservoir to refill it. This gives the plant more water to use to generate electricity.

#### Current uses of hydroelectricity

During the 1930s a large number of hydroelectric dams were built on the waterways of the United States. Many of these dam projects were the result of that decade's Great Depression. During the depression, the U.S. government sponsored public-works projects designed to put people to work and recharge the economy. These dams, such as Hoover Dam and the 192 dams that were built along the Columbia River in the Northwest, produced

### The World's Smallest Hydroelectric Power Plant

Someday soon the world's smallest hydroelectric power plants may appear—in people's shoes. On file at the U.S. Patent and Trademark Office is patent number 6,239,501. The patent is held by Canadian inventor Robert Komarechka, who conceived the idea that a tiny hydroelectric power plant embedded in the soles of shoes could provide power to run cell phones, compact-disc players, laptop computers, and other modern electronic gadgets.

The design is based on the way people walk. When a person takes a step, force is exerted downward on the heel. The foot then rolls forward, so that force is exerted on the toe. Komarechka found a way to harness this power by inserting sacs of fluid in the soles of shoes, one at the heel end and one at the toe end. Connecting the sacs is a conduit through which the fluid, a gel-like substance, can flow. As it flows, it turns a tiny turbine that is attached to a microgenerator, which in turn produces electrical power. A tiny socket allows the user to connect an electronic gadget to the power source, either directly at the shoe or at a power pack attached to, perhaps, a person's belt.

hydroelectric power, and by the end of the 1930s they were meeting about 40 percent of the nation's electricity needs.

Many dams were also built in a seven-state region around the Tennessee River Valley under the guidance of the Tennessee Valley Authority (TVA). In the early twenty-first century about two thousand hydroelectric dams in the United States provide about 9 to 10 percent of the nation's electricity. They have not kept pace with U.S. demand for power simply because most of the best sites for hydroelectric dams already have one. Worldwide, about 40,000 hydroelectric dams provide a total of 675,000 megawatts of power to a billion users.

#### Benefits of hydroelectricity

The chief benefit of hydroelectric power, like the power provided by waterwheels, is that fossil fuels do not have to be burned, releasing particulate matter and greenhouse gases (such as carbon dioxide and sulfur dioxide) into the atmosphere, where they produce smog and contribute to global warming and acid rain.

Chinese workers inspect the second section of the main dam of the Three Gorges project near Yichang in central China's Hubei province. China blocked the massive Yangtze River on June 1, 2003, to fill a reservoir for the world's biggest hydroelectric project that is a point of national pride but which critics fear will become an environmental nightmare. *©Reuters/Corbis.*

Hydroelectric power is also free in the sense that fuel does not have to be purchased to produce it, although of course money has to be spent to build and maintain the power plant and to distribute power to consumers.

Another major benefit of hydroelectric energy is that it is renewable. Over time, it will become more and more expensive to extract fossil fuels from the earth until eventually these fuels will be entirely depleted. Hydroelectric power will remain available as long as there are rivers. Hydroelectric energy, in contrast to oil, is not dependent on imported fuels from other countries, which could be cut off by one or more of those countries and make a nation vulnerable to political pressures from them. Hydroelectric dams can also have secondary benefits. They provide flood control on rivers, and their reservoirs often serve as lakes for recreational activities such as boating and swimming.

### Drawbacks of hydroelectricity

Hydroelectric energy has always been thought of as clean energy, but scientists and engineers have started to understand that it has significant drawbacks as well. One drawback is that damming rivers floods large areas of land. When the water fully rises behind the new Three Gorges Dam on China's Yangtze River (under construction in 2005), for example, it will wipe out 13 cities, 140 small towns, and over 1,300 small villages, forcing over two million people to leave some of China's richest farmland. In Quebec, Canada, the first phase of a major hydroelectric project on the watershed flowing into the James Bay flooded nearly 3,900 square miles (10,000 square kilometers); the second phase of the project more than doubled that figure. A third phase of the project was still in the planning stages in 2005, but if the entire project is carried out as planned, the size of the flooded regions would be greater than the size of the country of Switzerland. Flooding vast amounts of land like this often has a disproportionate effect on native peoples, whose way of life can be destroyed.

Constructing hydroelectric dams, converting a free-flowing river of fresh water into a lake, also has a profound effect on ecosystems. Dams and reservoirs affect such factors as water quality, the amount and kinds of bacteria in the water, bank erosion, nutrient transport, the salt content of soil, and water temperature. Some dams have been implicated in the spread of waterborne diseases such as malaria. When a large dam fails, the results can be catastrophic, wiping out wildlife, vegetation, houses, roads, even whole towns downstream.

Dams also affect the amount of water in rivers downstream, with effects on wildlife that are only beginning to be understood. They also block the flow of silt downstream, affecting the flow of nutrients through a river system. In Egypt, the Aswan Dam along the Nile River, which provides 10 billion kilowatt-hours of electricity every year (and has a reservoir of nearly 6 trillion cubic feet [170 million cubic meters], four times that of the Hoover Dam), blocked the flow of nutrient-rich silt to the nation's agricultural floodplains. Farmers have had to replace those nutrients with a million tons of artificial fertilizer each year. Meanwhile, the silt can build up at the dams over time, causing them to be less efficient.

Some scientists estimate that 93 percent of the declines in freshwater marine life are caused by hydroelectric dams. The dams in the U.S. Pacific Northwest are regarded as a major cause in the decline of the salmon population because the dams prevent salmon from migrating upriver to spawn. Although "fish ladders" are installed to lessen this impact, they are by no means 100 percent effective.

A general view taken June 7, 2003, of old Wushan county, near China's Chongqing Municipality, which was partially submerged by rising water levels after China blocked the massive Yangtze River for the Three River Gorges project. ©*Reuters/ Corbis.*

Another drawback is that hydroelectric energy may not be as clean as once thought. Decaying vegetation in reservoirs may give off quantities of greenhouse gases equal to those emitted by burning fossil fuels. This can be an ongoing problem because when the water level in a reservoir falls during an extended dry period, vegetation grows on the banks. This vegetation, then, is covered by water when the reservoir refills during wet periods, causing the vegetation to rot again and emit gases such as methane and carbon dioxide, contributing to global warming. Finally, this decaying vegetation can alter the form of mercury contained in rocks into a form that is soluble in water. Mercury, a heavy metal like lead, can accumulate in the tissues of fish. It thus poses a health hazard to people who consume the fish.

**Economic impact of hydroelectricity**

As of 2005 there are about 40,000 large hydroelectric dams in operation worldwide (a large dam is defined as one that is taller than a four-story building, or more than 49 feet [15 meters]). The country with the greatest number of large dams is China, with 19,000. The United States is second, with 5,500. Major dams are defined as those more than 492 feet (150 meters) in height. The United States leads the world with 50 major dams.

The economic impact of hydroelectric power can be considerable. In some countries, such as Norway, hydroelectric dams provide virtually all of the nation's electrical needs. In Canada, about 60 percent of the nation's electricity is provided by hydroelectricity. Canada, and especially the province of Quebec, provides a good example of the economic impact of hydroelectricity. In the 1960s Quebec launched a program to foster economic development. One of the centerpieces of this program was the development of hydroelectric power in the James Bay region of northwestern Quebec. The first phase of the project began in 1972, when three rivers—the Caniapiscau, Eastmain, and Opinaca—were diverted into reservoirs. These reservoirs, along with a system of 215 dikes and dams and four power stations, nearly doubled Quebec's hydropower production. Construction employed 12,000 people and required 203 million cubic yards (0.9 million cubic meters) of fill dirt and rock, 138,000 tons of steel, 550,000 tons of cement, and 70,000 tons of explosives—all of which provided economic opportunities for Canadians. This first phase of the project, completed in 1985, provided 10,300 megawatts of electricity at a total cost of $14 billion.

Construction on the second phase of the project began in 1989, but it was suspended in 1994, when the project was nearly complete, because of environmental concerns, as well as objections raised by the Cree, a native community that lived in the James Bay region. These problems were resolved, and construction was completed in 2002. Combined, the two phases of the project produce 15,000 megawatts of electricity, or three times the amount of power produced by Niagara Falls. A third phase of the project was scheduled to begin in 1989, but that phase was put on indefinite hold because of environmental concerns. In large part because of the James Bay project, Quebec's electrical output increased from 3,000 megawatts in the early 1960s to 33,000 megawatts in 2002. Further, in 1997 Canada sold about $600 million in electrical power to the United States; by 2002 that figure had climbed to $3.5 billion. Ninety-three percent of this electricity is hydroelectric power.

### Societal impact of hydroelectricity

The negative societal impact of hydroelectric power development is often felt most by native peoples. In northern Quebec, the

Cree, an Algonquin-speaking people, were profoundly affected by the James Bay project. In 1975 the Cree were awarded $225 million in compensation for the disruption that the project caused in the Cree way of life, which revolved around fishing, hunting, and fur trapping in the watershed around James Bay. That money, however, could not compensate the Cree for the immense changes the project caused in Cree society. One Cree band, or tribe, was forced entirely off the land. Among the two remaining bands, the hydroelectric project (along with other enterprises such as mining and lumber) virtually destroyed hunting and trapping grounds, threatening the economic and cultural survival of the Cree.

This type of social problem is not limited to Quebec. In the United States, the construction of the Grand Coulee Dam in Washington State forced the Colville Indian tribe off their traditional hunting and fishing grounds. The Colville tribe sued the federal government and in the 1990s was awarded a $52 million lump-sum settlement. An organization called the International Rivers Network estimates that worldwide, between thirty and sixty million people, about two million a year, have been displaced (driven off their land) by hydroelectric dams. In most cases, the displaced people are small farmers and native peoples.

### Issues, challenges, and obstacles of hydroelectricity

Hydroelectric power faces many obstacles. It is estimated that the amount of hydroelectricity available is about four times the amount being used. The United States has over 5,000 sites that have been identified as possible sites for hydroelectric dams. Many other sites have been identified in Asia and Africa. However, hydroelectric projects often meet with much resistance from environmental groups and others who are concerned about the effects of hydroelectric dams. In the past, the World Bank was willing to loan money to countries to build dams. In more recent years, largely because of environmental concerns and the effect of dams on native peoples, the World Bank has provided less money for these projects.

Research continues on the impact such dams have on fish populations, along with ways to minimize this impact. Research also continues on ways to improve water quality and dam safety, as well as ways to improve the efficiency of hydroelectric dams. In the United States, numerous efforts have been made to "uprate," or improve the efficiency, of older dams. The result since the late

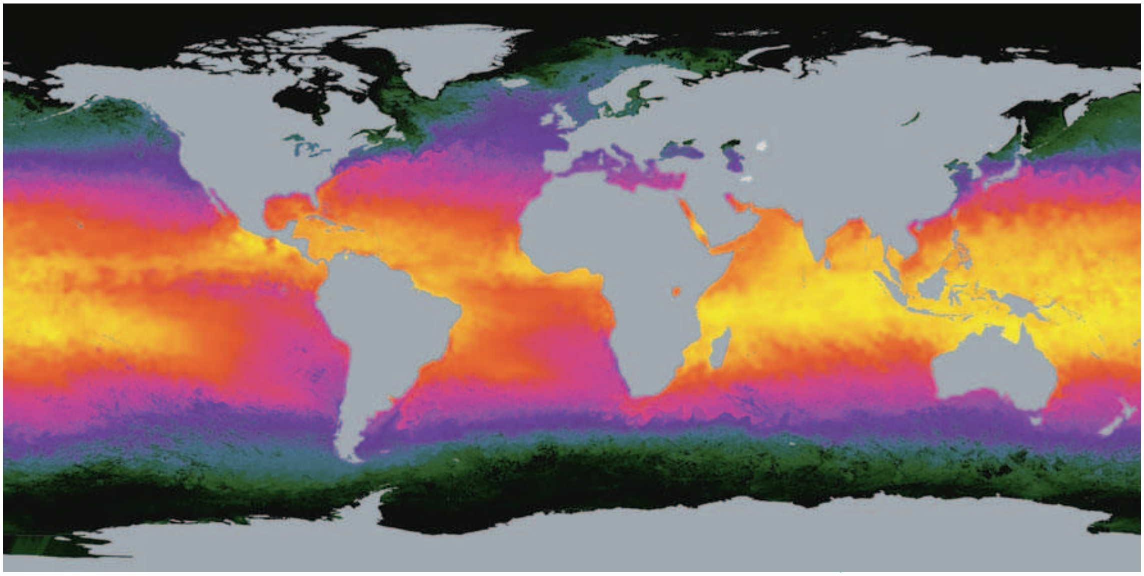
1970s has been to add about 1.6 million kilowatts to the nation's power supply without building new dams. This power costs less than one-fifth of the cost of electricity produced by new oil-fired generators.

## OCEAN THERMAL ENERGY CONVERSION

Ocean thermal energy conversion, or OTEC, is the primary means of extracting thermal energy from the world's oceans. It is based on the thermal gradient, which refers to the difference in temperature between the ocean's surface waters, which are warmed by the sun, and its deeper waters, which originate in polar latitudes and are therefore much colder. The concept of using the thermal gradient to produce electricity was first proposed by French biophysicist Jacques Arsene d'Arsonval (1851–1940) in 1881. D'Arsonval proposed the basic form of a system that is still used.

OTEC is based on two different technologies, closed cycle and open cycle, which can be combined into a hybrid system as well:

- Closed cycle: The system that d'Arsonval envisioned was a closed-cycle system. The working fluid was ammonia, which boils at a low temperature, 28°F (33°C). Heat transferred from the warm surface waters of the ocean boils the ammonia. As the vapors expand, they turn a turbine, which is connected to a generator that produces electricity. Cold seawater pumped up from depths of 2,625 to 3,280 feet (800 to 1,000 meters) is used to condense the ammonia vapor in a condenser. The ammonia is then recycled back through the system.
- Open cycle: In an open-cycle system, the working fluid is the warm surface water itself. In a near vacuum, the warm water vaporizes at the surface-water temperature. Like the ammonia vapor in the closed-cycle system, the expanding water vapor drives a turbine, which is attached to a generator that produces electricity. The open-cycle system has the added advantage of producing desalinized water, or water from which the ocean's salt has been removed. Thus, when the water is condensed by the cold water pumped from the depths, it can be siphoned off and used as drinking water. The underlying process is little different from the condensation that forms on a glass of iced tea on a humid summer day. Unlike the closed-cycle system, in which the ammonia is recycled again and again, the open-cycle system operates with a continuous supply of warm seawater.



Colored computer model of global sea temperatures in 2001, based on satellite data. The surface temperature of the Earth's oceans has been color-coded and combined with a projection of the land surface (gray). The temperature varies from a warm 35 degrees Celsius (yellow) in the tropics, through red, blue, purple, and green to a freezing minus 2 degrees Celsius (black) in the polar regions. *NASA/Photo Researchers, Inc.*

- Hybrid systems: Hybrid systems employ both closed- and open-cycle systems, getting the benefits of each. The closed-cycle system produces more electricity than the open-cycle system, but the open-cycle system produces fresh water as well as electricity.

### Current uses of ocean thermal energy conversion

Most research on OTEC is conducted by the Natural Energy Laboratory of Hawaii Authority (NELHA), formed in 1974. NELHA conducted the first at-sea test of a closed-cycle plant in 1979. The project was called Mini-OTEC, and it took place on a converted navy barge off the coast of Keahole Point, Hawaii. For three months the plant generated 50 kilowatts of gross power. The plant pumped 2,700 gallons (10,220 liters) per minute of cold (42°F [5.5°C]) seawater up from a depth of 2,200 feet (670 meters). The plant pumped an equal amount of warm (79°F [26°C]) surface water. Some of the plant's power had to be used to run the pumps, so the net power output of the plant ranged from 10 to 15 kilowatts.

From 1992 to 1998 NELHA conducted a major demonstration project at its Keahole Point facility. It designed and built a 210-kilowatt open-cycle plant. At its peak the plant produced about 255 kilowatts of power. However, it generally used about 200 kilowatts to pump 6,500 gallons (24,605 liters) per minute of

43°F (6°C) water from a depth of 2,700 feet (823 meters) and 9,600 gallons (36,340 liters) per minute of 76° to 81°F (24° to 27°C) surface water, for net power of some 50 to 55 kilowatts. Its highest net power output was 103 kilowatts, along with production of about six gallons (22 liters) per minute of desalinated fresh water. Designs were drawn for a 1.4-megawatt plant with the potential to produce about 400 net kilowatts, but funding was unavailable, so the project put on hold. As of the early 2000s no OTEC plant is operating anywhere in the world.

### Benefits of ocean thermal energy conversion

OTEC draws on natural resources that are renewable, abundant, and clean. Rather than burning fossil fuels, OTEC power plants rely on warm seawater on the oceans' surfaces and cold seawater from their depths. By replacing such fuels as coal and oil, they can help eliminate the need for mines and oil-drilling platforms, which are not only unsightly but also are potential sources of pollution. Further, the amount of solar energy absorbed by the oceans, particularly in tropical climates, is far in excess of current human energy needs. Unlike wind and tidal energy, thermal energy is always present at consistent levels, which would make it an extremely reliable source of energy.

A second benefit is that OTEC plants do not release greenhouse gases such as carbon dioxide that contribute to global warming, nor do they release sulfur dioxide, a chief cause of acid rain. Further, scientists have concluded that discharging water back into the oceans has only minimal environmental drawbacks. A third benefit is that OTEC can reduce dependence on imported fuel. A state such as Hawaii, as well as many nations around the world, has to import most or all of its fuel. This need to import fuel both drains cash from the economy and makes the state or country dependent on other countries for its energy needs.

Finally, OTEC has a number of secondary benefits. It produces fresh water as well as electricity, a potentially major benefit for countries in which the amount of fresh water is limited. The amount of fresh water created can be up to 1.3 gallons for every 264 gallons (5 liters for every 1,000 liters) of cold seawater in an open-cycle plant. The cold seawater in OTEC can also be used to air-condition buildings, and contribute to mariculture, the cultivation of fish, shellfish, kelp, and other plants that grow abundantly in cold water. Also, eighty-four of the Earth's elements are in solution in the oceans' waters in trace amounts. Some of these elements, such as magnesium and bromine, have commercial value and could be efficiently extracted from the water used in OTEC.

### Drawbacks of ocean thermal energy conversion

The major drawbacks to OTEC are geographical and economic. OTEC plants have to be located in places where the difference in temperature between the warm surface waters and cold deep-sea waters is great enough—at least 36°F (2°C); 40°F (4°C) would make the plant even more efficient. For shore-based plants, this difference would have to be present fairly close to the shore, although floating OTEC ships could expand the range of plants' geographic locations.

OTEC faces a number of economic obstacles. The cost of producing electricity through OTEC is higher than the cost of producing it from fossil fuels. Presently, there is not enough economic incentive for nations to invest billions of dollars in OTEC plants. Scientists and engineers estimate that after the high initial construction costs, the electricity produced over a long period, perhaps thirty years, would be economical, but no one knows how long these types of plants could function without requiring a major overhaul. Scientists and engineers are continuing to work on the development of major OTEC components to make them more durable, more efficient, and less costly.

### Environmental impact of ocean thermal energy conversion

OTEC has very little in the way of environmental impact. The only hazardous substance is the working fluid, which in the case of closed-cycle plants is ammonia. However, the ammonia is recycled through the system, so an OTEC plant does not release any noxious substances into the water or atmosphere. An open-cycle plant releases some carbon dioxide, but the amount is 1 percent of the amount released by fuel-oil plants per kilowatt-hour.

What needs to be tested in a large commercial or experimental station is the effect of an OTEC plant on water temperatures and on marine life in the upper layer of the water. An OTEC plant pumps cold, nutrient-rich water from the depths up to the surface. This mixing of different temperatures of water could have effects on marine life that are currently not well understood. OTEC engineers are also concerned about the potential effects on fish populations. The discharge of nutrient-rich water could increase fish populations in the vicinity of a plant. On the other hand, the plant itself could also disrupt spawning patterns or result in the loss of fish eggs and tiny young fish. Again, these potential environmental impacts are not known.

### Economic impact of ocean thermal energy conversion

Given current technology and the cost of fossil fuels, the economic impact of OTEC would most likely be greatest for small island nations that have to import all their fuel. Such a country, for example, Nauru in the South Pacific, would be able to benefit from a 1-megawatt plant. Such a plant could produce electricity for pennies per kilowatt-hour. It has been estimated that a 100-megawatt OTEC plant could produce electricity for about $0.07 per kilowatt-hour. The chief problem, however, is the initial cost of construction. That same 100-megawatt plant would cost about $4,200 per kilowatt capacity, or about $420 million. It is unlikely with the cost of fossil fuels relatively low that nations will make this type of investment. However, as of 2005 the cost of fuel oil was rising and reached $60 per barrel. If fuel oil continues to become more expensive, OTEC may become more of an option, and organizations such as the World Bank may become more willing to loan funds for construction.

### Issues, challenges, and obstacles of ocean thermal energy conversion

The chief obstacle to OTEC development is the high initial construction cost of such a plant. Researchers continue to find ways to bring down the construction costs, particularly to reduce the cost of condensers and other components of the system. Research is also being conducted to find ways to boost the net power output of the system—that is, the amount of power left over after a portion of the power is used to pump water through the system. As of 2005, governments and international organizations remained reluctant to provide funds for the development of OTEC plants, whose long-run benefits are not entirely clear.

## TIDAL POWER

Tidal power refers to the use of the oceans' tides to generate electricity. Sir Isaac Newton (1642–1727) pointed out in the seventeenth century that every day, the gravity of the moon exerts a pull on the Earth. This gravitational pull has little effect on the Earth's solid landmasses. But the oceans' waters are fluid, so as the moon's gravity pulls on them, they bulge outward. These bulges, which place along an axis (an imaginary line) that points toward the moon, are called lunar tides; on the other side of the Earth, the side away from the moon, the waters bulge out away from the gravitational pull of the center of the Earth.

Annapolis Royal Tidal Generator, a hydroelectric power station in Nova Scotia, is located in Annapolis Royal by the Bay of Fundy, home of the world's highest tides. Twice a day, the tide comes in and out. Twice a day the turbine turns. Twice a day electricity is generated and supplied to the provincial electric grid. *Stephen J. Krasemann/Photo Researchers, Inc.*

While the moon does most of this work, the sun helps out, but to a lesser extent. This is because the gravitational attraction one body has on another is the result of two factors: its size and its distance. Although the sun is much bigger than the moon, the moon is much closer to the Earth, so it exerts a greater gravitational pull. Nonetheless, the sun's gravitational pull also creates tides, called solar tides.

When the Earth, moon, and sun are aligned in a straight line during a full or new moon, both the sun and moon are pulling together in the same direction, like two teammates in a tug-of-war. During a full moon the pull is greatest, creating large tides called spring tides. During half-moon periods, when the moon and sun are at right angles, or 90 degrees, to each other, the tides created, called neap tides, are lower, simply because the lunar tides are being pulled out along one axis and the solar tides along a perpendicular axis. During these times the coasts have two low and two high tides over a period of less than twenty-four hours.

At the same time, the Earth rotates beneath these bulges, passing under each one during a twenty-four-hour period. The result is

## Tidal Power Forever?

In most discussions of tidal power, one of the chief advantages cited is that tidal power is endlessly renewable—that the Earth will never run out of it because the tides will always be there. Technically, this claim is not entirely true. The bulging oceans exert friction on the Earth, gradually slowing down the speed of the Earth's rotation. This means that in time, tidal power will no longer exist.

As a practical matter, though, this is no cause for concern. This slowing of the Earth's rotation will not have any significant effect for billions of years! By that time humankind will no doubt have harnessed a form of power that cannot be imagined today. In the meantime, scientists have calculated that harnessing all of the tidal power of the oceans would slow the Earth's rotation by twenty-four hours every two thousand years.

that tides rise and fall rhythmically along the world's coastlines approximately twice each day in predictable patterns. These flows of water are very like the flows of rivers, and their energy can be harnessed in much the same way that a river's energy is by a hydroelectric dam.

There are two ways to harness energy in tidal power-generating stations: the tidal barrage and tidal streams. A tidal barrage, also called an ebb generating system, is very similar to a dam. The barrage is constructed at the mouth of a bay or estuary (a water passage where the tide meets the lower end of a river). For a barrage to be workable, the difference in water elevation between low tide and high tide has to be at least 16 feet (5 meters).

When the tide flows in, the water moves through moveable gates in the barrage called sluice gates, similar to a "doggy door" a family pet can use to enter the house just by pushing on it. When the tide stops flowing in, the gates are closed, trapping the water in a basin. The water now represents stored energy, in much the same way that the reservoir behind a hydroelectric dam does. As the tide then flows out (ebb tide), the gates in the barrage are opened. This allows the water to turn turbines as it flows back out to sea. Just as in hydroelectric plants, the turbines are connected to a generator, which produces electricity. It is possible to have flood-generating systems, where the water turns the turbines as it flows in rather than out, but hydrologists and engineers believe that these systems are less efficient. It is also possible to have systems that work in both directions, but these kinds of systems would be difficult and more expensive to build because the turbines that would have to be used would have to work in both directions. Consequently, the best design for most sites is the ebb-generating system.

Other technologies exist for harnessing tidal power, but all these technologies are in early stages of development. In each case, the goal is to tap the energy contained in tidal streams. A tidal stream is a fast-flowing current of water caused by the movement of the tides. These streams can occur wherever a natural barrier constricts the flow of water, which then speeds up after it passes the constriction. Thus, a tidal stream might flow between two islands, or between the mainland and an offshore island. The chief advantage of these technologies is that a tidal basin does not have to be constructed.

### Current use of tidal power

Currently, only one major tidal power generating station is in operation. This station is located on the estuary of the La Rance River in France. Construction of the barrage began in 1960 and was completed in 1966. The barrage is almost 1,100 feet (330 meters) long with a 13.7-square-mile (22-square-kilometer) basin. The station uses twenty-four turbines, each 17.7 feet (5.4 meters) in diameter. Each turbine is rated to produce about 10 megawatts of power, so the station can produce a maximum of 240 megawatts. (To put that figure in perspective, the average coal- or oil-fired power plant produces about 1,000 megawatts.) There are 8,760 hours in a year, so the system can produce 2,102,400,000 kilowatt-hours per year, enough to supply most of the electricity needs of the Brittany region of France.

Other nations have explored the possibility of harnessing tidal power. Since the 1960s tidal power has been proposed in the Kimberley region of western Australia. There, it was estimated that tidal power could provide 3,000 megawatts of electricity. Australia's Renewable Energy Commercialisation Program awarded a grant to develop a 50-megawatt plant in the Derby region of Australia. Scotland, too, has explored tidal energy, and proposals have been made for the construction of a tidal station on Solway Firth in southwest Scotland; in the 1970s Scotland built a 15-kilowatt experimental tidal turbine on Loch Linnhe. In England, the Severn River has been identified as a promising site for a tidal power station. The most promising site in the world is the Bay of Fundy in Canada, which, at up to 56 feet (17 meters), has the highest tides in the world.

### Benefits and drawbacks of tidal power

The chief benefits of tidal power, as of most forms of alternative energy, are that it is clean, renewable, and does not consume resources such as coal or oil. It does not discharge pollutants into the water or atmosphere, so it does not contribute to acid rain or global warming. Further, the energy source is free. Tidal power barrages have a secondary benefit, for they can function as bridges linking communities on opposite sides of an estuary, making travel quicker.

The chief drawback of tidal power stations is their expense. It has been estimated, for example, that construction of a tidal power station on the Severn River in England would cost about $15 billion. A second drawback is that not every coastal region is suitable for tidal power. Generally, a difference between high and low tides of about 16 feet (5 meters) is necessary for a tidal power station to be cost-effective. Only about forty such sites in the world have been identified. A third drawback is that the tides are in motion only about ten hours per day. This means that tidal power cannot be provided consistently throughout the day and would have to be supplemented with other forms of power.

### Environmental impact of tidal power

The environmental impact of tidal power stations has not been fully explored for the simple reason that only one major power station exists. Although the potential environmental impacts would be specific to the individual site, a few generalizations can be made. A tidal power station would change the water level in an estuary, affecting patterns of vegetation growth. It would have an impact on the ecosystems of the shoreline and of the water. It would likely have an impact on the quality of the water in an estuary; for example, it could change the cloudiness of the water, which in turn could affect the types of fish that could live in the water. This which would in turn have an effect on birds that feed off the fish. Fish life would also be affected by a barrage unless a way was found to allow the fish to pass through. Further, a tidal station could change patterns of bird migration and reproduction.

### Economic impact of tidal power

Because of the limited availability of suitable sites, only about 2 percent of potential tidal power can currently be harvested. The potential amounts to 3,000 gigawatts (*giga-*, meaning billion) of electricity, so roughly 60 gigawatts could actually be produced with current technology. The economic impact to tidal electricity would likely be local. For instance, it is estimated that a tidal power station on England's Severn River could produce up to ten percent of England's electricity.

### Issues, challenges, and obstacles of tidal power

The chief issues facing tidal power are economic. The cost of building such a plant is high. However, once the plant is built, the energy it generates is essentially free, although the costs of maintaining the plant and distributing the power have to be included in cost estimates. The cost of such a plant would therefore be spread out over a period of thirty years or more, but finding initial funding is difficult. Also, because of limited experience with tidal power stations, their environmental impacts are not well understood. A final challenge is developing equipment that can withstand the harsh marine environment.

## OCEAN WAVE POWER

Wave power is actually another form of solar power. As the sun's rays strike the Earth's atmosphere, they warm it. Differences in the temperature of air masses cause the air to move, resulting in winds. As the wind passes over the surface of the oceans, a portion of the wind's kinetic energy is transferred to the water, producing waves. These waves can travel essentially unchanged for enormous distances. But as they approach a shoreline and the water becomes shallower, their speed slows and they become higher. Finally, the wave collapses near shore, releasing an enormous amount of energy. It has been estimated that the amount of kinetic energy contained in a wave is up to 110 kilowatts per meter.

Capturing wave energy means that the kinetic energy of waves is converted into electrical power. In many respects, the technology is the same as it is with tidal and hydroelectric power. The kinetic energy turns a turbine attached to a generator, which produces electricity.

### Current uses of ocean wave power

Scientists and engineers have devised hundreds of ways to capture wave power. The first, developed by a company called Wavegen, is being used at the world's only major wave power station in operation, the 500-kilowatt Land-Installed Marine-Powered

Energy Transformer (Limpet) on the island of Islay off Scotland's western coast. The basic design is called an oscillating water column (OWC). The water from a wave flows into a funnel and down into a cylindrical shaft. The rise and fall of the water in the shaft drives air into and out of the top of the shaft, where it blows past turbines, causing them to turn. In a sense, then, an OWC is a combination of hydropower and a windmill, with the "wind" consisting of air pressurized by the power of the wave. As with most other forms of hydropower, the turbines are attached to a generator, which produces electricity. In the case of Limpet, two turbines are in place. A chief advantage of this design is that the generators are not submerged in the water, making maintenance easier. Wavegen has built and tested a number of prototypes and in the early 2000s was constructing an OWC station on Pico Island in the Azores. It was anticipated that the plant would provide ten percent of the island's power requirement for its 15,000 people.

A second design is generally referred to as a wave-surge or focusing device. With these systems, sometimes called tapered channel or "tapchan" systems, a structure mounted on shore, which looks a little like a skateboard ramp, channels the waves and drives them into an elevated reservoir. As water flows out of the reservoir, it generates electricity in much the same way a hydroelectric dam does. A variation of this design was developed by a Norwegian company called WaveEnergy. This design consists of a series of reservoirs layered into a slope. WaveEnergy has also proposed attaching its design to old deep-sea oil-drilling platforms.

Engineers continue to work on other designs. One example that can be cited is the hosepump, which makes use of a type of hose called an elastomeric hose, the volume of which decreases as the hose is stretched in length. The hose is attached to a float that rides the waves on the ocean's surface, pulling it and relaxing it. This movement pressurizes seawater in the hose, which is then fed through a valve past a turbine attached to a generator. This is one example of the many ingenious devices with which scientists are experimenting. Many of these devices have fanciful names: the Mighty Whale, the Wave Dragon, Archimedes Wave Swing, WavePlane, Pendulor, and the Nodding Duck.

### Benefits and drawbacks of ocean wave power

Like other forms of hydropower, wave power does not require the burning of fossil fuels, which can pollute the air, contributing to acid rain and global warming. The energy is entirely clean and endlessly

Limpet 500, the world's first commercial-scale wave power station, generates 500 kilowatts of electricity, enough to power 300 homes. It lies on the coast of Islay, a Scottish Hebridean Island. As the wave moves into this partly-submerged hollow concrete chamber, air is forced out through a turbine-containing blowhole in its rear. When the wave falls, air is sucked back through the blowhole. Electricity is generated using a Wells turbine that rotates the same way despite the two-way air flow. *Martin Bond/Photo Researchers, Inc.*

renewable. Further, in contrast to tidal power and thermal energy stations, which can be built in only a limited number of locations, wave power stations could be built along virtually any seacoast. Some of these devices could provide artificial habitats for marine life. They could also serve a secondary function as breakwaters.

The chief drawback of any onshore wave power station is the disruption caused to the natural environment by the presence of the station itself. OWC stations could potentially be noisy, although engineers continue to work on ways to dampen the noise they produce. A further drawback is that many of the technologies are new and untried, making it difficult to find funding to build the plants. In addition, these types of devices could cause navigational hazards for the shipping and fishing industries. Because of their location by the open ocean, these power stations could sustain severe damage from storms affecting the coastline, such as hurricanes.

### Impact of ocean wave power

Wave power stations could impact the environment in a number of ways. Offshore or near-shore devices could change the flow of sediment, affecting marine life in unpredictable ways. Onshore devices could have an impact on, for example, turtle populations or other shoreline creatures that use the shorelines for nesting and breeding.

The economic impact of wave power is hard to calculate, but the potential impact is enormous. It is estimated that the total amount of wave energy that strikes the world's coastlines is about 2 to 3 million megawatts. In many locations throughout the world, the waves along one mile of coast contain the equivalent of 65 megawatts of power, or about 35,000 horsepower. Some experts say that if existing technologies were widely adopted, wave power could provide about 16 percent of the world's electricity needs. A large wave power station (100 megawatts) could provide power for as little as three to four cents per kilowatt-hour; a smaller station (1 megawatt) could provide power for seven to ten cents per kilowatt-hour. Both of these ranges include the cost of the plant's construction divided out over a period of years.

### Issues, challenges, and obstacles of ocean wave power

As with other forms of water power, the chief obstacle is funding. Many wave-power technologies are unproven, particularly on a large scale, so it is difficult for developers to attract funding from private and governmental organizations. Another challenge is building equipment that is sturdy enough to withstand the harsh marine environment over long periods of time.

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# Wind Energy

## INTRODUCTION: WHAT IS WIND ENERGY?

The word “windmill” for many people brings to mind the Netherlands, whose countryside for centuries has been dotted with thousands of windmills. Windmills represent an early technical skill or ingenuity (inventiveness) that seemed to be lost during the industrial revolution, when fossil fuels replaced wind and running water as the most widely used energy sources. Some people of the twenty-first century support a return to greater reliance on the wind that powers windmills, chiefly because wind power is clean and endlessly renewable.

### Historical overview

The first written record of a windmill is in a Hindu book from about 400 BCE (before the common era). About four hundred years later, the Greek inventor Hero of Alexandria devised a wind-driven motor he used to provide air pressure to operate an organ. From about 400 CE (common era), there are references to prayer wheels driven by wind and water in the Buddhist countries of central Asia. These devices were handheld windmills that contained prayers and religious texts on rolls of thin paper wound around an axle. Individuals could access the prayers whenever they wanted (the thought was increasing the speed of the spinning prayer wheels strengthened the prayers). Early devices used the power of the wind, but it was not until much later that wind power was developed as a way to do work.

Some historians believe that the earliest true windmills—that is, windmills built to do work—were built in China two thousand years ago, but no records exist. The first recorded references to true windmills date from seventh-century Persia, later called Iran, particularly the province of Sijistan, which became Afghanistan.

## Words to Know

**Anemometer** A device used to measure wind speed.

**Coriolis force** The movement of air currents to the right or left caused by Earth's rotation.

**Drag** The slowing force of the wind as it strikes an object.

**Kilowatt-hour** One kilowatt of electricity consumed over a one-hour period.

**Kinetic energy** The energy contained in a mass in motion.

**Lift** The aerodynamic force that operates perpendicular to the wind, owing to differences in air pressure on either side of a turbine blade.

**Nacelle** The part of a wind turbine that houses the gearbox, generator, and other components.

**Rotor** The hub to which the blades of a wind turbine are connected; sometimes used to refer to the rotor itself and the blades as a single unit.

**Stall** The loss of lift that occurs when a wing presents too steep an angle to the wind and low pressure along the upper surface of the wing decreases.

**Wind farm** A group of wind turbines that provides electricity for commercial uses.

During the reign of the Muslim caliph 'Umar I (633–44), windmills were constructed primarily to obtain water for irrigating crops and grinding grain. These working windmills may have been imported into China from the Middle East by Genghis Khan (1162–1227), the Mongol conqueror of much of what is now Iran and Iraq (1216–23). The first reference to a Chinese windmill dates from the year 1219, when a statesman named Yehlu Chhu-Tshai documented construction of one. Windmills became widely used along the coasts of China during this period.

The design of these seventh-century windmills, some of which survive in Iran and Afghanistan, was the reverse of modern windmills. In modern windmills the axle is horizontal and is positioned at the top of the windmill. In early Middle Eastern windmills the blades that turned in the wind were enclosed in a chamber at the bottom of the windmill. The blades were attached to a vertical axle, which was attached to a millstone above. The early windmills, which are still used, could grind a ton of grain per day and generate about one-half the power of a small car.

### Windmills in Europe

During the Crusades, which took place over a two-hundred-year period beginning in 1095, European conquerors of Palestine probably became familiar with Middle Eastern windmills and imported the technology back to Europe. The first documented reference to a

This windmill, seen in the Netherlands, is typical of what many people envision for windmills. © *Royalty-Free/ Corbis.*

European windmill dates to 1105 in France, the home of most of the early crusaders. A similar reference is made to a windmill in England in 1180. Both of these windmills were built to pump water to drain land.

For reasons that are unknown, the Europeans mounted the windmill blade on a horizontal axle rather than a vertical one. They may have adopted the design from water wheels, which by this time were being mounted on horizontal axles (poles around which an object rotates). Some of the windmills from this period were able to lift more than 16,000 gallons (60,566 liters) of water per hour, using augers (a type of screw) that raised the water from lower levels to higher levels, where the water could be sent into channels. The augers acted like spiral staircases that carried the water up as the windmills turned.

## Al-Dimashqi Describes a Windmill

In the thirteenth century, the Arab historian al-Dimashqi (1256–1327), described a windmill:

> When building mills that rotate by the wind, they proceed as follows. They erect a high building, like a minaret, or they take the top of a high mountain or hill or a tower of a castle. They build one building on top of another. The upper structure contains the mill that turns and grinds, the lower one contains a wheel rotated by the enclosed wind. When the lower wheel turns, the mill stone above also turns. . . . Such mills are suitable on high castles and in regions which have no water, but have a lively movement of the air.

These windmills were often arranged in what were called gangs, meaning that they were arranged in rows so that water could be drained in stages, especially from lower to higher levels.

Because much of the Netherlands is below sea level, the Dutch made extensive use of windmills to drain land and to grind grain. By the fourteenth century the Dutch had introduced or adopted a number of technologies, such as post mills and tower mills. The post mill consisted of a four-bladed mill mounted on a central vertical post or shaft. Wooden gears transferred the power of the shaft to a grindstone. The grindstone turned to make grain into flour. The tower mill, which originated along the Mediterranean seacoast in the thirteenth century, consisted of a post mill mounted on top of a multistory tower. This tower housed the grinding machinery and had rooms for grain storage and other milling functions as well as living quarters in the bottom story. The tower mill is the type most often seen in pictures of Dutch windmills.

A major concern of windmill operators was to make sure that the mill was positioned correctly in relation to the wind. This task was done with a large lever at the back of the windmill that was pushed to move the windmill blades toward the wind. The blades were made of lattice frames over which canvas sails were stretched. By 1600, windmills were in such widespread use in Holland that the bishop of Holland, seeing a chance to increase funds for the church, declared an annual tax on windmill owners.

Also by that time the basic technology of windmills was in place. It remained for engineers and inventors to find ways to increase efficiency, primarily by coming up with new designs for windmill blades. Some of these designs included improvements in the blade's

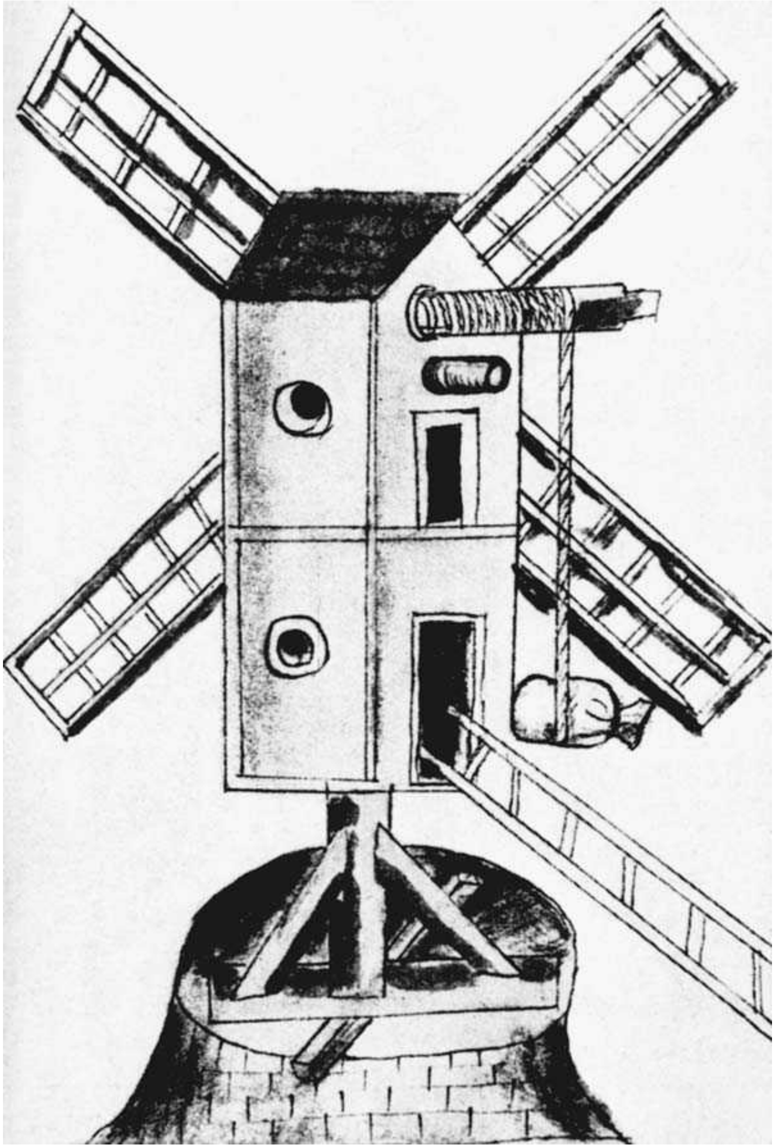
Interior of a windmill, in Spain, showing the wooden gears that were powered by the wind. © *Corbis.*

camber, or the outward curve of the blade from its leading edge (the edge first struck by the wind) to its trailing edge. Other experiments were conducted to find the best location for the blades spar, or the long piece of a blade; its center of gravity; and the correct amount of twist in the blade. One of the most prominent millwrights (mill builders) during the period, Jan Adriaanzoon Leeghwater (1575–1650), experimented with these matters. Largely through his efforts, about twenty-six lakes in the Netherlands were drained.

By the end of the nineteenth century, at least 30,000 windmills were operating in Europe. These windmills were used not only to pump water and grind grain but also to power sawmills and for other industrial uses, including processing agricultural products such as spices, cocoa, dyes, paints, and tobacco.

### Windmills in North America

In the seventeenth and eighteenth centuries, the Dutch migrated to the American colonies in large numbers. They brought with them the technology for constructing windmills, and many Dutch-style windmills were built throughout New York and New England, where they worked well in the relatively gentle eastern winds.



An illustration depicting an early wind mill (around 1430), with an automatic elevator for lifting flour bags. The post was designed to turn in the direction of the wind. *Bettmann/Corbis.*

In the nineteenth century, American settlers moved westward and onto the Great Plains. The settlers wanted to harness the power of the wind to irrigate the land and water their cattle. However, on the plains a fundamental design flaw in Dutch windmills became apparent: The slow-moving blades were too fragile for the strong winds that swept across the prairies in places such as Kansas and Nebraska. As soon as they were hit with high winds, these windmills fell apart.

## What's in a Name?

One project that Jan Adriaanzoon Leeghwater started in Holland was a drainage plan to protect Amsterdam and Leiden from the Haarlem Meer, a lake that was growing each year and threatening to flood the cities. The project that he began in 1643 was so large that it was not completed until 1852. One of the three pumping stations still operating in the early twenty-first century was named after Leeghwater. The engineer's life course may have been set the day he was born. In Dutch ''Leeghwater'' means ''empty water.''

Back in New England, a designer named Daniel Halladay (1826–?) patented a design that could withstand the high winds of the plains. His company, the Halladay Windmill Company, began building windmills with the new design in 1854. The chief improvement Halladay made was to use numerous blades, rather than the four blades that were common on New England windmills. The new windmills also had a tail that would orient them to the wind, and they had hinged blades that would fold up in high winds so that they would not fall apart. In 1857 Halladay's company began doing business as the U.S. Wind Engine and Pump Company.

In about 1870 windmill manufacturers made another improvement when they began using steel rather than wood in the manufacture of blades. These blades were stronger but also could be curved, making them much more efficient than the flat wooden blades in use up to this time. In 1886 the inventor Thomas Perry designed a more aerodynamic blade, a blade that gets the most power from the wind and a design that continues to be used in the early twenty-first century.

Halladay's company, along with numerous competitors, sold thousands of windmills. Many windmills were sold to farmers and ranchers, but another industry emerged as a major customer. The railroads needed large amounts of water for their steam engines at their many stops across the plains and on to the West Coast. Windmill-powered pumps pumped water into tanks at the side of the railroad tracks. Trains could stop at each tank and get water enough to continue the journey to the next tank.

Another major improvement occurred in 1915, when the Aeromotor Company designed an enclosed, self-lubricating gearbox. Until then, the open gears of windmills had to be lubricated every week, often by horse-mounted cowboys who rode out with their saddlebags

Windmills are still used today by farmers and ranchers to pump water for family and livestock use. © *2005 Kelly A. Quin.*

packed with bottles filled with oil. In windmills with the Aeromotor gearbox, the gears had to be oiled only about once a year.

About one million windmills made by about 300 companies were built in the United States between 1850 and 1970. Although most of these windmills were small, and used on family farms primarily to pump water, others were large, with blades up to 26 feet (8 meters) long. These were purchased mainly by the railroads for their system of track-side water tanks.

## Electrification

The next step in the development of wind energy was electrification. Until the late nineteenth century, all windmills produced only mechanical power for pumping or grinding. With the emergence of electricity, designers and engineers quickly recognized that windmills could be attached to electric generators and that the power they produced could be used for heating and lighting.

The first windmill used to generate electricity on a large scale was built in 1888 by Charles F. Brush (1849–1929) in Cleveland, Ohio. Its rotor, which consisted of 144 blades, was almost 56 feet (17 meters) in diameter. The rotor includes the hub and the blades that are attached to it. Brush's major technical challenge was to find a way for the windmill's rotor to produce the 500 revolutions per minute he needed for the generator to operate. Brush designed a step-up gearbox (a series of parts that transmitted motion from one part of the machinery to another) in a fifty-to-one ratio. This meant that for every turn of the rotor, the operational parts of the generator turned 50 times. During the 20 years it was in operation, the Brush machine produced about 12 kilowatts of power, which Brush stored in batteries in his nearby mansion.

From 1890 to 1930 the windmill industry in the United States boomed. Spurring the boom was the prominent place given to electric windmills at the World's Columbian Exposition in Chicago in 1893, where they were used to generate power to light the fairgrounds after dark. Electric lights were not common in 1893 homes; most still used gaslights. So people were amazed that a cheap source of power could make this new marvel available to them, even if they lived out in the country. However, the windmill industry soon collapsed after the U.S. Rural Electrification Administration, or REA, was established. This government program was one of many created to help the nation overcome the effects of the Great Depression (1929–1941). The REA provided partial federal funding for electricity to homes and farms in rural areas, much of it produced by hydroelectric dams. If these hard-to-reach places could now get inexpensive electrical service from the government, then they no longer needed windmill-generated power.

## Decline and revival

From the 1930s to the 1970s in the United States coal and oil remained relatively inexpensive, and little interest was shown in harnessing the wind to meet the need for electricity. In Russia, however, a 100-kilowatt wind generator was built in Balaclava in 1931. Mounted on a tower 100 feet (33 meters) high, the rotor was 100 feet in diameter and produced power when the wind speed exceeded 25 miles (40 kilometers) per hour. The wind generator supplied this energy to a steam power station 20 miles (32 kilometers) away. The turbine did not

## Watts, Kilowatts, and Kilowatt-hours

Electric output is generally measured in watts, named after the Scottish inventor James Watt (1736–1819). A watt is 1/746th of one horsepower (the power of one horse pulling). Because 1 watt is a small amount, power is generally measured in kilowatts, or thousands of watts. Large power-generating stations often measure power output in megawatts, or millions of watts.

By itself a wattage figure does not indicate how much power is being consumed. A 100-watt lightbulb needs 100 watts to operate, but more power is consumed if the light is left on for an hour than if it is left on for a minute. The term ‘‘kilowatt-hour’’ takes into account the time dimension. If a 100-watt bulb is left burning for 10 hours, 1 kilowatt-hour of electricity has been consumed. A typical family in the United States uses about 10,000 kilowatt-hours of electricity each year.

last very long because the blades were made of old roofing metal and the gears were made of wood. During one year of operation, however, the wind generator produced 279,000 kilowatt-hours of power.

From the mid-1930s until 1970 commercial-sized wind generators were built in Denmark, England, Germany, and France. These countries were left with shortages of fossil fuels and most everything else because of the destruction left by World War II (1939–1945). The development of wind power in Europe filled some of the need for electricity that was not being filled by fossil fuels. In Denmark, for example, a 200-kilowatt wind generator was built and operated until the early 1960s. Denmark led the way in wind-power generation in terms of the percentage of electricity that was wind generated, about 20 percent.

Although Europe was leading the way, the largest commercial-grade wind generator was located on Grandpa’s Knob, a 2,000-foot-high (610 meters) hill near Rutland, Vermont. It was called the Smith-Putnam wind turbine after its designer, Palmer C. Putnam, and the company that provided the money to build it, the S. Morgan Smith Company of New York. The generator was built over a two-year period beginning in 1939. The 175-foot-diameter (53 meters) rotor produced an enormous 1.25 megawatts of power during the four years it was in operation. The Smith-Putnam turbine stopped operating when metal fatigue caused

Wind turbines capture the kinetic energy of wind with blades shaped much like airplane propellers. These blades are attached to a tower that rises at least 100 feet (30 meters) above the ground. © *George D. Lepp/ Corbis.*

some of the blades and bearings to break. Replacements could not be found because metals and other materials were being used by the military to build weapons to fight World War II. Although the Smith-Putnam turbine was not a long-term economic success, it was considered a technical success because it produced a lot of electrical power while it was working.

During the years following World War II, several wind energy designs were built and tested. In England the Enfield-Andreau wind turbine, built in St. Alban's in the 1950s, had a 79-foot (24 meters) rotor that produced 100 kilowatts of power. A unique feature of this turbine was that its hollow propeller blades acted as air pumps for transmitting power from the rotor to the generator.

In Denmark the Gedser wind turbine was built in 1957, and its 79-foot blades produced about 400,000 kilowatt-hours per year until the turbine was shut down in 1968. Also during the 1950s, two large machines were built in France. One produced 130 kilowatts and the other 300 kilowatts. In Germany the Hütters wind turbine achieved great efficiency by producing 100 kilowatts of power in only 18-mph (29 kph) winds. Earlier systems needed higher wind speeds.

## The Coriolis force

The Coriolis (kawr-ee-OH-luhs) force, sometimes called the Coriolis effect, is named after the French mathematician Gaspard-Gustave de Coriolis (1792–1843). The principle behind the Coriolis force is that because Earth rotates, any movement in the Northern Hemisphere is diverted to the right, if observed from a fixed position on the ground. In the Southern Hemisphere, the movement is to the left. This means that wind tends to rotate counterclockwise around low-pressure areas in the Northern Hemisphere and clockwise in the Southern Hemisphere.

The Coriolis force has a major effect on prevailing wind patterns throughout the world. As equatorial air heats, rises, and moves toward the poles, expansion of the air creates low pressure. Cooler air from the poles flows in behind the warmer air to equalize the pressure. At about 30 degrees latitude north and south, the Coriolis force prevents air from moving much farther toward the poles, because the warmer air encounters a high-pressure area of cooler, sinking air. Because of the diversion of the air caused by Earth's rotation, prevailing winds generally blow in the following directions:

| Latitude | Direction |
|---|---|
| 90°–60° | N Northeast |
| 60°–30° | N Southwest |
| 30°–0° | N Northeast |
| 0°–30° | S Southeast |
| 30°–60° | S Northwest |
| 60°–90° | S Southeast |



The Coriolis force does not explain wind direction in all places at all times. Local factors also determine the speed and direction of the wind. A good example is a sea breeze. Land masses warm faster in the sun than water does. This means that the air over land expands and rises faster than the air over the sea. As the land air rises,

During the 1970s it seemed as though the United States was ready to make the necessary investments to develop wind power. In 1973 the country was affected by the Arab oil embargo. Countries that normally sold oil to the United States were refusing to do so. This served as a warning to the nation that it was too dependent on foreign oil, which could be cut off at any moment. In 1974 the U.S. Federal Wind Energy Program was established. Over the next decade scientists from U.S. agencies such as the National Aeronautics and Space Administration (NASA) and the U.S. Department of Agriculture built and tested at least thirteen different wind turbine designs, ranging in output from 1 kilowatt to 3.2 megawatts. Major efforts were made to develop more efficient rotor designs. Many of these designs were successful, and engineers learned to design better ones.

However, by the late 1980s it was becoming more and more difficult to attract funding for wind energy efforts. Many people remained unconvinced that wind power could ever provide more than small

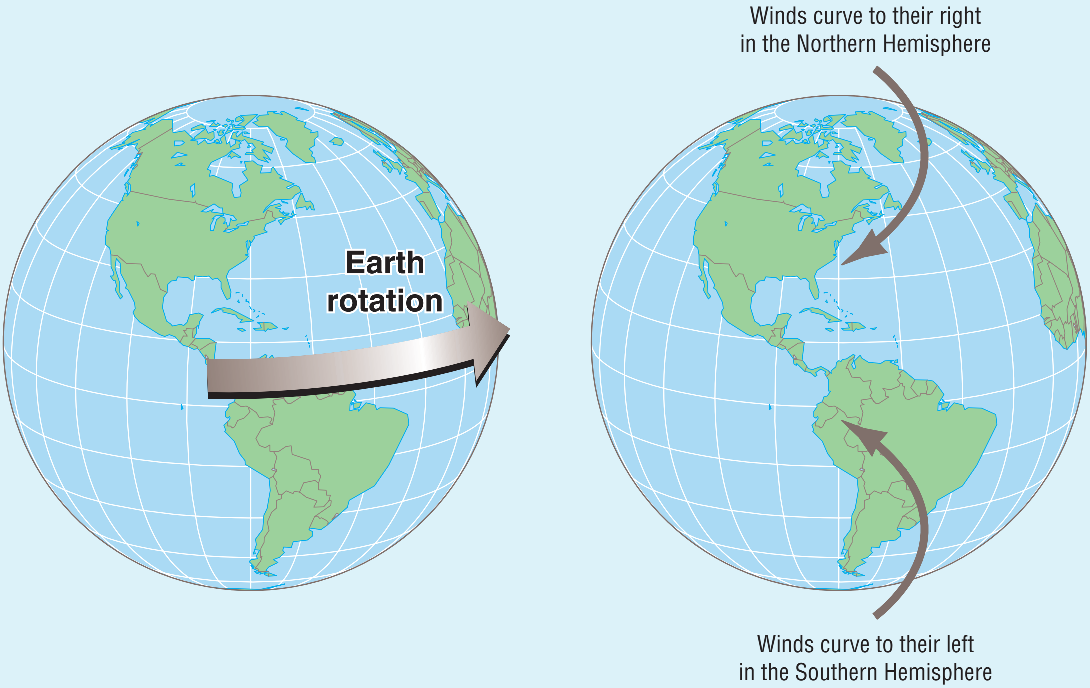



Illustration of the Coriolis effect in the Northern and Southern Hemispheres as the Earth globe rotates. *Thomson Gale.*

the sea air flows in behind it, causing wind to blow onshore. At night, the process is reversed, and wind tends to blow offshore, that is, from land out to sea. Mountain ranges also play tricks with the wind, diverting it in different directions.

amounts of electricity for local use. Since that time research on wind technology has been conducted in the United States largely by the National Wind Technology Center near Boulder, Colorado.

## HOW WIND ENERGY WORKS

In everyday discussions of alternative forms of energy, most people make a distinction between wind power and solar power. From one point of view, however, this distinction is unnecessary because the wind that powers wind turbines is itself a form of solar power.

Earth absorbs overwhelming amounts of energy from the sun: $1.74 \times 10^{17}$ kilowatt-hours, or 174,423,000,000,000 kilowatts every single hour of the day. Although the oceans and land masses absorb a great deal of this energy, much is absorbed by the atmosphere (the whole mass of air surrounding Earth).

The energy from the sun does not strike Earth evenly. Air around the equator absorbs more energy than the air above the poles. This difference causes air, a fluid much like water, to move in currents. Air, like any substance, expands when it is warmed and contracts when it is cooled. Warm air, because it is less dense than cool air, is lighter, so it rises, much like a less-dense piece of wood rises to the top of more-dense water. This effect can be seen by looking at the hot air above a fire, which seems to shimmer as it expands and moves upward, carrying smoke and ash with it. Cold air, because it shrinks, is denser than surrounding warm air, so it sinks. This property explains in part why a freezer generally operates more efficiently when it is placed at the bottom of a refrigerator rather than at the top and why the basement is generally colder than the upper levels of a house.

As warm air rises, colder, heavier air flows in to replace it, causing a current of air—in other words, wind. Earth's rotation also plays a role in wind production. If Earth did not rotate, air heated at the equator would rise only about 6 miles (10 kilometers) into the atmosphere and flow toward the North Pole and the South Pole, where it would cool, sink, and return to the equator. Earth's rotation allows winds to circulate in more or less predictable patterns across the Northern Hemisphere and Southern Hemisphere. These winds contain huge amounts of kinetic (kuh-NET-ik) energy, or the energy contained in any fluid body in motion. About two percent of the solar energy that strikes Earth is converted into wind. For various reasons, including the revolution of Earth and features of its terrain, some parts of Earth have more wind than others.

The southeastern United States has relatively little wind on a steady basis, so this region is generally not considered a good place to place wind turbines. In addition, the storminess in the Southeast would leave wind turbines vulnerable to damage from high winds, during hurricane season, for example. The Rocky Mountain states experience a great deal of wind on a consistent basis, making them better candidates for wind power. The best places to build the turbines are North Dakota, Texas, and Kansas, which by themselves could provide all of the electricity needed in the United States, according to a 1991 U.S. Department of Energy wind resource report.

According to the Battelle Pacific Northwest Laboratory, the top twenty states and the amount of wind power they could produce, measured in billions of kilowatt-hours per year, are as follows:


| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1. North Dakota | 1,210 kw | 6. Nebraska | 868 kw | 11. Colorado | 481 kw | 16. Illinois | 61 kw |
| 2. Texas | 1,190 kw | 7. Wyoming | 747 kw | 12. New Mexico | 435 kw | 17. California | 59 kw |
| 3. Kansas | 1,070 kw | 8. Oklahoma | 725 kw | 13. Idaho | 73 kw | 18. Wisconsin | 58 kw |
| 4. South Dakota | 1,030 kw | 9. Minnesota | 657 kw | 14. Michigan | 65 kw | 19. Maine | 56 kw |
| 5. Montana | 1,020 kw | 10. Iowa | 551 kw | 15. New York | 62 kw | 20. Missouri | 52 kw |

An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States, Top Twenty States in Wind Power, August, 1991, PNL# 7789. Reproduced by permission. *Thomson Gale.*

According to the American Wind Energy Association, by the end of 2004 wind facilities in thirty U.S. states were generating a total of 6,740 megawatts of electricity, enough to provide power for about 1.6 million homes.

The states leading the way were these:

California: 2,096 megawatts

Texas: 1,293 megawatts

Iowa: 632 megawatts

Minnesota: 615 megawatts

Wyoming: 285 megawatts

The largest wind farms, or large facilities with numerous turbines, operating in the United States were the following:

Stateline, Oregon-Washington: 300 megawatts

Commercial wind power usually is generated at wind farms rather than from single turbines. The largest wind farm in the United States is the Stateline Wind Energy Center, located on the Vansycle Ridge, which runs along the Columbia River on the Washington-Oregon border. © *Russell Munson/Corbis.*

King Mountain, Texas: 278 megawatts
New Mexico Wind Energy Center, New Mexico: 204 megawatts
Storm Lake, Iowa: 193 megawatts
Colorado Green, Colorado: 162 megawatts
High Winds, California: 162 megawatts

The countries that led the world in wind power production in 2004 were as follows:

**World Leaders in Wind Capacity, December 2004**

| Country | Capacity in Megawatts |
|---|---|
| Germany | 116,629 |
| Spain | 8,263 |
| United States | 6,740 |
| Denmark | 3,117 |
| India | 3,000 |
| Italy | 1,125 |
| Netherlands | 1,078 |
| United Kingdom | 888 |
| Japan | 874 |
| China | 764 |

## CURRENT AND FUTURE TECHNOLOGY

Throughout the twentieth century, engineers experimented with various rotor designs. One was called the Darrieus windmill, named after the person who invented it in the 1920s. Rather than using blades that look like airplane propellers, the Darrieus windmill looks more like a giant eggbeater, with thin blades connected at the top and bottom of a vertical shaft. The Darrieus windmill has the advantage of working no matter which way the wind is blowing. In addition, generators can be mounted at the bottom rather than the top.

The most common type of windmill in the early twenty-first century was called the vertical-axis wind turbine, which had airplane propeller-type blades mounted at the top of a tall tower. This windmill, called the MOD-2, was designed by NASA. Each MOD-2 was mounted on a 200-foot-tall (61 meters) tower. The blades were up to 150 feet (46 meters) long. The MOD-2 could produce about 2,500 kilowatts of power in a 28-mph (45 kph) wind. Other wind turbine rotors may be larger, but their fundamental design owes much to the design of the MOD-2.

The technology of wind-power generation is well-developed. Although refinements in blade configuration and other factors probably can be made, the technology is cost-effective and sound. The major challenge for the future is harnessing the technology on a big enough scale to provide power to large numbers of users.

## BENEFITS AND DRAWBACKS OF WIND ENERGY

The chief benefits of wind power are that it is clean, safe, and endlessly renewable. The fuel that powers wind turbines is free, so its price to utility companies does not vary. Wind power does have a number of drawbacks. Wind speed does not remain constant, so the supply of power may not always be the same as demand from consumers. Because many of the best locations for wind turbines are far from urban areas, there are problems with distributing the energy.

### Environmental impact of wind energy

Wind power is clean and renewable, but it also raises environmental concerns. Wind power farms require large stretches of land or have to be placed in environmentally sensitive areas such as deserts or on ridgelines. Many people consider wind farms

The Darrieus wind turbines have the advantage of working no matter what direction the wind is blowing. *U.S. Department of Energy, Washington D.C.*

unsightly, a form of visual pollution. A major environmental concern is the effect of wind farms on patterns of bird migration. Many birds have been killed by flying into wind turbine blades.

**Economic impact of wind energy**

The cost of generating electricity with wind power has steadily decreased. Wind-power electricity can be generated for about four to six cents per kilowatt-hour, making wind power competitive with other forms of generation of electricity.


Wind power can have harmful effects on the environment. Some environmentalists are concerned about soil erosion, bird safety, and noise pollution. *© PICIMPACT/Corbis.*

**Societal impact of wind energy**

The societal impact of wind power is similar to that of many other renewable fuels. About two billion people worldwide do not have electricity. Many of these people live in areas where connecting them to the power grid would be extremely expensive. Wind power may be an alternative way to provide power to these people, improving their quality of life.

Wind power also may reshape the way people think about electricity and their place in a nation's power distribution system. Most electric power is provided by huge facilities, which often are far from the consumer's home or business. Wind power, at least for the near future, is likely to be generated closer to home, in communities and even at the neighborhood level. As fossil fuels become increasingly more expensive and eventually are depleted, alternative energy, including wind, solar, tidal, and wave power generated locally, may contribute to a sense of people belonging to communities rather than to large, anonymous societies. Decisions about power supplies and distribution would be made close to home in response to local needs.

## WIND TURBINES

In the early twenty-first century, wind turbines are mainly used to produce electricity. Some turbines are on wind farms and contribute electricity to the power grid for commercial use. Remote areas also use turbines, providing electricity to small villages that are too far away from the transmission lines of the commercial areas. Turbines have other uses besides producing electricity, such as pumping water, and ice making. Near oceans there is some use of wind turbines to help remove the salt from the ocean water.

### How wind turbines work

The technology of wind turbines is simple. Wind turbines capture the kinetic energy of wind with, in most cases, two or three blades shaped much like airplane propellers. These blades are attached to a tower that rises at least 100 feet (30 meters) above the ground. At this height air currents tend to be stronger but less turbulent than they are at ground level. When the wind strikes the blade, the angle and configuration of the blade form a pocket of low pressure on the downwind side of the blade. This low pressure sucks the blade into movement, causing the rotor to turn. Force is added by the high pressure on the upward side of the blade. In aerodynamic theory, this property is called lift. If the blade is designed correctly, lift is stronger than drag, or the slowing force exerted by the wind on the front of the blade.

In wind turbines lift and drag work together to make the entire mechanism spin like a propeller. In earlier windmills drag rather than lift was the force that turned the blades. The process is the opposite of that of a fan. With a fan electricity is used to make wind. With a wind turbine wind is used to produce electricity. The turning rotor of a wind turbine is connected to a shaft, which is connected to an electric generator. Power can be distributed to users over the electric grid in exactly the same way any other electric power is distributed.

The most important feature in the operation of wind turbines is lift. To achieve lift, wind turbine designers have borrowed technology from aircraft designers. In cross-section an airplane wing looks like an irregularly shaped teardrop. The shape is irregular because the wing's bottom is slightly flatter than the top, which is more curved. When a plane flies, its wings slice through the air, creating wind. Because of the curve of the upper surface of the wing, the air has to flow faster to get around the wing. At the same time, the air flows at a lower speed along the bottom surface of the wing. Because of the difference in speed, the air above the wing is less dense; that is, the air pressure is lower than the pressure of the air below the wing. This difference in pressure creates lift perpendicular to the direction of the moving air, allowing the plane to fly. The same principle applies to turbine blades.

Unlike airplane wings, wind turbine wings are almost always twisted. The reason they are twisted has to do with another aerodynamic principle, stall. When an airplane wing is tilted back, the wind continues to flow smoothly along the bottom surface, but along the top surface, because of the steeper angle presented to the wind, the air no longer sticks to the wing but swirls around in a circle above it. The result of this swirling is the loss of the low pressure along the upper surface of the wing. Without this low pressure, the plane has no lift and drops like a rock.

Unlike airplane wings, wind turbine blades are constantly rotating, and the speed of the rotation differs along the entire length of the blade. At the precise geometric center, the speed of rotation is zero. This speed steadily increases along the length of the blade until at the tip the blade can be moving hundreds of feet (meters) per second. This rotation changes the direction at which the wind hits the blade all along its length. In effect, the angle at which the wind hits the blade would be different at each point along the blade if the blade were not twisted. When the blade is twisted, the angle at which the wind hits the blade is the same at each point, and stall is eliminated under normal wind conditions. Excessively high wind speeds can damage rotors, however, so engineers have designed blades that stall when the wind is too strong, and the rotor stops spinning.

Wind turbines come in two configurations. One, called a vertical-axis turbine, looks much like an oversized eggbeater. The axis of the turbine is positioned vertically, and the blades are connected to the axis at the top and the bottom. This configuration has one primary advantage: The turbine does not have to be faced into or away from the wind, so it operates no matter which way the wind is blowing, and it does not have to be repositioned to accommodate changes in wind direction.

The other configuration, the horizontal-axis turbine, is much more commonly used. With this style, the axis is parallel to the ground on a tower, and the blades, which look like airplane propellers, are perpendicular to the axis. This type of wind turbine looks like a pinwheel.

## The Mathematics of Wind Energy

Three factors determine how much energy the wind can transfer to a wind turbine: the density of the air, the area of the rotor, and the speed of the wind. The first factor is air density. Any moving body contains kinetic energy. The amount of this energy is proportional to the body's mass or weight. A truck hurtling down the road at 50 miles per hour (80 kilometers per hour) has more kinetic energy, and consumes more gasoline, than a subcompact car traveling at the same speed. With wind the amount of kinetic energy depends on the density of the air. Heavy air contains more energy than light air. When the atmospheric pressure is normal and the air temperature is 59°F (15°C), air weighs 1.225 kilograms per cubic meter (0.076 pounds per cubic foot). Humid, or damp, air is denser than dry air, so it weighs more. Air at high altitudes, such as in mountain regions, is less dense, so it is lighter.

The second factor that determines the amount of energy the wind can transfer to a wind turbine is the area of the rotor. The diameter of a 1,000-kilowatt wind turbine is 54 meters (177 feet). Rotor diameters can vary with designs, but this diameter is typical. The area over which a rotor of this size operates is 2,300 square meters (24,757 square feet). As the diameter of a rotor increases, the increase in the area it covers increases with the square of the diameter. Thus, doubling the size of a turbine allows it to receive four times as much energy, or $2^2 = 2 \times 2$.

The third factor that determines how much energy the wind can transfer to a wind turbine is the speed of the wind. The relation between wind speed and energy is cubic. In other words, when the speed of the wind doubles, the amount of energy increases eight times, or $2^3 = 2 \times 2 \times 2$.

When the three factors are put together, the formula used to calculate the amount of wind energy available at a given site is $P = 0.5 \ \rho \ v^3 \ \pi \ r^2$ where *P* equals power measured in watts; $\rho$ or the Greek letter rho (ROH), equals the density of dry air in kilograms per cubic meter (1.225); *v* equals the speed of the wind measured in meters per second; $\pi$, or the Greek letter pi (PYE), equals 3.14159; and *r* equals the radius, or half the diameter, of the rotor in meters.

A wind turbine has the following components:

- Rotor and blades. The rotor is the hub around which the blades are connected. Often, however, "rotor" is used to refer to the hub and the blades as a single unit. The rotor is the key component, because it translates the wind's kinetic energy into torque (TORK), or turning power.
- Nacelle (nuh-SELL), or the enclosure that houses the turbine's drive train, including the gearbox, the yaw mechanism, and

the electric generator. The gearbox connects a low-speed shaft to a high-speed shaft. This mechanism can increase the speed of the shafts by a factor of as much as fifty to one, meaning that the high-speed shaft turns fifty times faster than the low-speed shaft. The yaw mechanism automatically senses the direction of the wind and rotates the rotor to keep it facing into the direction of the wind.

- Tower, or the support for the rotor and drive train.
- Electric equipment such as controls, cables, and an anemometer (an-uh-MAH-muh-tuhr)

Blades come in various sizes and have tended to grow over the years. In the early 1980s, a typical blade was likely to be 33 feet (10 meters) long, and such a wind turbine could generate about 45 megawatt-hours per year. By 1990 the typical blade measured 89 feet (27 meters) and could produce 550 kilowatt-hours per year. In the early twenty-first century blades as long as 233 feet (71 meters) can generate 5,600 megawatt-hours per year.

Building a wind turbine is far more than simply a matter of finding a field or mountaintop where the wind is blowing and plopping one down. Engineers give a great deal of attention to finding the proper site for a wind turbine. The main factor they consider is the average speed of the wind over an extended time. Using a device called a wind-cup anemometer, which looks like three or four ice-cream scoops arranged in pinwheel fashion, engineers take extensive measurements of wind speed over a long time.

Wind speed measurements have to be precise. If engineers overestimate the amount of wind, the power output of the turbine can be reduced considerably. If, for example, wind is believed to average 10 miles (16 kilometers) per hour but is only 9 miles (14 kilometers) per hour, the power output of the turbine is reduced 27 percent. If the wind speed is only 8 miles (13 kilometers) per hour, the power output is 41 percent less than expected. If the wind speed is higher than believed, power output increases. If the wind speed is 11 miles (18 kilometers) per hour, the power generated increases 33 percent. If the wind speed is much higher than expected, the equipment may be too small and too fragile for the site.

In addition to wind speed when looking for a place for a wind turbine, engineers consider factors such as wind hazards, characteristics of the land that affect wind speed, and the effects of one turbine on nearby turbines in wind farms. The following factors are important:

- Hill effect. When it approaches a hill, wind encounters high pressure because of the wind that has already built up against the hill. This compressed air rises and gains speed as it approaches the crest, or top, of the hill. Siting wind turbines on hilltops takes advantage of this increase in speed.
- Roughness, or the amount of friction that Earth's surface exerts on wind. Oceans have very little roughness. A city or a forest has a great deal of roughness, which slows the wind.
- Tunnel effect, or the increase in pressure air undergoes when it encounters a solid obstacle. The increased air pressure causes the wind to gain speed as it passes between, for example, rows of buildings in a city or between two mountains. Placing a wind turbine in a mountain pass can be a good way to take advantage of wind speeds that are higher than those of the surrounding air.
- Turbulence, or rapid changes in the speed and direction of the wind, often caused by the wind blowing over natural or artificial barriers. Turbulence causes not only fluctuations in the speed of the wind but also wear and tear on the turbine. Turbines are mounted on tall towers to avoid turbulence caused by ground obstacles.
- Variations in wind speed. During the day, winds usually blow faster than they do at night, because the sun heats the air, setting air currents in motion. In addition, wind speed can differ depending on the season of the year. This difference is a function of the sun, which heats different air masses around Earth at different rates, depending on the tilt of Earth toward or away from the sun.
- Wake. Energy cannot be created or destroyed. As wind passes over the blades of a turbine, the turbine seizes much of the energy and converts it into mechanical energy. The air coming out of the blade sweep has less energy because it has been slowed. The abrupt change in speed makes the wind turbulent, a phenomenon called wake. Because of wake, wind turbines in a wind farm are generally placed about three rotor diameters away from one another in the direction of the wind, so that the wake from one turbine does not interfere with the operation of the one behind it.

- Wind obstacles, such as trees, buildings, and rock formations. Any of these obstacles can reduce wind speed considerably and increase turbulence. Wind obstacles such as tall buildings cause wind shade, which can considerably reduce the speed of the wind and therefore the power output of a turbine.
- Wind shear, or differences in wind speeds at different heights. When a turbine blade is pointed straight upward, the speed of the wind hitting its tip can be, for example, 9 miles (14 kilometers) per hour, but when the blade is pointing straight downward, the speed of the wind hitting its tip can be 7 miles (11 kilometers) per hour. This difference places stress on the blades. Too much wind shear can cause the turbine to fail.

## CURRENT AND POTENTIAL USES

The American Wind Energy Association predicted that in 2005 as much as 2,500 megawatts of new wind power capacity could be added in the United States, bringing the total to more than 9,000 megawatts. Worldwide, as of the end of 2003, about 39,000 megawatts of wind power were being generated, producing about 90 billion kilowatt-hours of power, enough for about nine million average American homes.

The power produced with wind energy is only a fraction of the potential. The U.S. Department of Energy says that, in theory, wind can provide the equivalent of 5,800 quadrillion British thermal units, or quads, of power each year, a number that is fifteen times the total world energy demand each year. Just a single quad has as much power as 45 million tons of coal or 172 million barrels of oil. In the United States, it is estimated that wind realistically could supply 20 percent of the nation's electricity requirements. In 2005 it was supplying about 0.4 percent. A goal is for the United States to generate 5 percent of its electricity from wind power by the year 2020.

An example of wind power in action in the United States is Spirit Lake, Iowa. At Spirit Lake, the elementary school has a 250-kilowatt wind turbine that provides 350,000 kilowatt-hours of electricity each year, more than the school needs. The rest of the power is fed into the local utility grid, earning the school $25,000 during its first five years. The school, however, is not fully dependent on the wind turbine. When the wind is not blowing, the school purchases electricity from the power company. Officials at Spirit Lake considered the system so successful that a second turbine, with a capacity of 750 kilowatts, was installed.

Commercial wind power usually is generated at wind farms rather than from single turbines. Wind farms consist of a group of turbines at the same site. The largest wind farm in the United States is the Stateline Wind Energy Center, located on the Vansycle Ridge, which runs along the Columbia River on the Washington-Oregon border. The ridge is an ideal site because of its consistent average winds of 16-18 miles (26-29 kilometers) per hour. The farm consists of 454 wind turbines, each 166 feet (51 meters) tall and at peak capacity generating 660 kilowatts of power. This wind farm provides power to about seventy thousand homes. Plans are to expand the farm so that it can produce 300 megawatts of power.

### Benefits of wind turbines

Wind power has grown to be economically competitive with other forms of power. Although it costs more to generate 1 kilowatt of electricity by wind power than it does with coal- or oil-fired generators, the gap is closing. If 20 percent of a family's electricity were to come from wind power, the electric bill would be less than $2 higher per month. The cost of generating wind power has decreased 85 percent since 1980.

Wind power can be an alternative crop for farmers and ranchers. A small family farm in western Pennsylvania provides 5 percent of the power used at the University of Pennsylvania. Many farmers and ranchers are leasing their land to produce electricity. A farmer can be paid as much as $4,000 per wind turbine, and the farmer can continue to use the land for traditional farming. Wind turbines add to the local tax base. In Lamar, Colorado, wind-power generation added $32 million to the county tax base, providing money for schools and other local needs.

Wind turbines do not consume water, making them ideal for dry or drought-stricken areas. In contrast, conventional and nuclear power plants consume large amounts of water for cooling and other purposes. According to the California Energy Commission, the number of gallons of water consumed per kilowatt-hour by nuclear power plants is 0.62; by coal plants, 0.49; and by oil, 0.43. In contrast, wind-power turbines consume 0.001 gallons of water per kilowatt-hour.

Wind power is homegrown, unlike oil, which the United States and other countries have to import in large quantities from areas of the world that are often unstable. Not buying these fuels from abroad increases national security and improves the nation's balance of payments. Because wind is free, consumers are not at the mercy of frequently increasing fuel prices.

Wind power in inexhaustible and renewable, in contrast to fossil fuels, and it is clean. Wind power does not contribute to acid rain, smog, global warming, or mercury contamination. It does not release dangerous particles into the air. In 2000 the Harvard School of Public Health conducted a study on the health effects of two conventional power plants in Massachusetts. The researchers concluded that among the health effects of the plants' air pollution were 159 premature deaths, 1,710 emergency department visits, and 43,300 asthma attacks.

Wind energy is safe. Although the risk exists for industrial accidents in the construction of a wind turbine, the same can be said about the construction of any facility. The risk that the public will be harmed by a wind-power facility is nearly zero. With nuclear power the risk of catastrophe is ever present, and with fossil fuel plants, the danger from fire and explosions is high. There has been only one case of a person's being killed by a wind turbine: A skydiver sailed off course and fell into the rotating blades of a turbine.

Wind power has many uses. Small turbines can power schools, businesses, campuses, homes, farms, and ranches. They can be used in remote locations for telecommunications, ice making, and water pumping, eliminating the need for remote communities to run smoky and noisy diesel-powered generators. Turbines could benefit native communities in small, poorer nations.

### Drawbacks of wind turbines

Wind turbines can be noisy, and engineers are working on ways to quiet the noise. The best method has been to reduce the thickness of the trailing edges of blades. Noise also has been reduced by placing turbines in an upwind rather than a downwind position. The wind hits the blades first, then the tower, rather than the other way around, eliminating the thumping sound that downwind designs make as the blade passes the wind shadow cast by the tower.

Wind turbine blades can cause shadow flicker as the blades rotate in the path of the sun's rays. The flickering of light and dark can be a minor annoyance for local residents when the sun is low in the sky. Most turbines are set back far enough away from homes and businesses so that shadow flicker is not a concern.

Wind farms require a fair amount of land, about 24 hectares (60 acres) per megawatt. However, the turbines themselves plus service roads occupy only about 1 hectare (3 acres) of the 24 hectares. Once the turbines have been built, farmers and ranchers can continue to use the land under them for traditional purposes. Land is difficult to find near larger cities. One solution to this problem is to place wind turbines in shallow waters offshore where possible.

Wind turbines are visible, contributing to visual or horizon pollution. Placing some wind turbines offshore can help lessen this problem. Some people consider wind turbines sleek and attractive, embodying a forward-looking concern for the environment. Wind turbines are no more visible than ski resorts, water towers, and junkyards.

The wind is intermittent, meaning that wind power has to be supplemented by other forms of power. Wind-power generation poses additional challenges for power-grid managers, who have to ensure that enough power is available to meet peak demand at all times, even when the wind is not blowing.

Not all areas of the United States, or any country, are suitable for wind-power generation. Wind towers and rotors can interfere with radar, posing a potential hazard for air travelers. They can also interfere with television and radio transmission, particularly if they are in the line of sight between the signal source and the receiver. Finally, wind turbines can be a hazard to birds, which sometimes fly into the rotors.

### Environmental impact of wind turbines

The use of wind power benefits the environment, because this form of energy is clean and it does not consume water. It has been estimated that in 2004, existing wind power prevented the release of 10.6 million tons of carbon dioxide, 56,000 tons of sulfur dioxide, and 33,000 tons of nitrogen oxides. It also has been estimated that if only ten percent of wind potential were developed in the ten windiest U.S. states, total carbon dioxide emissions could be cut by one-third.

Wind power, however, can have harmful effects on the environment. Some environmentalists are concerned about soil erosion, particularly in desert regions, where a thin, fragile layer of topsoil would be disturbed in the construction of turbines, and in the eastern United States, where turbines would be built on mountain ridgelines. Good engineering practices could lessen these effects.

Another potential problem is the effects of wind farms on bird life. Although birds and bats sometimes fly into wind-turbine blades and are killed, this problem is site specific and has been exaggerated. In a study in California researchers concluded that in a total of ten thousand bird deaths, 5,500 birds were killed by flying into buildings and windows and that motor vehicles caused seven hundred deaths. Cats caused one thousand bird deaths.

Wind turbines, in contrast, accounted for less than one in ten thousand bird deaths. Environmentalists are also concerned that wind farms with their service roads and transmission lines may break up the habitat of birds and other wildlife.

**Economic impact of wind turbines**

The chief economic impact of wind power is that the fuel is free, so it does not have to be mined, transported, stored, and purchased by utility companies. In the early 1980s, when the first large wind turbines were being installed, the electricity they generated cost about thirty cents per kilowatt-hour. At that time, wind power was not competitive with other forms of power because it was just getting its start at a commercial level.

As the scale of wind operations grew and the technologies used to exploit wind energy improved, wind power in the early twenty-first century cost about four to six cents per kilowatt-hour, making it competitive with traditional power sources. The cost of wind power tends to be higher in the eastern United States, where wind speeds are lower, wind farms are smaller, and the cost of construction is higher because most wind turbines are constructed on elevated ridgelines. The cost tends to be lower in the Great Plains, where wind speeds are higher, wind farms are larger, and the cost of construction is lower because of the flat terrain. To put the figure of four to six cents per kilowatt-hour in perspective, the cost of electricity per kilowatt-hour in some U.S. states in 2000, according to the Energy Information Administration, was as follows:

Hawaii, 14 cents

New York, 11.2 cents

Connecticut, 9.5 cents

California, 8.4 cents

Florida, 6.9 cents

Illinois, 6.6 cents

Colorado, 6.0 cents

Nebraska, 5.3 cents

Kentucky, 4.1 cents

Wind power provides jobs. Every megawatt of wind power provides about 4.8 job-years of employment. Wind power also provides exports. It is estimated that by the mid-2010s, 75,000 megawatts of new wind power will be installed worldwide at a cost of $75 billion. Countries with the industrial capacity to build wind turbines, such as the United States, could capture a share of that growing market, providing employment for thousands of people. Many farmers and ranchers earn money by leasing their land to wind-power companies. They receive as much as $3,000 to $4,000 per year for each wind turbine. Wind farms increase local tax bases, providing funds that counties can use to improve schools and providing other services to residents.

Wind power does not have the hidden costs of other energy sources. Hidden costs are those that society has to pay but that are not reflected in the price of the resource. Such costs include transportation and storage with their risk of causing polluting accidents, air and water pollution, and the health effects of pollution.

### Societal impact of wind turbines

The effects of wind power on society are difficult to measure. Because the fuel is free, use of wind power would release billions of dollars that are currently spent mining, transporting, storing, and burning fossil fuels. However, the price of land near wind turbines often decreases, which is a concern to local land owners.

Most conventional power-generating plants, and even some alternative energy plants such as hydroelectric dams, are large facilities that often alter the course of rivers and other natural landscapes. Nuclear power and coal-fired generating plants are considered necessary, but they pose health and safety dangers particularly related to smoke and other emissions. Wind power, in contrast, is perhaps the most harmless form of power available. It consumes no fossil fuels or water, it poses no health risk and only the smallest safety risk, and as the technology develops, it is likely to be relatively inexpensive, especially as the cost of fossil fuels rises. Wind energy would provide the United States, or any nation, with at least some measure of energy independence, making the nation less reliant on the energy sources that come from other parts of the world. In many communities, using wind energy would bring power generation closer to home, so that cities, counties, and states would be responsible for their own power needs. Being responsible for their own power may contribute to a greater sense of community among local residents.

## ISSUES, CHALLENGES, AND OBSTACLES

Three principal issues surrounding wind power continue to be discussed by policy makers and legislators: the renewables portfolio standard, the production tax credit, and net metering.

The renewables portfolio standard, or RPS, refers to proposals for laws that would require electric utility companies to provide a portion of the electricity from renewable sources such as wind power. The company could either produce the energy itself, or it could buy the energy from another company. Rather than buying the electricity, the company could also buy credits, which it could then trade or sell to other utility companies. In this way, company A might not provide any electricity at all from renewable sources, but company B, which bought A's credit, might provide twice as much as it otherwise would have. Thus, the purpose of the RPS is not to force any single company to provide energy from renewable sources but to force the industry as a whole to provide such electricity. Twelve states have an RPS in place, and various proposals have been made to enact RPS laws at the federal level.

A second issue is the production tax credit. As a way to encourage the development of wind power, the government gives wind energy producers a 1.8-cent tax credit for every kilowatt-hour they produce. This money can be subtracted directly from the company's income tax bill, making it less expensive for the company to produce energy and therefore making the energy less expensive to consumers. In this respect, the wind industry is no different from other energy industries, all of which receive help from the tax code so that they can keep down costs to consumers. The tax credit was enacted in 1992. In 2004 President George W. Bush (1946–) signed a two-year extension to expire at the end of 2005. The wind industry would like to see the tax credit extended beyond that date so that the industry can continue making investments in wind-power plants.

A third issue is called net metering or sometimes net billing. This term refers to laws that permit citizens with wind turbines to allow their electric meter to run backward when they are supplying excess power to the electric grid. For example, a rancher has a wind turbine that generates 200 kilowatt-hours of electricity. During the day, the turbine provides much of the electricity needed to run the ranch, but when the wind is not blowing, the rancher has to buy supplemental power from the utility company. At night the turbine generates excess electricity that the rancher can sell to the local utility company.

Under net metering laws, each excess kilowatt-hour the rancher supplies would offset each kilowatt-hour he buys from the utility, lowering the ranch's electric bill each month. Some utility companies argue that this practice is unfair, because they say they are being forced to buy power from the rancher at high retail rates rather than at the low wholesale rates at which they usually buy power. The wind-power industry has successfully argued in thirty-four states that the rancher and the utility are swapping power and that this is a standard practice among utility companies. Meanwhile, other states are considering enacting net metering laws.

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# Energy Conservation and Efficiency

## INTRODUCTION

While scientists and engineers search for alternatives to fossil fuels that are clean, abundant, safe, and inexpensive, other important alternatives are available to businesses, governments, and other energy consumers: finding ways to reduce energy use and using energy more wisely and efficiently. For the foreseeable future, solar power, wind energy, and other alternatives are likely to function mainly as supplements to fossil fuels. That is, they can meet some percentage of the world's energy needs, but the potential of these alternatives in the early 2000s is limited by cost, environmental considerations, and even simple geography. Wind power, for example, can become a major power source only in those parts of the world that have sufficient wind.

In the short term, the world will continue to rely on fossil fuels. One way to stretch the supply of fossil fuels—while at the same time reducing the pollution caused by mining, transporting, and burning them—is to burn less of them. The cost of fossil fuels is likely to increase as reserves diminish and it becomes increasingly expensive to mine or drill for less-readily available supplies. However, energy consumers can reduce their dependence on fossil fuels and their energy bills by finding new ways to use less energy. Among the best ways to accomplish these goals are increasing energy efficiency and energy conservation. The first includes redesigning vehicles, buildings, appliances, and the like—both by building them with materials that require less energy to produce and by designing them in such a way that they require less energy

## Words to Know

**Carbon sequestration** Storing the carbon emissions produced by coal-burning power plants so that pollutants are not released in the atmosphere.

**Climate-responsive building** A building, or the process of constructing a building, using materials and techniques that take advantage of natural conditions to heat, cool, and light the building.

**Drag coefficient** A measurement of the drag produced when an object such as a car pushes its way through the air.

**Green building** Any building constructed with materials that require less energy to produce and that save energy during the building's operation.

**Hybrid vehicle** Any vehicle that is powered in a combination of two ways; usually refers to vehicles powered by an internal combustion engine and an electric motor.

**Lumen** A measure of the amount of light, defined as the amount of light produced by one candle.

**Sick building syndrome** The tendency of buildings that are poorly ventilated, lighted, and humidified, and that are made with certain synthetic materials to cause the occupants to feel ill.

**Thermal mass** The measure of the amount of heat a substance can hold.

**Trombé wall** An exterior wall that conserves energy by trapping heat between glazing and a thermal mass, then venting it into the living area.

while *in* use. The second includes the many ways in which the average person can make lifestyle choices that conserve energy, such as drying clothes on a clothesline rather than using a dryer; eating less meat; setting thermostats lower in the winter and higher in the summer; maintaining water heaters at lower settings; carpooling, using public transportation such as subways or buses, walking, or biking to work or school; purchasing smaller, more energy efficient vehicles rather than larger vehicles like SUVs; and choosing to replace incandescent light bulbs with compact fluorescent light bulbs. Some experts argue that energy conservation among consumers is a cheaper and more environmentally sensitive option to increased energy production from either fossil fuels or alternative sources.

### Conserving oil and gas

Scientists and energy officials agree that the need for conservation and greater fuel efficiency is pressing, although they debate just how urgent it is. In the 1990s the Intergovernmental Panel on Climate Change (IPCC) conducted investigations that led in 1997 to the Kyoto Protocol, a worldwide plan designed to reduce fossil-fuel consumption, with the goal of reducing global warming. At that time the IPCC estimated that the amount of oil remaining in the ground was about 5,000 to 18,000 billion barrels. The panel also estimated that world production of oil and gas would begin falling in about 2050. At that point the cost of oil and gas would become painfully high. Meanwhile, according to the World Energy Council, the world consumes over 71 million barrels (one barrel equals 42 gallons) of oil and natural gas per day.

In 2003 a team of geologists from the University of Uppsala, Sweden, presented findings that differed from those of the IPCC. The good news, according to the Swedish scientists, is that global warming, caused in part by pollutants emitted from vehicles, will never reach disastrous proportions. The bad news, however, is that global warming may be less of a threat than previously thought because the amount of fossil fuels remaining is dangerously low and the world will run out of these fuels before global warming becomes a critical problem. This team of scientists believes that the remaining supply of oil is only about 3,500 billion barrels and that production will begin to fall in about 2010 rather than 2050. Furthermore, about 80 percent of the known oil and gas reserves are in regions of the world that are politically unstable, so reserves could be sharply reduced or even cut off entirely as a result of political unrest.

In general, energy experts fall into two camps, the optimists and the pessimists. The pessimists believe many countries have exaggerated their figures about proven oil and gas reserves and that all the world's major oil and gas discoveries have already been made. Thus, the pessimists believe that the world is faced with declining oil and gas supplies. In this case, energy conservation and energy efficiency are necessary because world supplies will not support the use of energy at current levels for very long. The optimists, on the other hand, believe that technological advances will lead to the discovery of more oil and gas and, more importantly, enable engineers to tap that oil and gas in ways that were thought impossible in past years. In this case, energy conservation and energy efficiency are necessary because, with the discovery of more fossil fuels, the environmental impact of using them continues to grow.

### Conserving coal

Coal reserves are more abundant than oil and gas. Many experts say that the amount of coal reserves in the world—just over a trillion metric tons—is enough to last for about 200 years. The primary issue with coal, however, is that it is dirtier than oil,

## Carbon Sequestration

Some scientists argue that the key to using coal without emitting huge amounts of carbon dioxide into the atmosphere is a process called carbon sequestration. Carbon sequestration refers to several methods of removing or slowing the concentration of (''sequestering'') carbon dioxide in the atmosphere. According to the U.S. Department of Energy (DOE), natural sequestration occurs in various ways, including the absorption and storage of carbon by vegetation, soils, and the oceans in carbon ''sinks.'' The DOE, many environmental groups, and some power companies support enhancing natural sequestration with methods such as the reforestation of agricultural or urban areas and restoration of wetlands, though research is needed in order to create larger, longer-lasting carbon pools in various ecosystems. Another method in development includes the capture and injection of carbon dioxide at deep sea level, though the long-term effects of injecting carbon dioxide into the oceans are unknown. In addition, several countries, including the United States, China, and England, are funding research into the capture and storage of carbon in underground or undersea geologic formations such as depleted crude oil and natural gas reservoirs, unmineable coal seams, and deep saline reservoirs. The DOE states that not only does carbon storage in depleted oil reservoirs reduce carbon dioxide levels, the pressure created can force out additional oil.

Proposals have been made in England, the United States, and other countries to rely more on carbon sequestration. England has abundant coal reserves that could provide a significant percentage of the nation's energy needs for many decades, if ways can be found to deal with the carbon dioxide. Some British experts believe that there is enough space under the North Sea to store the United Kingdom's carbon emissions for a century.

contributing significantly to the emission of carbon dioxide, the chief pollutant behind global warming. While the amount of carbon dioxide produced by burning coal differs with the type and quality of the coal, the U.S. Department of Energy provides this analysis: When coal is burned, the chief element that provides heat is carbon. During the combustion process, one pound of carbon combines with 2.667 pounds of oxygen to produce 3.667 pounds of carbon dioxide. Thus, if the carbon content of a particular grade of coal is, say, 78 percent, and burning a pound of it produces about 14,000 British thermal units (BTUs) of heat, then producing 1 million BTUs of heat releases about 204.3 pounds of carbon dioxide into the atmosphere. This figure is about twice that of natural gas and about 50 percent more than that of oil, according to the U.S. Department of Energy.

Currently, coal is used almost exclusively in the production of electricity, while oil, after it is refined into gasoline, is the primary fuel source for cars and trucks. It is possible to design and build cars and trucks that are powered by electricity, but doing so would increase demand for electricity. This increased demand would require the combustion of increasing amounts of coal, which in turn would lead to the emission of more carbon dioxide.

Conventional energy sources can be conserved in various ways by individuals, for example consumers can make conscious choices to meet rather than exceed their needs in terms of the size of their homes and automobiles. Consumers can buy smaller homes to decrease home square footage, cutting the overall energy consumed by heating, cooling, and lighting. People can decrease dependence on automobiles by utilizing public transportation, carpooling, walking, or biking. Even with minimal changes to everyday life, consumers can take steps to reduce their energy consumption by making minor improvements in their homes, such as upgrading old inefficient heating systems and installing storm windows; relying on more energy-efficient lighting and appliances; and by changing their driving habits. There are also ways in which consumers can reduce energy use by requiring the housing and automotive industries to construct climate-responsive buildings; use "green" building materials; and design and build "hybrid" vehicles that use less gasoline. Any of these can significantly cut an energy consumer's bills, reduce pollution, and help stretch the world's energy supplies.

## CLIMATE-RESPONSIVE BUILDINGS

Climate-responsive building is sometimes called *green building* or *sustainable building*. In a broad sense, each of these terms refers to the same philosophy of building design and construction. This philosophy emphasizes the construction of buildings that use resources efficiently, both during their construction and once completed. Another goal is to minimize the impact of the building on the surrounding natural environment.

In this chapter the term climate-responsive building will emphasize issues pertaining to the siting (the placement), design, and layout of a building in order to take advantage of local weather conditions to reduce energy-use during the building's operation. The term green building will be used to emphasize the use of alternative construction materials that reduce energy demands. *Sustainability* is a more general term that refers to any technique,


A carpool lane sign on a California freeway near Los Angeles. © *Joseph Sohm; ChromoSohm Inc./Corbis.*

whether applied to construction or to such activities as agriculture, that enables the human community to "sustain" the natural environment for the future by using building materials and sources of energy that are renewable. These terms, though, all overlap. The design of a climate-responsive building emphasizes, in part, the use of green-building materials, and green-building practices are likely to be, at least in part, climate-responsive. The goal of both is sustainable building design.

### Climate-responsive history

The history of climate-responsive buildings dates back at least to the ancient Greeks. Around 500 BCE the Greeks in many areas of the country were running out of firewood. To heat their homes, they began positioning them in a way that would take advantage of the sun's rays and provide passive solar heating. Even the philosophers Socrates and Aristotle used their influence to call for construction that took advantage of solar heat during the winter by facing transparent mica windows toward the sun. (Mica refers to a number of transparent silicates that easily separate into thin

The house in the background uses solar panels on the roof to gather energy to recharge batteries stored in the basement to supply power for energy needs. The greenhouse is used for plants and to heat the house through vents opening into the upper floor windows. *©Michael Maloney/San Francisco Chronicle/Corbis.*

sheets.) The Greeks also began to use dark floors and other building materials that absorbed heat during the day so that buildings would stay warmer at night. They began to use window shutters to trap the day's heat, and they built structures in clusters so that each building would get some protection from cold winds.

Later the ancient Romans used similar building techniques. Moreover, the Romans were the first civilization to use glass greenhouses not only for growing plants and vegetables but also to trap heat. The Romans built bathhouses that took advantage of the sun, and whole cities were laid out to provide each resident with access to the sun—access that was protected by law. In the American Southwest, the Anasazi Indians, in a similar way, constructed villages that took into account the changing angles of the sun throughout the year.

In more modern times scientists and engineers developed new climate-responsive building techniques. In eighteenth-century Switzerland, physicist and geologist Horace-Benedict de Saussure (1740–1799) designed the first solar water heater. It consisted of a

The new Caltrans District 7 Headquarters, located in downtown Los Angeles, can harness the energy of the sun to create electricity with a second layer of vision glass panels with special photovoltaic components located on the southern exposure of the structure. There is a special, second metal skin that can open and close to maintain indoor comfort and filter air. © *Ted Soqui/Corbis.*

wooden box with a black base and a glass top. The water in the box could reach a temperature of 190°F (88°C). Other scientists focused on other ways to exploit solar energy in building construction or for commercial purposes. In 1878, for example, solar energy was focused to power a steam-operated printing press in France. However, much of modern construction after that point paid very little attention to climate-responsive building. Instead, humans focused on developing artificial means of heating and cooling using fossil fuels.

In the twenty-first century, architects and design engineers have rediscovered some of these techniques. Rather than simply putting buildings anywhere and relying on fossil fuels to heat, cool, ventilate, and light them, these designers are paying more attention to local climatic conditions to make buildings far more energy-efficient. They are learning to see buildings not just as collections of steel, glass, wood, and other materials, but as systems that interact with their natural environment. By paying attention to that environment, buildings can consume less energy while still providing for the comfort of their occupants.

### The need for climate-responsive buildings

Use of energy in commercial buildings is huge, so one place to start with energy conservation and efficiency is to design and construct such buildings with the principles of climate responsiveness in mind. Energy use within commercial buildings in the United States is actually higher than within the sectors of industry and transportation. And consumption of electricity within buildings doubled in the 1980s and 1990s and was expected to increase another 150 percent by 2030. As of the late twentieth century, 66 percent of the electricity used in the United States was that in commercial buildings.

In addition, buildings produce a considerable amount of carbon emissions. Buildings are responsible for 35 percent of all U.S. carbon emissions. On-site burning of fossil fuels accounts for 11.3 percent, while electricity usage accounts for 23.7 percent. Buildings also produce 47 percent of U.S. sulfur dioxide- and 22 percent of nitrogen oxide-emissions. Climate-responsive buildings can cut both this energy consumption and the greenhouse gas emissions. Such buildings can also contribute to a more healthful working climate for the building occupants.

### Climate-responsive building techniques

Some of the most common climate-responsive building techniques include the following:

1. Available solar energy can be used for heating and lighting. This would include daylighting, or using natural sunlight to provide for lighting needs; solar ventilation preheating, which makes use of greenhouses, atriums, and solar buffer spaces to provide some of the building's heat; solar water heating; and photovoltaics, or the use of photovoltaic cells to provide electricity. Using daylighting and solar energy for heating and lighting requires intelligent placement of the building relative to the sun. Solar water heating and photovoltaic features can be built right into the skin and roof of the building, as well as into skylights, shingles, roofing tiles, glass walls, and even ornamental features. In fact, buildings that are constructed with built-in photovoltaics can even become net energy producers, creating surplus power that can be sold to the local energy grid or traded for power the building needs during periods when the sun does not shine.

2. Controllable shading can prevent overheating and glare. In hot-weather climates coatings can be placed on windows to block heat from entering the building while still allowing light to enter.
3. Using external wind pressure and solar radiation can power ventilation systems, serving as a supplement to fan-powered ventilation systems.
4. Using thermal mass and shading to help control internal temperatures reduces the demand for artificial heating and cooling.
5. In private homes, some builders construct Trombé walls, named after French inventor Felix Trombé (1906–1985), who conceived the design in 1964. Trombé walls are built facing the sun from materials such as stone, adobe, concrete, or even water tanks—any material that has high thermal mass (an ability to store and give off energy). The walls also have an air space, insulated glazing, and vents. As sunlight passes through the glazing and strikes the wall, the wall absorbs heat, in turn heating the air between the wall and the glazing. This warmer air then rises and is channeled through the vents into the home; cooler air from the home, which sinks, flows through vents at the bottom of the interior walls and into the air space. Heat can be retained on cloudy days by placing insulation between the air space and the thermal mass.

While incorporating energy-saving features into a building's design is beneficial, modern architects who design climate-responsive buildings make it clear that to derive the maximum possible benefit, it is important to take a "whole building approach," seeing a building not just as a collection of parts but as a living, breathing system. Further, architects point out that what works in one locale or part of the country might not work in another. A major concern in Minneapolis, Minnesota, is heating a building in winter, while residents of Phoenix, Arizona, are more concerned about cooling, especially in the summer. In the Midwest and Deep South, expelling humidity is a major concern, while in the dry air of the Rocky Mountain region, the concern is just the opposite. Architects and designers take these differing conditions and needs into account, then by integrating solar, wind, thermal mass, and other features, they can create designs that cut energy consumption significantly.

Proving this is a pair of buildings in San Diego, California. The Ridgehaven Building, a commercial office building, is located next

## Sick Buildings

In addition to providing energy savings, climate responsive (and green) buildings have an additional benefit: They tend to be more healthful for the occupants, including workers in a commercial building or students in a school building. Sometimes, a building can be the site of specific illness, such as Legionnaires' disease, an illness caused by the *legionella* bacteria, which is thought to be spread through cooling systems.

Buildings, though, often suffer from what is called ''sick building syndrome.'' This syndrome became more apparent after the rise in energy costs in the 1970s, when people started to become more aware of air leaks in buildings and sealed them to reduce wasted energy. While sealing the air leaks saved energy, it also trapped toxins and stale air inside, giving rise to a host of physical problems for the occupants, including eye, nose, and throat irritation; dryness of the skin, throat, and nose; breathing difficulties; headaches; fatigue; and even rashes.

According to the World Health Organization (WHO), sick buildings typically have forced-air ventilation, are constructed with lightweight materials, have indoor surfaces covered with fabrics, especially carpet, and are airtight. These features create uncomfortable temperatures, humidity levels that are too low, noise, and reliance on artificial lighting—especially fluorescent lighting that can ''flicker'' and cause headaches. They also trap molds, spores, dust mites, and other microorganisms. Some equipment such as photocopiers and printers may have toxic solvents in their toners, while carpeting and adhesives release toxic vapors such as formaldehyde.

Some experts, such as those at the Renewable Energy Policy Project (REPP), argue that sick building syndrome has a distinct economic cost and that climate-responsive buildings can lessen those costs. According to the REPP, such features as daylighting and natural ventilation can reduce employee sick days, boost the achievement of school students, and even increase sales in retail outlets. The REPP says that a ten-percent improvement in the productivity of employees can actually pay back the entire cost of a building over a ten-year period.

door to a nearly identical building of the same size. The Ridgehaven Building was built using climate-responsive techniques and with green materials; the neighboring building was constructed using traditional techniques and materials. The Ridgehaven Building uses 65 percent less energy than the neighboring building, saving the building's owners $70,000 a year in utility bills.

### GREEN BUILDING MATERIALS

Closely related to climate responsiveness is the concept of using "green" building materials. "Green" is a word that is used in connection with environmentally sustainable building materials and practices. It does not refer to the actual color of the materials. Rather, because green is the predominant color of the natural world, the word has become a figure of speech to refer to any environmentally sound practice that reduces the impact of human activity on the natural environment.

### The need for green building materials

Many green building practices have goals other than energy efficiency. For example, using products made out of natural materials can reduce the level of toxins and other harmful substances in a building. These substances are emitted by such materials as synthetic carpets, adhesives (e.g., glue used to bind two elements together), and fiberglass insulation. Substituting materials made from natural products (like insulation made from recycled paper) can contribute to the health, and therefore productivity, of employees working in a commercial building. Other green building practices are designed to reduce water consumption, for example toilets that use less water and landscaping that does not require large amounts of water. Still other practices are designed to minimize waste. One simple technique is to design buildings with dimensions that use entire 4- by 8-foot (1.2- by 2.40-meter) sheets of particleboard rather than creating large amounts of scrap. Also, using other green building materials that are made from recycled materials. Roof shingles, for example, can be made from recycled vinyl and sawdust.

Many green building practices, however, have energy efficiency and conservation as their primary goal. Many green construction materials save energy not only in the day-to-day operation of the building but also in its construction, because producing and transporting the materials are less energy-intensive activities. Furthermore, some green building materials are more durable than their traditional counterparts. This represents a form of energy conservation because the structure will last longer. A good example is cement composite house siding. Used more and more in place of wood, the cement composite can last fifty years or more with virtually no maintenance, primarily because it is not only tough but the color is mixed into the composite rather than applied on the surface, so it does not have to be painted. Though the initial production of cement is more costly in terms of carbon dioxide emissions than wood, the energy-efficiency of a building made with cement composite may save more carbon dioxide emissions over the lifetime of the building than were used making the cement.

**Common green materials**

Below are some twenty-first century green building materials. Most of these are more practical for houses than they are for commercial construction such as office buildings. Nonetheless, the impact of using these materials in large numbers of homes could be considerable.

1. Adobe: Adobe is one of the world's oldest building materials. Essentially, adobe is nothing more than earth that has been mixed with water and shaped into bricks. Sometimes chopped straw is added to give the adobe additional strength. Adobe is most durable when the content of the earth is about 15 to 30 percent clay, which binds the material together. The rest is sand or aggregate (small bits of rock). While adobe is commonly used in the southwestern United States, it can be used in most areas of the country. The chief advantage of adobe is that it provides good thermal mass, meaning that it absorbs heat during the day, then slowly releases the heat during the cooler nighttime. Some homeowners use adobe because the walls absorb heat during the day, then transfer the heat to the main portion of the house at night. The chief disadvantages of adobe are that it is structurally weak and is not a good insulator. Thus, adobe homes are often built very thick and may include a layer of insulation.
   A variation of adobe is called cast earth, which consists of blocks made of a mixture of earth and plaster of Paris. The plaster gives the blocks greater strength, so the amount of clay is unimportant. Cast earth has a strong aesthetic appeal to some builders because of its stone-like appearance.
2. Cob: Cob, which was commonly used in nineteenth-century England, is similar to adobe, but it has a much higher straw content. Because of the additional straw, it works better as an insulator than adobe does, though cob is often much thinner than adobe construction it is also becomes rather brittle over time. Another difference is that while adobe is typically fashioned into bricks, cob is applied in a more freeform manner, similar to plaster. This can give structures a more artistic look. A variant of cob is called light straw. With light straw the primary component is the straw itself, which is bound together with an adobe-like mixture. Light straw has even higher value as an insulator.

It is more fragile, though, so it has to be used with a timber frame to bear loads.

3. Rammed earth: Rammed earth is another very old construction technique. Much of the Great Wall of China consists of rammed earth. Rammed earth construction again is similar to adobe in that it makes use of local materials. Rather than shaping the earth into bricks (as with adobe) or applying it like plaster (as with cob), rammed earth refers simply to the process of compressing large amounts of earth into thick walls. Often, a stabilizing ingredient, such as cement or even asphalt, is added to the earth to make it more stable and durable. Wooden or metal forms are used to give shape to the walls, in much the same way they are used in pouring a concrete foundation. Like adobe, rammed earth provides a great deal of thermal mass but is not a good insulator. Another disadvantage is that rammed earth is very labor-intensive, usually requiring considerable use of heavy equipment.
4. Earth bags: Some builders are experimenting with bags of earth, similar to the sandbags that are used for flood control. Builders fill the bags with adobe material or use crushed volcanic rock, which provides greater insulation. The bags are laid in courses, similar to brick, then covered with some sort of plaster-like substance. Many builders are turning to a covering called papercrete, which consists of shredded recycled paper mixed with cement.
5. Straw bales: Bales of straw are one of the most common green materials used in home construction, primarily as an insulator. The home is constructed using traditional framing methods. The chief difference is that much more space is left between the interior and exterior walls. This space is filled with bales of straw rather than fiberglass insulation, which is made from petroleum and therefore depletes petroleum reserves. Not only is the straw a good insulator, but many homeowners like the thick walls and deep windowsills that result from straw bale construction. Straw bale homes are also quiet, because the straw acts as a sound insulator. The chief disadvantage is that great care must be taken to prevent water from getting into the walls and to prevent the buildup of condensation, because moisture can cause the straw to rot.

## Thermal Mass

Energy experts always refer to thermal mass, which measures not the flow of heat but the amount of heat that a substance can hold. Thermal mass is important primarily in areas where there are wide temperature swings throughout the 24-hour day, such as the southwestern United States and parts of the Rocky Mountain region. During the day, as outside temperatures rise, the temperature of the outside of a house is higher than that of the inside. Thus, following the laws of thermodynamics, the heat flows from outside to the cooler inside. During the night, when temperatures tend to fall dramatically (primarily because in these regions the air is drier, so there is no blanket of humidity to trap the day's heat), the heat flow reverses. Heat now flows from the warmer inside of the house to the cooler outside. But thermal mass is always responsible for a time lag. It might take up to eight hours for heat to move from outside to inside in the daytime—but by that time, the sun has set and the heat flow has stalled and starts to reverse. Likewise, it might take up to eight hours for heat to move from outside to inside, but by that time the sun is rising, so once again the heat flow is reversed. The key point is that thermal mass, as in an adobe home, helps to keep the inside temperature relatively constant, so that it changes far less than the outside temperature. A building with a great deal of thermal mass ''holds'' the heat rather than transferring it.

Thermal mass is a much less important consideration in areas of the country where the temperature does not swing as dramatically. In the north, for example, the daytime high temperature in the winter is almost always lower than the indoor temperature; similarly, in the summer the nighttime low temperature is very often higher—or nearly so—than a comfortable indoor temperature. Because the heat flow does not reverse itself under these conditions, thermal mass is less important.

In addition to these common green building materials, builders have experimented with many other types of materials, all with a view to reducing energy consumption and recycling materials that would otherwise find their way into landfills. Some builders, for example, build walls out of recycled tires. They fill the tires with earth, stack them, then plaster over the walls so that the tires do not show. This type of construction, in combination with other methods such as passive solar design and bermed (mounded or piled up) earth on the north side of the house, contributes to very low energy bills for the homeowner.

### Embodied energy

In addition to focusing on the energy savings of new climate responsive buildings and use of green building techniques, the "embodied energy" of existing structures must be taken into account. Embodied energy is basically all of the energy (beyond that of the operating costs such as heating and lighting of the building itself) used during a building's life cycle. This would include things such as recycling or removing previous structures; harvesting wood or other resources used in the building; manufacturing other materials used in the building; and transporting materials to the site. In many cases, older buildings contain large amounts of embodied energy, so it consumes less additional energy and is more environmentally friendly to upgrade or restore the older building than to demolish and rebuild, even if green materials are used in the new construction.

When a building is demolished, all of the non-renewable energy used to create the original building is lost and more must be used to rebuild. There are several reasons why remodeling older buildings for efficiency may be a better environmental choice than destruction. The demolition and removal of materials can take up huge amounts of landfill space. Reusing old materials prevents the destruction of more trees, saves the energy used to transport them to mills and create new construction materials, and keeps more green space from development. And, since the energy used to create the original structure has already created pollution, especially with materials such as concrete, which is responsible for large amounts of carbon dioxide during production, tearing down the old structure means that all of the pollution created in building the original structure will be followed by more pollution caused in the creation of a new building.

## LIGHTING

Energy experts estimate that up to one-quarter of a typical homeowner's energy bill is for artificial lighting. While climate-responsive building techniques can help lower energy use by situating homes and buildings in a way that takes more advantage of natural light, doing so may not be possible for existing buildings, which have to continue to rely on artificial lighting. Further, even the best positioning of a home to take advantage of the sun is of little use on a cloudy day or after the sun has set. Nonetheless, building occupants can take steps to conserve energy on lighting.

## Did Thomas Edison ''Invent'' the Lightbulb?

The short answer to this question is ''yes and no.'' In 1860 British physicist and electrician Joseph Wilson Swan (1828–1914) invented an incandescent bulb using a carbon paper filament, but the bulb did not work very well. He abandoned the pursuit for 15 years, but he returned to the problem in 1875. In 1878, a year before Edison, he demonstrated a working incandescent lightbulb with a carbonized thread as a filament. Edison receives all the credit for the invention of the incandescent lightbulb because he developed the first bulb that was commercially successful.

When it was pointed out to Edison that most of his experiments were failures, he famously commented that they were not failures but successes, for he had successfully discovered that the substances he tried did not work.

### Incandescent lightbulbs

Until Thomas Edison invented the incandescent lightbulb in 1879, artificial light was produced primarily by candles and oil lamps, which were not only inefficient but also produced a fire hazard. For years during the nineteenth century, inventors experimented with ways to produce artificial light by passing electricity through some sort of filament in a vacuum. These experiments, however, repeatedly failed because the filament quickly crumbled as a result of the intense heat that made them glow. After numerous experiments testing about a thousand materials, Edison finally came up with one that worked: a carbon-based filament. His earliest lightbulbs burned for an average of about 170 hours before the filament crumbled.

Today the typical incandescent bulb—a design that has not changed much since Edison's day—lasts about from 750 to 1,000 hours, although more expensive long-lasting bulbs can last 2,500 hours. The bulb consists of a thin, frosted-glass "envelope" that houses the filament, which today is made of the element tungsten, as well as an inert gas (argon). Inert gases are used to fill the bulb for two reasons. One, the bulb cannot contain any oxygen; if it did, the intense heat of the filament would set the bulb on fire. Two, because a gas like argon is "inert," meaning that it does not combine with other elements, tungsten atoms that evaporate from

### In the Limelight

The traditional lightbulb is not the only form of incandescence. Incandescent light can also be produced by a rod of lime (a highly flammable solid) surrounded by a flame fueled by oxygen and hydrogen. In the nineteenth century this type of light was the brightest form of artificial light known. Its primary use was to light stages in theaters. This is the origin of the expression ''in the limelight,'' or being in the public's attention.

the filament bounce off the argon and most are redeposited on the filament, making the bulb last longer. The filament in a 60-watt lightbulb is about 6.5 feet (2 meters) long, but only about one one-hundredth of an inch thick. It is wound into coils so that it can fit into the bulb. Electricity is applied to the filament, exciting the atoms and producing light. A bulb eventually burns out because the tungsten in the filament evaporates and some of it deposits on the glass. In time, the filament develops a weak spot where it breaks.

Incandescent lightbulbs have a number of advantages. They are inexpensive and easy to use, and the quality of the light they produce is good. (They are so inexpensive that before the energy crises of the 1970s, some electric companies provided lightbulbs to their customers free, usually exchanging new bulbs for burned-out ones.) They can also be used with dimmer switches. But a chief disadvantage is that they are not energy-efficient. After an incandescent lightbulb has been on for a brief period of time, it becomes hot to the touch. This is because the electricity heats the filament to 4,500°F (2,500°C). In other words, most of the electrical energy going into the bulb is converted into heat rather than light. In this respect, an incandescent lightbulb is little different from an electric space heater or a toaster. This production of heat is a double disadvantage in hot-weather climates, where buildings have to be air-conditioned, because a large number of incandescent lightbulbs add to a building's interior heat, placing greater demands on the air-conditioning system. Thus, electricity is being wasted twice.

A more recent innovation is the halogen lamp. The basic technology of a halogen lamp is similar to that of the incandescent bulb. A halogen bulb uses a tungsten filament, but it is encased in an envelope made of quartz rather than glass. Further, this envelope is positioned very close to the filament, but since it is made of quartz, it does not melt. The quartz envelope is filled with gases from the halogen group, consisting of fluorine, chlorine, bromine, iodine, and astatine. What is unique about these gases is that they combine with tungsten vapor. As the tungsten of the filament evaporates, its atoms combine with the gases and then are redeposited on the filament. Thus, halogen lightbulbs last much longer than incandescent lightbulbs. Combined with a parabolic reflector, they produce a high-intensity, crisp light, making them useful for such items as car headlights, most of which are now halogen. The chief disadvantage is that they are energy wasters, for they get even hotter than incandescent bulbs, creating up to four times as much heat. Halogen lamps can be a serious fire hazard in a home, especially if they are too close to draperies or other flammable materials.

### Fluorescent lightbulbs

Fluorescent lightbulbs were first invented in 1896. Today they are more commonly used in commercial buildings than homes, although many homeowners use fluorescent bulbs in basements, workshops, and laundry rooms. They tend to be less popular in the living areas of a home for three reasons. First, they often have a subtle flicker, which at best is an annoyance and at worst can cause headaches for some people. Second, the quality of the light they give off tends to be less “warm” than that emitted by incandescent bulbs, which give off more light from the red end of the light spectrum and less from the blue end, in contrast to fluorescent bulbs. For many people, fluorescent lighting has a kind of “sickly” look, although modern fluorescent light has largely overcome this problem. Third, they tend to be a bit noisy, emitting a low hum, although this disadvantage, too, has been overcome by recent technology. The chief advantage of fluorescent lighting is that it is much more energy-efficient than incandescent lighting. Further, fluorescent lightbulbs last 10-15 times longer than incandescent bulbs—often up to 10,000 hours or more.

To measure that efficiency, a distinction is made between *watts* and *lumens*. A watt is a measure of electrical usage equal to 1/746th of a horsepower, or one joule per second. (A joule is a unit of energy equal to the work done by a force of one newton acting through a distance of one meter; a newton is the amount of force needed to impart an acceleration of one meter per second per second to a mass of one kilogram.) Typically, the size of an electric lightbulb is measured in watts. Thus, found throughout a typical home are likely to be bulbs of different wattages, such as 40- or 60-watt bulbs where less light is needed and 75-, 100-, and 120-watt bulbs where more light is needed, especially for reading or similar activities.

Wattage, though, measures electrical usage. It is not a measure of the amount of light the bulb produces, although higher watt bulbs are likely to produce more light. Light output, on the other hand, is measured in lumens. Defining a lumen is much easier than defining a watt. One lumen is equal to the amount of light emitted by one candle. The 40-watt incandescent bulb made by one major manufacturer emits 475 lumens, the 60-watt bulb emits 830 lumens, and the 100-watt bulb emits 1,550 lumens.

Fluorescent bulbs produce the same number of lumens as incandescent bulbs with about one-fourth to one-sixth the amount of wattage—that is, electricity. Thus, fluorescent bulbs are far more energy-efficient than incandescent ones. They achieve this greater efficiency because they do not produce nearly as much waste heat, so per watt of electricity consumed, they produce more lumens.

Fluorescent lightbulbs are easily recognizable because rather than being shaped like bulbs, they are tubular. This sealed glass tube contains mercury and an inert gas (such as argon). The inside of the tube is coated with phosphor powder, a substance that emits light when its atoms are excited. At each end of the tube is an electrode that is wired to an electrical circuit. When the current is turned on, the voltage across the electrodes causes electrons to move from one end of the tube to the other. The energy converts the mercury from a liquid into a gas. The electrons collide with the mercury atoms, exciting them so that their electrons move to a higher energy level and higher orbit. As the electrons move back to their original orbits, they emit light.

The process, though, does not stop there. The light that is emitted is in the ultraviolet wavelength range, so it is not visible. This is where the phosphor powder coating goes to work. The photons created during the first step in the process collide with the phosphor atoms, again exciting them and causing their electrons to move to a higher energy level. Once again, when the electrons return to their normal energy level, they emit photons. These photons have less energy than the original photons; this is because some of the energy is released in the form of heat. But these lower energy photons now give off light that is visible, so-called white light that the human eye can detect. By using different combinations of phosphors, bulb manufacturers can alter the color of the light.

For many years, one of the problems with fluorescent bulbs was that it took them several seconds to light up. "Rapid start" lights have been developed to overcome this problem. In these lights a mechanism called the ballast maintains current through the electrodes. When the light is turned on, the electrode filaments heat up very quickly to ionize gas in the tube. Modern ballast mechanisms have also helped to reduce or eliminate both the flicker and noise that earlier ballasts created.

### Compact fluorescent bulbs

Traditional fluorescent bulbs are long, thin tubes rather than actual "bulbs," making them unsuitable for use in floor and table lamps and even in many wall and ceiling fixtures. For this reason, they have been used primarily in special ceiling fixtures in commercial buildings, as well as in certain areas of the home. Further, they cannot be used in regular lamps or fixtures because of the nature of the plug, which consists of pairs of pins at each end rather than the metal screw portion of an incandescent lightbulb.

In the 1980s these shortcomings were corrected with the development of the compact fluorescent lightbulb (CFB). This type of bulb works in exactly the same way that a traditional fluorescent bulb does, but rather than being packaged in a long tube, the tube is smaller and folded in such a way that the bulb resembles a traditional incandescent bulb. Further, rather than pins at each end, the bulb screws into the light fixture in exactly the same way incandescent bulbs do (although occasionally some of these bulbs require special fixtures because the screw portion is a different size).

What this means is that fluorescent lighting can now be used throughout a home or other building, with the potential for enormous energy savings. The California Energy Commission estimates that a single 20-watt compact fluorescent bulb used in place of a 75-watt incandescent bulb (remember that fluorescent bulbs produce more lumens per watt than incandescent bulbs do) will save 550 kilowatt-hours of electricity over its lifetime. It takes about 500 pounds (227 kilograms) of coal to produce this much electricity, and burning this amount of coal releases about 1,300 pounds (590 kilograms) of carbon dioxide and 20 pounds of sulfur dioxide into the atmosphere. That is just one bulb. It has been estimated that if every American used CFBs, the nation could save 31.7 billion kilowatt-hours of electricity each year. A typical coal-fired power plant produces about 500 megawatts, or about 3.5 billion kilowatt-hours, of electricity per year. To generate this electricity,

Typically the amount of energy used by individual homes is measured by a meter attached to the outside of the house. *© 2005 Kelly A. Quin.*

it has to burn about 1.43 million tons of coal, releasing 10,000 tons of sulfur dioxide and about 3.7 million tons of carbon dioxide. Converting all home lighting to CFBs would in effect eliminate the need for roughly nine of these power plants.

CFBs have one disadvantage. While a typical incandescent bulb costs about $0.75, CFBs average about $11. The tradeoffs, though, are significant energy savings over the life of the bulb, combined with the fact that the bulb is likely to last up to ten times longer.

## ENERGY EFFICIENCY AND CONSERVATION IN THE HOME

Climate responsiveness and the use of green building materials are options for new home construction. Most people, however, do not have this option because their homes were constructed years ago before these innovations were widely used. Nonetheless, homeowners can take many steps to lower their energy bill by saving energy. Some of these steps involve changes they can make to the home itself to conserve energy; others involve steps they can take to reduce personal energy use or use energy more efficiently.

### Energy conservation

Experts recommend the following as ways to conserve energy in the home—many of these same steps can be taken in commercial buildings as well.

1. Phantom loads. Many electronic devices use electricity even when they are turned off. Such items as videocassette recorders, televisions, microwave ovens, and computers, as well as business machines such as copiers and faxes, all consume energy when they are not in use. A simple way to lower energy use with these devices is to plug them into a power strip, which can be turned off when the device is not being used. Another way is to unplug wall transformers (such as those used to charge a battery in a power tool or a cell phone) when they are not needed. A wall transformer, even if a tool or appliance is not plugged in, still operates and is warm to the touch. This warmth represents wasted energy.
2. Hot water. A major component of a family's energy bill is for hot water—typically about one-seventh of a home's energy bill. Hot water tanks, especially older ones, can be insulated with kits available at hardware stores. Point-of-use hot water heaters, which operate only when the hot water tap is turned on, reduce the need for a standing tank of hot water that is not being used. Most manufacturers preset the temperature on hot water heaters at 140°F (60°C), but 120°F (49°C) is sufficient for most households (and reduces the risk of scalding by water that is too hot). Lowering the thermostat temperature on a hot water heater by 10 degrees can save 3-5 percent on hot water costs. Moreover, low-flow shower heads—those that flow at a rate of 2.5 gallons (9 liters) per minute or less rather than the 4-5 gallons (15-19 liters) per minute of older shower heads—reduce the consumption of hot water, saving energy. One commonsense way to reduce hot water consumption is not to let the shower run for long periods of time while preparing to get in.
3. Heating and cooling. Thermostats can be turned down at night and when the family is away for the day. A programmable thermostat can be set to turn the heat down at night or during times when no one is at home, then warm the house up just before the family gets up in the morning or just before they are scheduled to return home at the end of the

day. Also, the style of indoor dress can be changed slightly so that indoor temperatures can be set lower in winter and higher in summer. In the summer, fans may be used to compensate for decreasing the use of air conditioning. Weather stripping can reduce heat loss around leaky doors and windows. Insulated curtains can help reduce heat loss through windows at night. Double-paned thermal windows allow the warmth of the sun to enter the home when the sun is low in the winter sky but block the sun's heat when the sun is high in the summer sky, reducing the need for air conditioning. Rooms that are not being used can be closed off and the heating in the room turned off (or the hot air duct closed). Changing filters on furnaces and having the furnace serviced each year can reduce energy consumption.

4. Insulation. Because heat rises, most heating energy is lost through a home's roof. An investment in a few hundred dollars' worth of insulation can reduce home heating (and cooling) bills by as much as 30 percent. Insulation can be installed in ceilings. Contractors can even insulate existing exterior walls by blowing insulation through small holes drilled between wall supports.
5. Landscaping. Well-placed landscaping can reduce heating and cooling bills. Deciduous trees (those with leaves) can be placed so that they block the sun, especially on the south side of a house, during the summer. The trees then lose their leaves in winter, allowing sunlight through to warm the house. Windbreaks, consisting of a row of trees or bushes, especially on the north side of a house in most areas, can block winter winds, lowering heating bills. According to Colorado State University researchers, windbreaks in some areas can reduce heating bills by as much as 25 percent.

### Energy efficiency

One major way to conserve energy is to use energy more efficiently. Using compact fluorescent lightbulbs, double-paned thermal windows, and insulation conserves energy by enabling homeowners to heat, cool, and light their homes more efficiently. But another way to conserve energy is to use appliances that consume less energy.

Beginning in the 1980s the United States Congress passed several laws mandating minimum energy efficiency for appliances such as refrigerators, freezers, washers, dryers, ovens, water heat-


Energy efficient fluorescent light bulb with EPA Energy Star. © *Peter ZiminskiVisuals Unlimited. Reproduced by permission.*

ers, and pool heaters. Smaller manufacturers make many of the most efficient appliances, which tend to be more expensive. But even the major manufacturers have models that are far more energy efficient than appliances used to be. Here are some guidelines that promote energy efficiency in appliances:

- Refrigerators: Models with the freezer on top are generally more efficient than side-by-side models and those with the freezer on the bottom. Refrigerators that have to be defrosted by hand use about one-half the energy of automatic-defrost models. The most efficient refrigerators tend to be in the

16- to 20-cubic-foot range. Generally, though, it is more efficient to run one large refrigerator than two smaller ones.

- Washing machines: Many homeowners overuse the hot wash cycle. The warm and cold settings are adequate for most laundry. Energy-efficient washers automatically control the water level for the size of the load. Also, the spin cycle, in which the machine spins quickly to eliminate as much water from the clothes as possible, is faster in energy-efficient washers. Thus, more water is expelled from the clothes, and they do not have to spend as much time in the dryer. Horizontal axis machines—that is, front loaders—use far less water and soap and are much more efficient than vertical axis machines, or top loaders. The cost of running a front loader is about one-third that of running a top loader. One major manufacturer makes a washing machine that communicates with the dryer and presets it to deliver the most efficient results.
- Clothes dryers: The most energy-efficient clothes dryer is the sun and a line to hang the laundry on. In rainy or cold weather, racks for drying laundry can be used indoors, and the humidity the drying clothes add to indoor air is an added plus.
- Dishwashers: One way to boost the energy efficiency of dishwashers is, of course, not to use them as often and only for full loads. Many dishwashers have a "no-dry" cycle that saves energy; the dishes air-dry instead of being dried by heat produced by the dishwasher itself. Also, many dishwashers have water heaters so that only the water going to the dishwasher is being heated.

The guidelines for energy efficiency focus on conventional appliances, like those that can be purchased at such places as department stores. For consumers who want to achieve even greater savings on their energy bills, specialty products are available. Examples include solar-powered hot water heaters (especially heaters for smaller quantities of water, enough, for example, for one person to take a shower); solar cookers that focus the sun's rays to produce enough heat for cooking purposes or straw ovens that store the heat in the heated food to cook it; washing machines that require no electricity, relying instead on soaking and using a hand crank to wring out water; and point-of-use water heaters that activate when the hot water tap is turned on and heat just the water that is being used rather than a tank of standing water.

Solar cookers use alternative technology to generate heat from the sun. *Joyce Photographics/Photo Researchers, Inc.*

One conventional appliance that has potential for significant energy savings is the refrigerator, which on average uses about nine percent of the energy consumed in homes. Standard refrigerators and freezers use about 3,000 watt-hours per day, although it is possible to find commercial models that use just 1,500 watt-hours per day. Some manufacturers, however, build superinsulated refrig-erators that use only about 750 watt-hours per day, depending on

### Energy Star Ratings

Energy experts urge consumers to look for the Energy Star label when they shop for appliances. The label appears on appliances such as refrigerators, washing machines, dishwashers, water heaters and heat pumps, and even on windows. The label indicates that the energy efficiency of the appliance exceeds that required by federal regulations. Appliances that earn the Energy Star label are at least 13 percent more efficient than normal machines, but many are 15, 20, and even 110 percent more efficient. For example, Energy Star washing machines use 50 percent less electricity than those that do not have the Energy Star label.

the size and model. Smaller superinsulated refrigerators use only 200 watt-hours per day. These types of refrigerators are ideal for people who run their homes primarily on solar power. Fewer solar panels have to be added to the home to power the refrigerator.

## TRANSPORTATION

Energy savings in the home and in commercial buildings makes a vital difference in the total amount of energy consumed. Still, the energy used to power cars and trucks represents a major portion of energy expended. Just in the United States, drivers consume about 360 million gallons of gasoline each day, or about 131 billion gallons of gasoline each year. If one gallon of gas, when burned, releases about 5-6 pounds (roughly 2.5 kilograms) of carbon dioxide into the atmosphere, then U.S. drivers are releasing about 2 billion pounds of carbon dioxide into the atmosphere each day. While U.S. drivers consume about 45 percent of the world's gasoline, they are not responsible for the entire problem with vehicle gasoline consumption. As of 2005, for example, the number of private cars in Beijing, the capital of the People's Republic of China, was 1.3 million, up 140 percent just since 1997. In 2005 China consumed about 252 million gallons of gasoline per day, but that figure was predicted to double to 504 million a day by 2025. Meanwhile, according to the World Bank, sixteen of the twenty most polluted cities in the world are in China, and vehicles cause most of that pollution.

Before the energy shortages of the 1970s, Americans tended not to care very much about what kind of gas mileage their cars got.

Large, "gas-guzzling" cars were the norm, and gasoline was relatively inexpensive, so little attention was paid to gas mileage. In the 1960s it was not uncommon for a family car to get as little as 10 miles (16 kilometers) per gallon or even less. Beginning in the 1970s, though, efforts were made to improve the gas mileage of cars by making them smaller and lighter and by introducing technical innovations that enabled them to burn gas more efficiently. While cars became more efficient in the following years, Americans also developed a taste for larger, heavier vehicles such as sport utility vehicles (SUVs). Thus, by the year 2000 many Americans were driving vehicles that got the same gas mileage as those that they drove 25 years earlier.

## HYBRID VEHICLES

The early 2000s saw the introduction of so-called hybrid vehicles. A "hybrid" of any sort is a combination of two or more features that produces a benefit. In the case of vehicles, a hybrid combines two technologies for using energy in a way that reduces energy consumption. While conceivably any two technologies might be used in hybrid vehicles, the most common is to combine a conventional internal combustion engine with an electric motor and batteries that power the car with electricity. In the future, hybrids are likely to make use of other technologies, including hydrogen fuel cells and possibly even steam power.

Hybrid vehicles are not entirely a new concept. The moped, a motorized pedal bike, is a hybrid vehicle that combines a gasoline motor with pedal power. Locomotives are diesel fuel–electric hybrids, as are many giant trucks used for mining. Submarines, too, are hybrid vehicles using diesel-electric and in many cases nuclear-electric combinations. In 1899 German automaker, Ferdinand Porsche (1875–1952), engineered a hybrid car. The current generation of hybrid vehicles uses a combination of gasoline and electricity for power, as did Porsche's car.

The hybrid design overcomes the chief disadvantages of all-electric cars. Cars powered entirely by electricity have to be plugged in to a power source when they are not in use. These cars have limited range—generally about 100 miles or so—before the electrical power stored in the car's batteries is depleted. Moreover, the process of "refueling" is time-consuming and inconvenient. In a hybrid car the gasoline-powered engine and the batteries work with one another. Typically, an electrical motor, powered by batteries, powers the car's engine. The internal combustion engine


A multi-information display provides the driver with feedback regarding the vehicle's use of energy in the Toyota Prius. Yellow arrows indicate when the battery is in use. *Leonard Lessin/Photo Researchers, Inc.*

provides a power boost when necessary, especially when the car is accelerating. The gas-powered engine keeps the batteries charged, so the car does not have to be plugged in. On some models, when the car is idling, the internal combustion engine does not operate, so no gas is being consumed. This feature makes hybrid cars very quiet when the car is stopped at an intersection.

**The components of a hybrid vehicle**

A typical hybrid vehicle consists of the following components:

- Gasoline engine: A hybrid has a gasoline-powered engine similar to that found on a standard vehicle. This engine, however, is small and more fuel-efficient than the engine on a normal vehicle, boosting gas mileage and lowering emissions.
- Fuel tank: The hybrid has a tank for storing gasoline.
- Electric motor: Hybrid vehicles use sophisticated motors to provide some portion of the power the vehicle needs and to recharge the batteries.

- Generator: In some hybrids the motor acts both as a motor and as a power generator. In others a separate generator produces electrical power.
- Batteries: A battery pack stores energy produced by the motor and braking system. One major problem with electric vehicles is that gasoline is much more energy dense than batteries. That is, one gallon of gasoline contains as much energy as 1,000 pounds (454 kilograms) of batteries. The advantage of hybrids over all-electric vehicles is that the battery pack does not need to be as large because the motor is continually recharging the batteries.
- Transmission: The transmission of a hybrid is similar to that on a standard car, although some manufacturers have introduced more sophisticated transmissions that can be powered both by the electric motor and by the gas-powered engine.

### Advantages of hybrid vehicles

Hybrid vehicles have at least two advantages. First, a hybrid's internal combustion engine is generally much smaller and more fuel-efficient than the engine of a standard car. This is because the engine does not do all the work. It is assisted by the batteries that supply power to the car's drive train. Generally, the internal combustion engines of standard cars are much larger than they need to be. A standard car might be capable of 200 horsepower or more, but a car generally needs only about 20 horsepower to overcome drag as the car pushes its way through air, to compensate for the friction produced by the tires and transmission, and to power such accessories as the power steering and air-conditioning. All the extra power is used primarily for sudden acceleration or to climb an uphill grade, but that extra capability is used only about one percent of the time the car is on the road. Therefore, in contrast to big, high-horsepower engines, hybrids use smaller, lightweight engines. One model's engine weighs only 124 pounds (56 kilograms), has only three cylinders (as opposed to the six or eight cylinders on many larger vehicles), and produces just 67 horsepower. By using small engines and designing them so that they operate at close to their maximum load, hybrid vehicles cut down on gas consumption.

A second advantage is that hybrid vehicles make use of what is called a regenerative braking system. Such a system is based on the laws of thermodynamics, which say that energy cannot be created or destroyed but can only change form. When a car is moving

The 2005 gas/electric Toyota Prius with Hybrid Synergy Drive offers better fuel efficiency than typical automobile engines. © *Ted Soqui/Corbis.*

down the road, it burns gasoline, releasing energy that is converted into the mechanical energy of the car's drive train. Some of the energy is lost to friction where the tires meet the surface of the road, as well as in the transmission. But much of a car's energy is lost when the brakes are applied, converting the kinetic energy of the moving car into friction, which is released in the form of heat in the car's brakes. (This explains why cars periodically need a brake job to replace the brake pads, which have been worn down by heat.) A hybrid vehicle recaptures some of this otherwise lost energy and sends it off into the car's batteries, where it is recycled to power the car. The end result is vehicles that generally get much higher gas mileage—up to 60-plus miles (97 kilometers) per gallon for some models—and that release one-tenth the amount of pollution into the atmosphere compared to standard vehicles.

Hybrid manufacturers incorporate other ways to increase the fuel efficiency of their vehicles. They recover energy and store it in the battery and allow the gasoline-powered engine to shut down when the car is idling. In addition, they use advanced aerodynamics to reduce drag. The chief way this is accomplished is by

### Drag Coefficient

Engineers use the term *drag coefficient* to refer to measurements they make of the amount of drag a vehicle generates as it pushes air out of the way while it is in motion. Engineers can calculate the drag coefficient of various shapes under normal conditions. Thus, the drag coefficient of a sphere is 0.47; of a cube, 1.05; of a long cylinder, 0.82; of a short cylinder, 1.15. The most aerodynamic shape—that is, the one with the lowest drag coefficient—is the streamlined ‘‘teardrop’’ shape with the pointed end at the front, at 0.04. Energy-efficient vehicles cannot use a pure teardrop shape, but they can use something that approaches it by reducing the front area of the vehicle.

reducing the front area of the vehicle so that the volume of air the car has to push through is reduced.

Automakers have even found ways to reduce the drag caused by objects such as mirrors that stick out from the vehicle. Some have replaced side mirrors with small cameras. Others partially cover the rear wheels to reduce drag and also enclose parts of the undercarriage (the underside of the car) with plastic panels. The result is a very low drag coefficient, sometimes as low as 0.25. Hybrid makers often install low-rolling resistance tires. These tires are stiffer and inflated to a higher pressure than standard tires, two aspects that reduce drag by as much as half. Finally, hybrid manufacturers make use of lightweight materials, such as aluminum, so the vehicle needs less energy to accelerate.

Hybrid vehicles have other advantages. In 2003, 2004, and 2005, buyers of hybrid vehicles were entitled to a $2,000 federal income tax “clean fuel” deduction, the government’s way of promoting interest in hybrid vehicles. As of 2005 that deduction was scheduled to be reduced and then phased out. Supporters of hybrids, naturally, were working to get legislation passed to extend the deduction.

As of 2005 at least fifteen states gave tax credits to hybrid vehicle buyers, and thirteen other states were considering doing so. Oregon offered a state tax credit of up to $1,500; Connecticut waived the 6 percent sales tax on the car, and Colorado offered a tax credit of up to $4,713. Hybrids can also go on some toll roads free. In some cities, such as San Jose and Los Angeles, California, hybrid car owners do not have to feed parking meters in city lots or on the streets. Some states allow hybrid cars with just the driver and no passengers to use car-pooling lanes. And some states release hybrids from emissions inspections. In London, England, hybrid vehicle owners pay the lowest amount of tax on their cars and do not have to pay a "congestion charge," a tax levied on all other vehicles in the city.

### Types of hybrid vehicles

Hybrid vehicles come in two basic types: series and parallel. In a series hybrid, the first generation of modern hybrids, the gasoline-powered engine never powers the car directly. Rather, the gasoline engine turns a generator, which powers an electric motor that in turn powers the drive train, or it recharges the batteries. In a parallel hybrid, the second generation of modern hybrids, the gasoline-powered engine and the batteries power the car at the same time. In these cars, both the gasoline-powered engine and the electric motor are attached, independently, to the car's drive train. A third generation of hybrids is being developed. These vehicles use a differential-type linkage and a computer to allow the vehicle to be powered by the internal combustion engine, the electric motor, or both. The computer shuts off the gas engine when the electric motor is providing enough energy.

Other terms are frequently used to describe various sorts of hybrids. Sometimes the terms *strong hybrid* or *full hybrid* refer to the third-generation vehicles that can be powered by the gas engine, the electric motor, or both. The term *assist hybrid* refers to vehicles in which the battery and electric motor are used to accelerate the vehicle in combination with the gas engine. *Plug-in hybrids,* sometimes called *gas-optional* or *griddable,* have larger batteries and are able to run entirely on electricity from the electric motor and batteries. These vehicles can be recharged by plugging them into the power grid. The vehicle can rely on this electricity for short hops and daily commuting, but it also has a gas-powered engine for use during longer trips. *Mild hybrids* are often sold as hybrids, but they are not true hybrids because the electric motor never powers the vehicle. They are able to achieve greater fuel efficiency, however, because a starter motor spins the engine to the number of revolutions per minute it needs to operate before fuel is injected. These vehicles also use "regenerative" braking, and their engines do not run when the vehicle is coasting, braking, or idling.

### The future of hybrid vehicles

As of 2005 only about one percent of new cars purchased were hybrids. In 2004, however, the number of hybrid registrations was up 81 percent from the year before, to just over 83,000. Many car industry observers believe that momentum is building in the hybrid industry and that consumer demand is growing enough to encourage manufacturers to design and build them. In the early 2000s the three hybrid cars available in the United States were the Honda Civic Hybrid, the Honda Insight, and the Toyota Prius. In designing its cars Honda aimed for the highest gas mileage possible, and its cars can get up to 68 miles (109 kilometers) per gallon. Toyota, on the other hand, aimed primarily for pollution reduction. The gas mileage of the Prius is in the mid- to high 40s.

Other car manufacturers made plans to release hybrid models. Scheduled for release in 2005 were hybrid vehicles from DaimlerChrysler (Dodge and Mercedes), Ford, and General Motors (Chevy, GMC-Sierra, and Saturn). In the early 2000s many conservationists were growing concerned about the large and growing number of SUVs, which are classified as trucks and therefore are not required to get gas mileage as high as that of cars. Accordingly, some manufacturers are designing hybrid trucks and SUVs. In 2005 Toyota and Lexus were both planning to release hybrid SUVs, and Chevy scheduled offerings of two models of hybrid pickup trucks. Industry observers believe that the number of hybrids sold in 2005 could equal the total number sold in the four preceding years combined.

Some experts question the value of hybrid cars, at least from a strictly economic standpoint. While they support efforts to reduce pollution, they point out that, as of 2005, the higher price of hybrids offsets much of the energy savings. The magazine *Consumer Reports* calculated that it would take about 21 years of energy savings to offset the higher price of one popular hybrid model without the tax deduction. With the tax deduction, it would still take about four years for the buyer to break even. These estimates, however, assume that gas prices will remain consistent. In 2005, and early 2006, gas prices rose dramatically, thus making the payback period for hybrids shorter. For the near term, industry experts are also concerned about the resale value of hybrids, given that improvements are continually being made in the technology. Further, auto industry experts note that it is possible to achieve nearly similar energy savings with standard cars, some of which cost much less. Driving a stick shift vehicle as opposed to one with an automatic transmission can achieve gas savings of up to 18 percent.

### *Tips for more fuel-efficient driving*

Though hybrid vehicles offer promise for reducing the U.S. reliance on fossils fuels, they are not the only solution. There are many other ways in which people can immediately reduce the amount of fossil fuels used by making personal choices to limit their own use of traditional automobiles. Drivers can also take a number of steps to increase the fuel efficiency of their existing vehicles or to use less fuel, whether the vehicle is a hybrid or not:

1. Use your legs. People can bicycle or even walk to many of their destinations, a solution that is better for both for the environment and an individual's health in general.
2. Utilize public transportation when possible. Public transportation is an option in many larger cities, though the structure of many U.S. cities (or their urban sprawl) needs to be addressed in others. One city bus can keep 40 or so vehicles off the road and save over 21,000 gallons (79,493 liters) of gasoline each year.
3. Car-pool. Car-pooling not only saves fuel by taking vehicles off the road, but it also reduces traffic congestion. Many cities encourage car-pooling with special lanes set aside for cars with two or more passengers.
4. Plan efficient trips. For long-distance trips, drivers can save fuel by taking the most efficient route, which may not necessarily be the shortest route. Taking a bypass around a city might add miles, but it eliminates the stop-and-go driving of cities and suburbs that uses more gasoline.
5. Avoid short trips when possible. A vehicle reaches its peak operating efficiency only after it has warmed up for a few miles. Short hops of under a few miles use more fuel per mile than longer trips. Drivers can save fuel by combining errands in the same trip. In winter, combining errands can also reduce the number of cold starts the car has to make.
6. Reduce quick accelerations and stop-and-go driving. Cars consume the most fuel when they are accelerating. Fast accelerations waste fuel, and racing up to stoplights or stop signs, applying the brakes, then racing on to the next stop is especially wasteful. By anticipating stops, coasting, then gently accelerating, drivers can save fuel. One test showed

that "jackrabbit" driving, or driving with quick starts and hard braking, saves only 4 percent of a driver's time (two-and-a-half minutes for a one-hour trip) but consumes 39 percent more fuel.

7. Slow down. Driving at 55 mph (89 kph) can produce gas mileage gains of 15 percent compared to driving 65 mph (105 kph).
8. Reduce idling. Most drivers tend to let their car idle when it is stopped. Many believe that it takes more gas to restart the car than is consumed by idling. Tests, however, show that this is not true if the idle time is more than about 10 seconds. Turning the car off when a long delay is anticipated (for instance, at a railroad crossing, when waiting to pick someone up, or when waiting in line at drive-through windows) can save significant amounts of fuel. Idling a car for long periods of time in order to warm it up in cold weather wastes fuel. The best way to warm a car up is by driving it—again, avoiding quick acceleration, especially when the car is cold.
9. Use engine-block heaters in cold weather climates. For a short trip a car can use up to 50 percent more fuel in cold weather than in warm weather. Plug-in engine-block heaters allow a car's engine to reach peak operating efficiency in cold weather much faster, saving fuel.
10. Reduce weight. Two ways to reduce weight are to clear snow and ice off the car, including ice that builds up in the wheel wells, and not to carry around excess items in the trunk or in the bed of a truck. Removing items such as ski racks and bicycle racks when they are not being used can increase fuel efficiency by reducing both weight and aerodynamic drag. Airlines discovered that they could save thousands of dollars per year in fuel costs solely by switching from glass to lighter plastic bottles for beverages on jumbo jets.
11. Keep tires inflated. A tire that is underinflated by just two pounds per square inch can increase fuel consumption by one percent. Tire pressure drops in cold weather, so it is especially important to check the tires' pressure in winter.
12. Service the vehicle. Such things as fouled spark plugs and dirty air filters can reduce fuel efficiency. A periodic wheel alignment can increase gas mileage by up to ten percent.

13. Use tires appropriate for conditions. Most city and suburban drivers do not need snow tires, which are softer and increase fuel consumption. For these drivers all-season radial tires are sufficient. On the other hand, drivers in rural areas, where roads can often be snow-packed, might achieve greater fuel efficiency with snow tires because they can reduce slippage.
14. Shift up. With manual transmissions shifting into a higher gear as soon as possible saves fuel. Manual-transmission vehicles get up to 18 percent better gas mileage than automatic-transmission vehicles.
15. Turn off the air-conditioner. Minimizing the use of air-conditioning, which is powered by the vehicle's engine, increases fuel efficiency, especially at lower speeds, when the amount of aerodynamic drag is not significantly increased by opening the vehicle's windows.

## LEAVING AN ENERGY FOOTPRINT ON THE EARTH

Though innovation and creativity in creating energy efficient buildings, cars, and appliances and using renewable energy sources will begin to reduce the use of fossil fuels in the future, the choices that people make today, in their everyday lives, can also make a major difference. Every person on the planet leaves a "footprint" on the Earth, a demand on nature that includes the energy taken to support a person's consumption habits, whether they are choosing food, housing, utilities, transportation,or other goods and services (like clothing, recreation, and cleaning products). For the Earth to support a growing population, there must be a balance between increasing human needs and wants and nature's ability to sustain all of the energy requirements placed on the planet's resources.

There are daily actions beyond those mentioned above that everyone can take to reduce the overall energy footprint on the Earth and to help stay within the planet's capacity for regenerating energy, food, and materials, including:

1. Limiting excess consumption. People can make choices not to buy items they do not need, to purchase recycled or secondhand items, or, if a new product is necessary, to purchase non-disposable items that require little or no packaging. Energy is used to make any product; thus, the fewer products people buy, the less energy is used. Many times, a secondhand item, especially a durable good such as a piece of furniture, is just as good as purchasing a new

A technician holding a handful of shredded waste plastic at a recycling facility. These shredded fragments will be heated to over 750°F (400°C) in a fluidized bed of sand. This breaks down the plastic into its basic hydrocarbon constituents, which are given off as gases. These are filtered and cooled to produce a very pure, waxy substance which can be used by oil refineries and the petrochemical industry. *J. King-Holmes/Photo Researchers, Inc.*

item, and will be cheaper for the consumer as well. The excess packaging of items affects energy consumption in several ways, including in the production of the packaging itself and the fuel necessary to power the dump trucks that must take the additional garbage to the landfill. Rather than buying a product that is contained in both a box and a plastic bag, people can choose items that have less packaging or are not packaged at all.

2. Recycling. Many items that go into landfills can be recycled into products to save energy. Waste paper can be made into insulation. Plastic can be turned into a host of products, such as durable carpeting for use in cars. In the United States, about 250 million automotive tires are scrapped each year. In 1989 only about 10 percent of those tires were recycled, but by the 2000s, that percentage had increased to 80 percent. The tires are commonly shredded to provide fill in building

Bales of HDPE (high density polyethylene) plastic is inspected at a recycling plant. HDPE is used in a variety of rigid packaging for food and beverages. It is sorted and compressed into these bales before being cleaned and shredded. It is then shipped in chipped form to manufacturing plants for re-use. *Hank Morgan/Photo Researchers, Inc.*

projects, mulch for gardens and under playground equipment, and as an ingredient in road asphalt. Soda pop bottles can be recycled to make the synthetic fleece common in winter jackets. Aluminum cans are 100 percent recyclable. In 2003, 54 billion aluminum cans were recycled, saving an amount of energy in aluminum manufacture equal to about 15 million barrels of crude oil.

3. Lighting. Artificial lighting is a major consumer of electricity. Energy can be saved by turning off lights that are not in use, relying on natural lighting during the day, and attaching motion sensors to outdoor lighting so that the lights come on only when they are needed for outdoor activity. The use of compact fluorescent lightbulbs throughout a home can cut energy usage for lighting by about three-fourths.
4. Food choices. Eating a diet with fewer animal-based and more plant-based products generally requires less energy, land, and other resources. Planting a garden or choosing

locally grown goods rather than buying items that must be transported cuts down on energy and pollution from shipping, packaging, fertilizers, and pesticides. Buying items that are not processed saves energy used in the canning, freezing, or packing industries.

Even if it seems that the actions you take are small and will not affect the planet, your contributions over your lifetime can make a difference. You can also ask your parents, other family members, and friends to take some of the steps listed above, and work together to encourage changes in energy efficiency and conservation.

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# Possible Future Energy Sources

The word "energy" fills the pages of this book, and many forms of energy are described in previous chapters. Energy is, however, really a very tricky and difficult term to define exactly, even for students who have studied physics and engineering for many years. While it is very useful to think of energy as something that can flow like a river from one thing to another, or be stored in a battery, energy really isn't a "thing" at all. Energy does not exist by the gallon or liter, but a gallon or liter of gasoline has a certain amount of energy, an ability to flow through the process of combustion inside a properly designed engine, to turn gears and wheels that move a car.

Scientists and engineers usually describe or define energy as an object's ability to do work, to move things, make things hotter, and so forth. For example, the sun does not transfer a substance called energy to Earth. The nuclear reactions in the sun produce light that travels through space and that increase the energy level of objects the light strikes on Earth. For example, the light strikes objects and the light's own energy or ability to do work then changes molecules in the object that allow them to undergo chemical reactions or make them move and thereby cause the object's temperature to rise. As students advance in their studies their understanding of energy will change.

When thinking about the possible sources of energy to be used in the future, however, it is important to keep in mind that because energy is not a thing itself, but rather something that everything *has*, we can look for potential sources of useable energy. The world

## Words to Know

**Cold fusion** Nuclear fusion that occurs without high heat; also referred to as low energy nuclear reactions.

**Electromagnetism** Magnetism developed by a current of electricity.

**Fusion** The process by which the nuclei of light atoms join, releasing energy.

**Heisenberg uncertainty principle** The principle that it is impossible to know simultaneously both the location and momentum of a subatomic particle.

**Magnetic levitation** The process of using the attractive and repulsive forces of magnetism to move objects such as trains.

**Perpetual motion** The power of a machine to run indefinitely without any energy input.

**Superconductivity** The disappearance of electrical resistance in a substance such as some metals at very low temperatures.

**Thermodynamics** The branch of physics that deals with the mechanical actions or relations of heat.

**Tokamak** An acronym for the Russian-built toroidal magnetic chamber, a device for containing a fusion reaction.

**Zero point energy** The energy contained in electromagnetic fluctuations that remains in a vacuum, even when the temperature has been reduced to very low levels.

will eventually run out of substances such as oil that can be found and used at a reasonable cost, but the Earth will never run out of energy. The challenge for future generations is the ability to harness and use new sources of energy to do work.

### IS ALTERNATIVE ENERGY ENOUGH?

Overuse of fossil fuels such as coal, natural gas, and petroleum as a source of energy can cause pollution, mining damage, and contribute to climate change. They are increasingly limited resources that because they are valuable, can even become a cause of war. Regardless of attempts to make cars, machines, and devices that use fossil fuels more efficiently, fossil fuels will someday be very scarce and hard to find. The world needs other energy sources that are clean, renewable, and affordable.

Most sources of "alternative" energy—which usually means energy from any source other than fossil fuels and nuclear fission—depend on obvious, natural sources of energy. The sun bathes Earth with light, which can either be turned into electricity or used directly for light or heat. The wind and rivers are loaded with kinetic energy (the energy of matter in motion). Tides raise and lower the sea, and hold a potentially useable source of energy.

There is nothing new about these energy sources. People have always used the sun to light spaces, dry food and clothing, and heat buildings. Water wheels and windmills have done useful work for centuries. The challenge for modern scientists and engineers, however, is to find effective ways of harnessing these power sources (and others) on a scale large enough and a cost low enough to meet the needs of the more than six billion people already living on Earth, a number that is expected to increase.

Many alternative or renewable energy sources, especially hydroelectric power, wind, and solar power, are already providing important amounts of energy or are capable of providing significant amounts of energy in the near future. These energy sources have many advantages over fossil fuels, but they also have limitations. One problem with some of them is that to provide truly large amounts of energy, they require huge, expensive facilities. Hydroelectric power needs massive dams that drown land, displace towns and villages, and threaten wildlife habitats (the living environment). Tidal or wave power needs dams across tidal basins and machines for gathering wave energy, all of which would not only be expensive but might spoil wild shorelines and disturb sea life. Solar cells to turn sunlight into electricity are getting steadily less expensive, but a solar power plant big enough to make as much energy as a coal or nuclear plant would cover a large area of land. Today, large windmills can make electricity more cheaply than either coal-burning plants or nuclear power plants, yet wind farms consist of large numbers of towering windmills—often twice the height of the Statue of Liberty—that change landscapes and can kill birds with their whirling blades. In addition, people often need more electricity than can be produced or stored while the sun is shining or when the wind is blowing.

Nuclear power plants produce steady-flowing energy, but not all experts agree that building many new nuclear power plants would be an affordable way to meet the world's energy needs. Quite apart from possible problems like radioactive waste, potential terrorist attacks on reactors, or reactor accidents, nuclear power has always been—and, according to some experts, still is—more expensive than other energy sources. Contrary to popular belief, for example, orders for nuclear plants practically stopped in the United States *before* the near-disaster at the Three Mile Island nuclear power plant in Pennsylvania in 1979. Nuclear plants were simply too expensive. And they have remained so. Since 1973, orders for new nuclear power plants in the United States have consistently been cancelled. The last non-military nuclear reactor to start operations in the United States was at the Watts Bar nuclear power plant in Tennessee in the late 1990s.

But nuclear power is not the only energy source with problems. Large, centralized renewable-energy projects must be placed in specific geographic locations and may damage the environment. A hydroelectric dam needs to be built on a river, for example, and many rivers have already been dammed in some way. A wave-power or tide-power generating station would have to be built on a specific type of ocean shoreline. Windmills need strong, reliable winds, which are not found everywhere. Solar power does best with steady sunshine, as in deserts and the tropics. Only in certain places is geothermal heat is close enough to the Earth's surface to be useful. There is really not one electrical energy problem but two: the problem of generating electricity and the problem of transporting electrical power.

So, while the energy of the wind, sun, oceans, and atoms is inexhaustible, our ability to capture it is limited by geography, money, safety, and other considerations. In fact, experts argue that these sources of power will never be able to safely, cleanly, and affordably supply the world with all the energy it needs. Furthermore, all the sources of energy mentioned so far in this chapter are sources of *electricity*, but not all our energy needs can be met by electricity. Heating buildings with electricity is very expensive, and electric cars and trucks that can compete with the power and speed of fossil-fuel-powered vehicles do not yet exist. Electricity, whether it comes from windmills or nuclear power, cannot help us to break our addiction to the liquid fossil fuel known as "oil,"—petroleum, from which gasoline and other fuels are made.

However, defenders of new energy sources have at least possible answers to many problems and objections. Just as advocates of nuclear power argue that with new reactor designs, nuclear power can be made safer and cheaper, supporters of windmills and solar power argue that new designs will eliminate limitations of these technologies. For example, large windmills might coexist with ranching on the wide-open landscapes of the American Midwest or be located far out to sea, while smaller, more efficient, vertical-axis windmills (which resemble upside-down eggbeaters and do not harm as many birds as other designs) can be placed on rooftops. Solar panels can also be placed on rooftops, producing power where it is needed without using more land. And by using electricity from windmills or solar panels to break water ($H_2O$) into

The world's most technically advanced solar power facility, Solar Two, focuses the sun's rays on a tower containing liquid salt, which is pumped into an insulated tank so that stored heat can drive turbines and provide electric power 24 hours a day. *© George Steinmetz/Corbis.*

hydrogen and oxygen and then using the hydrogen in fuel cells (a type of chemical battery) to make electricity, we can get power from the wind and sun even when the wind is not blowing or the sun is not shining. Hydrogen can also power cars and trucks, and biofuels may also help fuel vehicles.

As for whether renewable energy sources can make all the energy that modern civilization needs, many experts argue that by using energy more efficiently we can reduce our energy demand to the point where we can rely on what renewables can give us without giving up any of the advantages of a high-technology lifestyle. Some experts also argue that nuclear power will, in fact, be necessary. This remains a controversial subject.

But apart from increasing efficiency—which has already reduced energy use for many tasks and could reduce energy usage much more—no alternative perfect solutions are yet available. Solar panels are still too expensive to put on every rooftop (though

Japan and Germany, with their huge government-backed solar programs, may be changing that). Claims of greater safety and lower cost for new nuclear power-plant designs are still just promises. Vertical-axis windmills have not yet been widely installed or tested. As of early 2006, the closest thing to an alternative-energy "revolution" is what is happening in wind power: large windmills have been the cheapest, mostly rapidly-growing source of new electricity worldwide since the early 2000s. Yet some people are objecting to plans to build large wind farms in visible or fragile locations, such as the mountaintops of Vermont or off the coast of Massachusetts. Windmills are still making only a small fraction of our electricity, and until it is affordable to use them to make hydrogen for fuel cells on a large scale—which it is not, yet—we will not be able to obtain most of our electricity from wind no matter how many windmills we build.

## DREAMS OF FREE ENERGY

Many of these problems with alternative energy sources will undoubtedly eventually be solved. In the long run, some mixture of wisely-used alternative sources could power our civilization for as long as need be. Yet some people still dream of very inexpensive, inexhaustible energy from exotic or unproved sources. Nuclear power itself began as one such dream. In 1954, the chairman of the U.S. Atomic Energy Commission said in a speech that that "it is not too much to expect that our children will enjoy electrical energy too cheap to meter." (Metering is the process of measuring how much a given amount of electricity costs.) Some scientists even predicted that small nuclear plants would someday power individual homes, cars, and airplanes. Those dreams or predictions did not come true, mostly because nuclear energy still requires dangerous and complex technology. Far from being too cheap to meter, nuclear power is as expensive as any other standard way of making electricity.

But could some other technology, something completely new, fulfill the dream of cheap, endless power? Most energy experts and engineers urge us not to expect an energy miracle, and to be prudent in the use of resources we have and know, but scientists and inventors continue the search for new sources of energy.

Some of the methods that have been proposed for making cheap, endless power have no scientific basis and are simply "fake science" ("pseudoscience.") The most famous of these fake energy sources is perpetual motion. Some other proposed methods, such

## Johann Bessler and the Bessler Wheel

One of the most famous figures in the dubious history of perpetual motion was German engineer and inventor Johann Bessler (1680–1745). In 1712 Bessler unveiled his first machine, called the Bessler wheel, which he claimed was a perpetual motion machine that drew its power from gravity. Throughout his career, Bessler attempted to sell the machine, wanting the money to establish a Christian-based school of engineering. He never found any buyers and he refused to reveal the ‘‘secret’’ of the machine until he was paid. Never able to find a buyer for his machine, he died in poverty without having revealed the ‘‘secret’’ of the Bessler wheel.

Skepticism (a preexisting doubt in the truth of a matter) was increased when one of Bessler’s maids testified that she and other servants were manually turning the wheel with a crank from another room, which was attached to the wheel by a rod and series of gears.

Bessler allegedly encoded the ‘‘secret’’ of his perpetual motion machine in the text of his books, including *Apologia Poetica* (*Poetic Defense*, published in 1716), *Das Triumphirende Perpetuum Mobile Orffyreanum* (*The Triumphant Orffryrean Perpetual Motion*, published in 1719), and *Maschinen Tractate* (*Tract on Machines*, published in 1722).

as “zero point energy,” have some slight scientific basis, but most scientists still think they are not useable given human and Earth’s own limitations. Still other possible energy sources (such as cold fusion and sonofusion) are studied seriously by a number of real scientists, but the majority are still not convinced that they can produce useable energy in the foreseeable future. Finally, there are some methods that all scientists agree are physically possible, such as hot fusion and solar power satellites, but many experts do not agree that these schemes will ever be practical. A number of possible cheap-energy schemes, from the silly to the serious, are discussed in the rest of this chapter.

### PERPETUAL MOTION, AN ENERGY FRAUD AND SCAM

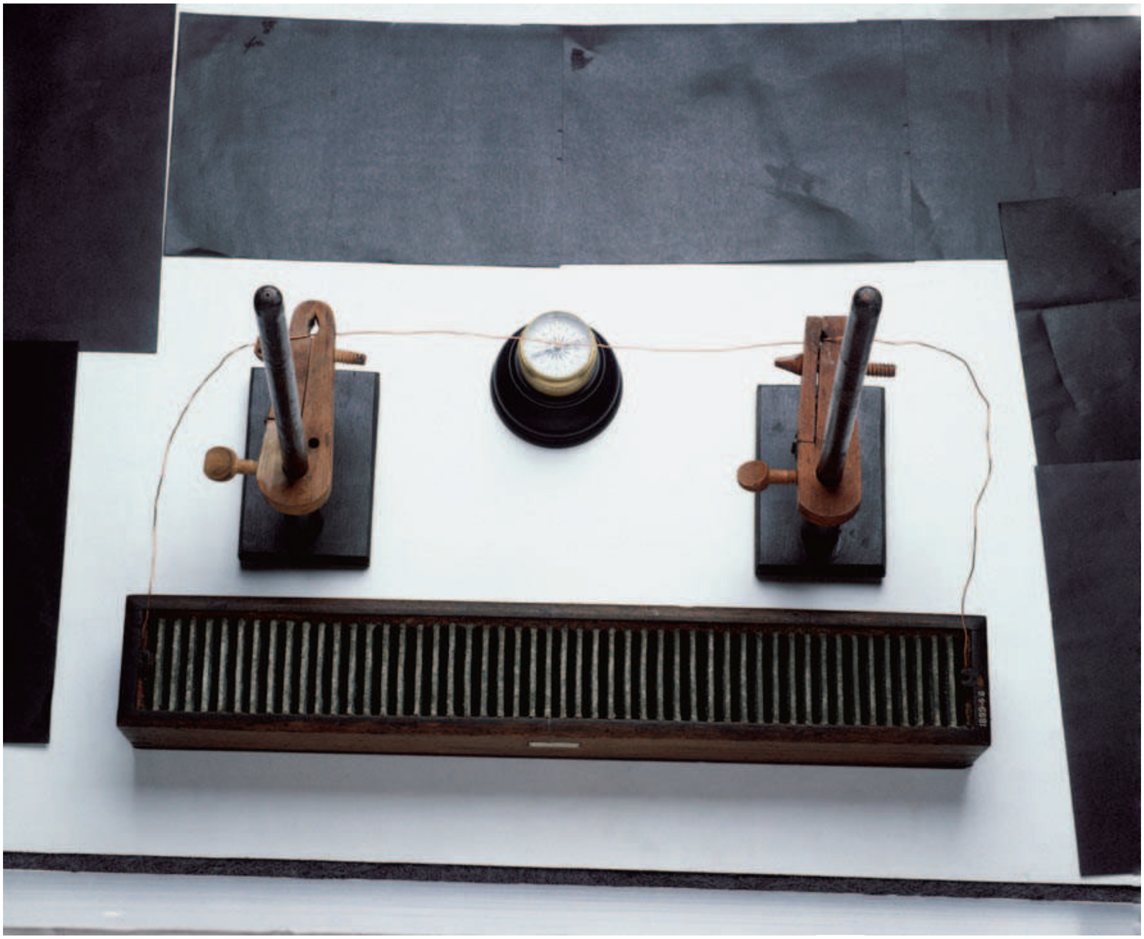
Some people argue that a “perpetual motion machine” can be built that will produce endless energy without having to burn fuel or harvest energy from an outside source such as the wind or sun. The search for such a magical machine dates back to at least the thirteenth century, when French artist Villard de Honnecourt drew fanciful pictures of perpetual motion machines. Since that time, many inventors and tinkerers have sought, without success, to design a machine that produces energy without any need for energy to be put in. Some fake perpetual motions have even been built to fool the public or steal money from investors.

Any so-called perpetual motion machine would violate laws of thermodynamics, which places limits on the nature and direction of heat transfer and the efficiencies that can be achieved by any type of system. This means it is impossible to construct any such system or machine with 100% efficiency. An important but complex part of the laws of thermodynamics is termed *entropy*. Entropy essentially means that without the use of energy, all systems or machines must move to disorder (experience decayed or diminishing efficiency) over time. Accordingly, the only way anything can be perpetual is to use energy to maintain the system or machine. Any statement to the contrary (against) violates the laws of physics.

Despite the claims of scam artists or "inventors," scientists agree that perpetual motion can never be an energy source. It is impossible to get more energy out of a machine than you put into it: machines can only change the form that energy is in. The laws of physics say that you can't get something for nothing—at least, not for long. In a sense, it is possible to store "energy" for a while in some devices, but batteries and other storage devices (which also decay over time) can only give back whatever energy is put into them. Perpetual motion machines will never supply the world with energy.

## ADVANCES IN ELECTRICITY AND MAGNETISM

As scientists continue to explore the nature of electricity and magnetism (actually different aspects of a combined fundamental force appropriately termed electromagnetism) so, too, are engineers advancing ways to convert this knowledge into useable forms of energy, and to improve the efficiency of power transmission, transportation, and so forth. Although improved efficiency does not provide new energy, it can have the same impact as developing new sources because it allows existing sources to do more things or last longer.



A reconstruction of an experiment that Hans Christian Oersted (1777-1851) constructed to show that elecromagnetism can be produced by an electrical current. © *DK Limited/Corbis.*

## Magnetism

People have known about the power of magnetism for thousands of years. In ancient Greece, near the city of Magnesia, mysterious stones with the power to attract iron were first discovered. Later, the Chinese discovered that if one of these stones was stroked with a needle, the needle became magnetic. Around the year 1000 the Chinese discovered that when such a needle was suspended, it would point in the direction of the North and South Poles. The result of this discovery was the magnetic compass, which helped to open the world's oceans to navigation and exploration.

It was not until the nineteenth century that physicists began to understand magnetism and magnetic fields. Essentially, magnetism is a force that attracts such substances as iron, but also cobalt and nickel, at a distance. What causes the attraction is decribed by lines of flux (“lines” on a plane that cross or include magnetic poles) that come from electrically charged particles that spin. These lines flow from one end of an object to the other. The ends are commonly referred to as the north and south poles, similar to the terms applied to Earth’s poles. In a magnetic field, the flux flows from the north to the south. While individual particles such as electrons can have magnetic fields, so can larger objects, such as the magnets that hold notes and shopping lists to the door of a refrigerator. When an object with a magnetic field exerts its force on another object with a magnetic field, the result is magnetism.

The north pole of one magnet attracts the south pole of another and, conversely, the north pole (or south pole) repels the north pole (or south pole) of another magnet. The lines of flux cause this attraction or repulsion. Just as these lines flow from the north to the south of one object, they can flow from the north of one object to the south of another, pulling the two objects together, almost like two spinning gears in a car that mesh smoothly together. When like poles—for example two north poles—are brought together, the lines of flux are flowing in opposite directions, causing the two objects to, in effect, bounce off each other, like two spinning tops that collide and bounce away.

## Electromagnetism

In the twenty-first century magnetism powers devices such as tape drives, speakers, and read/write heads for computer hard drives. The energy is captured through electromagnetism, which is based on the simple principle that an electrical current, which consists of a flow of electrons passing through a wire, creates its own magnetic field. This magnetic field moves in a direction perpendicular to the flow of the current in the wire. This force is called the Lorenz force, named after Dutch scientist Henrick Antoon Lorenz (1853–1928).

A simple electromagnet can be created with a battery and a piece of wire. If the wire is connected to the positive and negative poles of the battery, the electrons collecting at the negative pole will “flow” through the wire to the positive pole, rapidly depleting, using up, the battery. Generally, something is attached to the middle of the wire—a radio, a lightbulb, a toaster—so that the electricity can do work while at the same time offering resistance


The magnetic compass was one of the first uses of magnetic properties. Maglev trains are also based on the power of magnets.
*© Matthias Kulka/zefa/ Corbis.*

so the battery does not quickly go dead. The magnetic field of a single strand of wire, however, is likely to be relatively weak, because the Lorenz force weakens as the distance from the wire increases. One way to strengthen the magnetic field is to coil the wire, in effect recruiting multiple strands of wire to create a magnetic field that pulls (or pushes) in the same direction. The more coils of wire, the stronger the magnetic field.

This is the basic science behind magnetic levitation. In its application, magnetic levitation is a process by which train cars are "levitated," or raised, so that rather than riding on tracks, they ride on a cushion of air. The chief advantage of "maglev" trains is that this cushion of air, combined with the trains' aerodynamic design, virtually eliminates the energy lost because of friction. The result is lower cost per operating mile and lower maintenance costs because of less wear and tear on the equipment. Although exact estimates of savings vary, the operating cost of a maglev train in

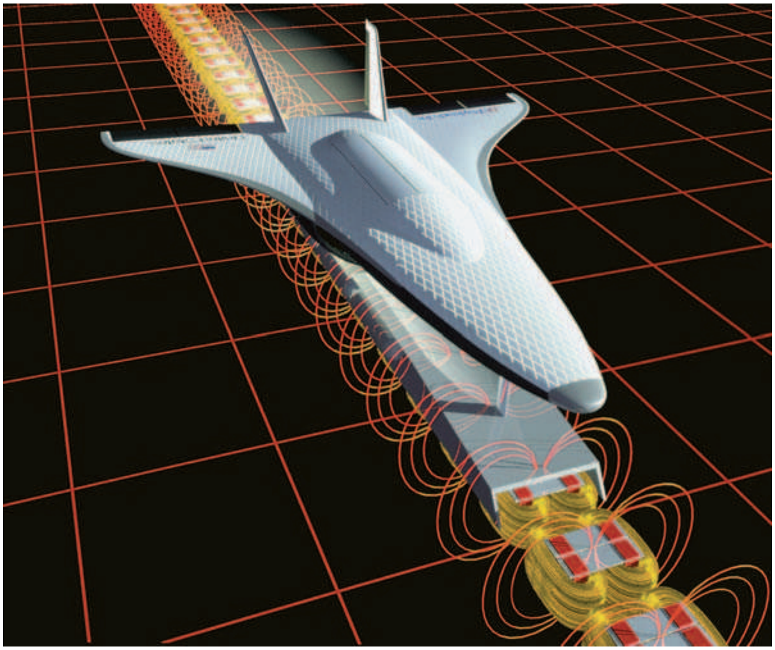

Shanghai's $1.2 billion maglev train arrives at Long Yang station after its 267 mph (430 kph) trip from Pudong Airport in Shanghai, China, June 7, 2005. © *Mark Ralston/Reuters/Corbis.*

terms of cost per passenger mile traveled is only a fraction of the cost of auto and air transport.

## ZERO POINT ENERGY

Zero point energy sounds like magic or science fiction: energy that comes straight out the vacuum of empty space. A handful of scientists argue that zero point energy can be harnessed to provide power. Most scientists, however, are very skeptical (doubtful) that it can ever be turned into a practical power source.

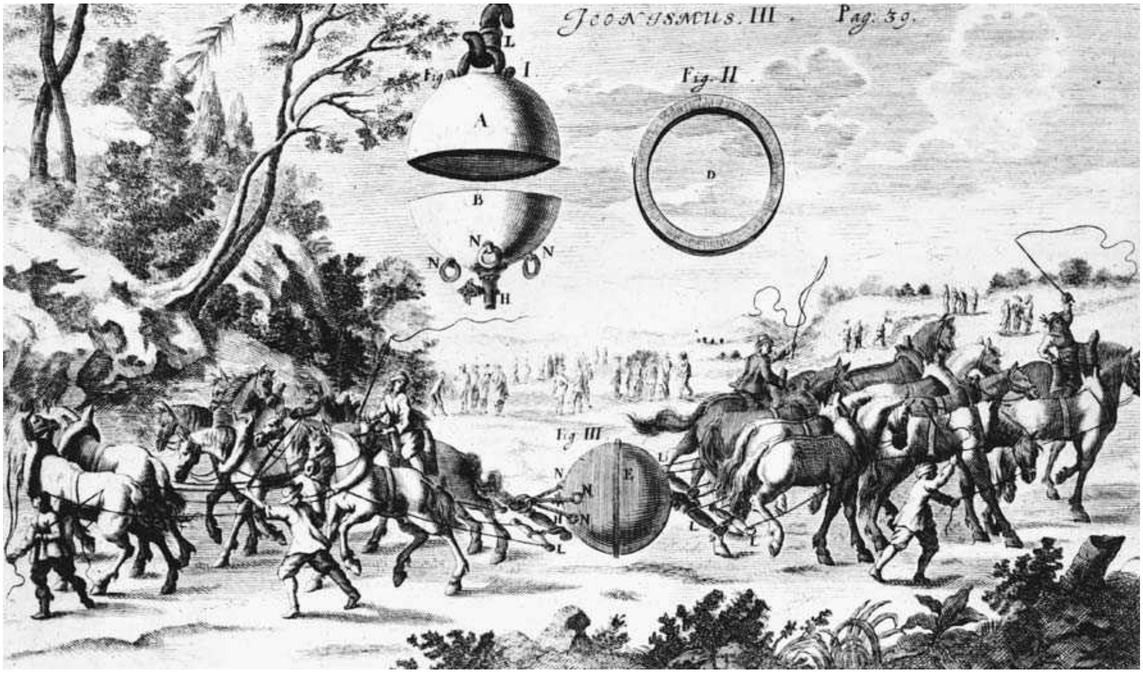
The idea of the nature and potential of a vacuum has long interested scientists. In ancient Greece, the philosopher Aristotle (384–322 BC) argued that "nature abhors a vacuum." That is, he taught that it was impossible for any region of space to be totally empty. For almost two thousand years, scientists accepted Aristotle's teachings, but by the middle of the seventeenth century they had come to reject it. In 1644, an Italian scientist named Evangelista Torricelli (1608–1647) invented an early barometer, a standing glass tube filled with mercury. The top of the tube was sealed and the bottom curved back up to an opening so



Computer-aided design (CAD) of a spacecraft being launched by maglev. This system uses magnets to float a vehicle along a track, and will reduce the cost of space travel. It could help launch a spacecraft from an airport runway to orbit every 90 minutes. *NASA/Photo Researchers, Inc.*

that the atmosphere could push on the exposed mercury. When the pressure of the atmosphere rose or fell due to the weather, it would push on the mercury with changing pressure, causing it to rise and fall in the glass tube. Torricelli noticed that even if the tube was made without air above the mercury, an open space would appear there. Because air cannot pass through mercury, Torricelli reasoned that this empty space at the top of the tube had to be a true vacuum—a volume of space containing no matter. In later experiments, other scientists confirmed his arguments.

For several hundred years after Torricelli, scientists argued that a vacuum was a region of space in which "nothing" existed. In the early twentieth century, however, physicists discovered the strange properties of matter that are obvious only for very small objects such as atoms and electrons. The new knowledge, called quantum physics, forced scientists to question whether the vacuum was in truth entirely empty. It became clear that Aristotle had been right (though for the wrong reasons), and that there is really no such thing as empty space. (In physics, "space" does not mean outer space, but rather any volume, including the space inside an atom, a bottle, or a room.)




A woodcut, ca. 1850, of Otto Von Guericke's experiment with the Magdeburg Hemisphere demonstrating the pressure of air. © *Bettmann/Corbis.*

Quantum physics is that branch or subdivision of the study of physics that started with the observation that an atom is like—and yet unlike—a tiny solar system. The atom's nucleus—a very small object or particle, much heavier than anything else in the atom—is positioned like a microscopic "sun,", and electrons, many times smaller than the nucleus, orbit it in some ways like tiny "planets." A question that puzzled physicists in the nineteenth century was why the orbiting electrons of an atom do not quickly radiate away their energy in the form of light and fall into the nucleus. On the contrary, they *never* do so. To explain this fact, modern physicists developed quantum physics, which explains matter and energy as having both wave- and particle-like features. They found that energy does not flow smoothly, but always changes in small jumps or fixed quantities. They called each of these jumps a "quantum", thus giving the new physics its name, "quantum physics." Quantum physicists showed that electrons orbiting an atom's nucleus are not really like tiny planets at all, except as we may picture them in our minds.

The German physicist Werner Heisenberg (1901–1972) deepened our understanding of quantum physics in 1927, when he announced what is now called the "uncertainty principle." The uncertainty principle states that by the very nature of matter and energy, it is impossible to measure everything about an object with perfect accuracy. For example, the better one's measurement of the position of an electron gets, the poorer one's knowledge of its momentum (a measure of both mass and velocity) gets, and that the reverse is also true because the better the understanding of momentum, the less one can know about position. There is no way to make better measurements: as Heisenberg proved, the uncertainty or lack of ability to know is not a form of ignorance, but arises from the nature and laws of the universe itself. It isn't that we don't know what the precise values are; the precise values simply don't exist.

According to the uncertainty principle, which has been tested many thousands of times in laboratories, there is a certain amount of fuzziness or uncertainty about all physical phenomena. This includes the vacuum. In fact, the uncertainty principle says that there can be no such thing as a perfect vacuum. Perfect emptiness or vacuum would mean that there was zero matter and energy, but "zero" is a precise value, and absolutely precise values are forbidden by the nature of the universe.

Instead, physicists now know that "virtual" particles are continuously popping into and out of existence everywhere, throughout all space, including the "vacuum"—the apparently empty space found between atoms and stars, and also at the top of Torricelli's glass tube. These virtual particles include photons (particles of light). All particles and waves are forms of energy, as German scientist Albert Einstein (1879–1955) proved in 1905, so the existence of virtual particles means that the "vacuum" is boiling invisibly with energy all the time, everywhere. This energy is called "zero point energy." A few physicists—but not most—argue that zero point energy can provide energy for human use.

A physicist working in the field of zero point energy, Dr. Hal E. Puthoff of the Institute for Advanced Studies in Austin, Texas, explains zero point energy in these terms:

> When you get down to the tiniest quantum levels, everything's always 'jiggly.' Nothing is completely still, even at absolute zero. That's why it's called 'zero point energy,' because if you were to cool the universe down to absolute zero—where all thermal motions were frozen out—you'd still have residual [leftover] motion. The energy associated with that 'jiggling' will remain, too.

Absolute zero temperature then is not zero energy, but the minimum energy that can exist.

## A Childhood Genius

When Werner Heisenberg was in his early teens, another, older student needed a calculus tutor. Heisenberg had not studied calculus, because it was not taught at his school. So he taught himself calculus so that he could tutor the older student—while also practicing to become an accomplished musician. Heisenberg won the Nobel Prize for physics in 1932 and, besides his scientific work in quantum physics, wrote many books about the relationship of physics to philosophy.

Scientists agree that zero point energy is real. This energy cannot usually be felt or easily measured because it surrounds everything equally. Thus, its forces in effect cancel one another out, exerting pressure in all directions at once, just as the pressure of the Earth's atmosphere can't be felt because it pushing on the outside of your chest and on the inside of your lungs at the same time.

Puthoff is one of the scientists who argue that the amount of zero point energy in the vacuum is very large. "It's ridiculous," he says, "but theoretically, there's enough [zero point] energy in the volume of a coffee cup to more than evaporate all the world's oceans. But that's if you could get at all of it, and you obviously can't."

Whether the zero point energy is useable is a question, but it is certainly there. Physicists have measured a number of effects that prove its existence. One is called the Lamb effect or Lamb shift, named after physicist Willis Lamb (1913–). The Lamb effect refers to small changes in light given off by an excited atom. This is predicted as a side effect of zero point energy.

A more impressive demonstration of zero point energy is the Casimir effect, measured in 1948 by Dutch physicist H. B. G. Casimir (1909–2000). Casimir showed that if two metal plates are brought very close together, they attract each other very slightly. As the plates are drawn or pushed together (whether to describe it as drawn or pushed depends on the exact explanation of zero point energy used), it is at least potentially possible to extract energy from their motion.

So not only is zero point energy real, physicists agree that it can be made to do work. But they do not agree that zero point energy can ever be made to do enough work to be useful. The fact that something happens in the realm of quantum physics doesn't prove that it can be made to happen in the world of everyday objects.

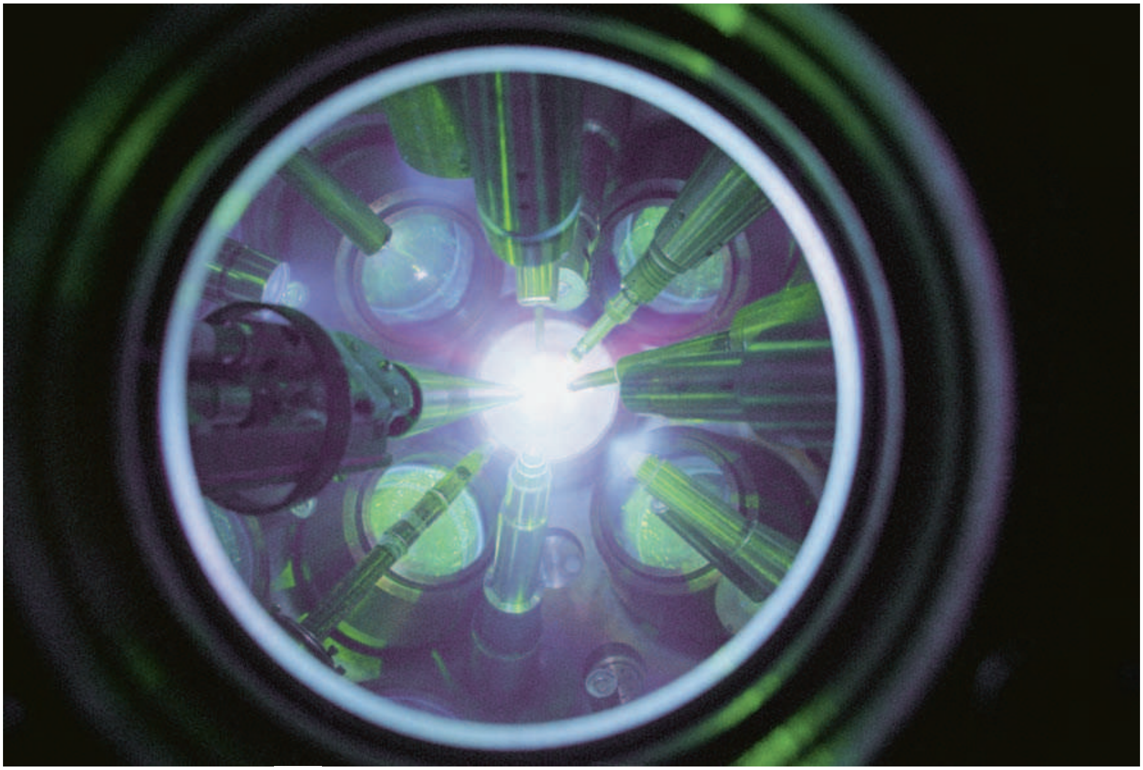
A few scientists explore the idea that zero point power sources might make interplanetary space travel practical, for a spacecraft would be able to extract the energy it needs from the vacuum of space rather than having to carry fuel. Some science fiction writers (and some scientists too) envision a day when zero point energy could power fighter planes flying at four times the speed of sound, power 1,200-seat airliners flying at altitudes of 100 miles (161 kilometers) and covering 12,000 miles (19,312 kilometers) in 70 minutes, and power spacecraft making 12-hour trips to the moon.

But most scientists do not accept that such science-fiction scenarios are possible. It would take billions of Casimir plates to produce a useful amount of power, and more energy would be consumed in constructing and positioning of the plates than the plates could ever produce. Such a machine would use more energy than it made. Therefore, many scientists debate whether money and time spent on zero point energy research should be spent instead on research of other forms of energy. Nevertheless, it is true that unlike mechanical perpetual motion machines, zero point energy is studied by some real scientists. Physicists agree that *some* energy can be had "for nothing" from the vacuum. It is simply a question of how much.

## FUSION

Fusion powers the sun and all other stars. Fusion is, however, very different from the process of generating nuclear power that is used in today's nuclear power plants. These are powered by nuclear fission, meaning that they release energy by splitting atoms apart into smaller atoms ("fissioning" them). This energy is used to turn water into steam, and the steam is used to turn generators that make electricity. Fusion, on the other hand, produces heat by "fusing" atoms, forcing them to come together into larger atoms. Fusion power, unlike fission, would produce only small amounts of radioactive waste and its fuel would not be dangerous to people's health.

But fusion does not yet produce useful power on Earth. For fusion power to be practical, scientists have to figure out how to



Lasers are focused on a small pellet of fuel in an attempt to create a nuclear fusion reaction for the purpose of producing energy. The fuel pellet undergoes a fusion reaction while being bombarded by the light from 24 lasers. © *Roger Ressmeyer/Corbis.*

make fusion happen in a steady, small-scale way, producing neither a fizzle nor an explosion. However, this has turned out to be a difficult trick. Billions of dollars have been spent over the last forty years trying to make fusion work, and success is still decades away—or may never be achieved. Three kinds of fusion research are described below: conventional or "hot" fusion, "cold" fusion, and sonofusion.

### Conventional fusion

In nuclear fusion, the nuclei of two light atoms (such as helium or hydrogen, the lightest atoms) bind together to form a single heavier nucleus. For example, the nuclei of two ordinary hydrogen atoms, each of which is simply a proton (a positively-charged particle), merge to form the nucleus of a deuterium atom, which is a neutron and a proton bound together. (A neutron is a particle that weighs about the same as a proton but has no electrical charge. Deuterium is also a kind of hydrogen.) When a deuterium nucleus or other particle is formed by the coming together of smaller particles, its mass is generally less than the total mass of the original particles before they came together. The mass that seems to have disappeared has been released in the form of energy. The amount of this energy can be calculated by using Albert Einstein's famous equation, $E = mc^2$, which means that when the correct units are used, energy ($E$) is equal to mass ($m$) times the speed of light ($c$) squared. Not much mass has to "disappear" for the amount of energy released to be very large. This is because the speed of light is so large: about 300,000 kilometers per second (186,000 miles per hour).

Fusion reactions occur naturally throughout the universe. For example, scientists have learned that the primary component of stars is hydrogen gas. Over time, this hydrogen is turned by fusion into the gas named helium, as the nuclei of four hydrogen atoms combine to form one helium nucleus. Many other fusion reactions take place in stars. In fact, all the heavier elements of which Earth (and our own bodies) are made, such as carbon, iron, oxygen, silicon, aluminum, and uranium, are produced by the fusion of lighter elements in stars.

For fusion to happen, "electrostatic repulsion" must be overcome. Particles with the same electrical charge repel or push each other apart. Electrons have negative charge, protons have positive charge. The closer two negative charges or two positive charges get to each other, the harder they repel and the harder it gets to bring them any closer. If two protons are to fuse together to form a single nucleus, therefore, they must be thrown together at high speed. Where does that energy come from?

It comes from heat. Heat is merely the motion of atoms and molecules. The hotter a piece of metal is, for example, the faster the atoms in it are vibrating. The atoms in a hot gas shoot around freely like balls on a pool table, only much faster. The hotter a gas gets, the faster its particles go. As a gas is heated, for instance, its atoms move with faster and faster, so they collide harder and harder. When the collisions are hard enough, the nuclei of the colliding atoms may fuse, or join together. This type of reaction is called a "thermonuclear" reaction, from the Greek *thermo*, meaning heat.

The temperature needed for this type of fusion to take place is extreme, on the order of tens or hundreds of millions of degrees. This kind of heat can be found in the centers of stars, including the sun, but does not occur naturally on Earth. It does occur artificially on Earth, however, in fusion laboratories and hydrogen bombs.

## Mike

The detonation of the first thermonuclear bomb, codenamed ‘‘Mike,’’ took place on November 1, 1952, on the Eniwetok atoll, a small coral island in the Pacific Ocean. The U.S.-built bomb consisted of a cylinder 20 feet (6 meters) tall and 6 feet, 8 inches (2 m) in diameter, weighing 164,000 pounds (61,212 kg).

Even the bomb’s designers were amazed by its explosive force. Its fireball was 3 miles (4.8 km) wide. Within ninety seconds, the mushroom cloud had risen 57,000 feet (17 m) into the air. Eventually, after five minutes, the cloud reached a height of 135,000 feet (41 m), with a ‘‘stem’’ eight miles (13 km) across. People on ships 100 miles (161 km) away saw the flash. The explosion completely destroyed the island of Elugelab, carving out an underwater crater that was 6,240 feet (1,902 m) wide and 164 feet (50 m) deep and lifting 80 million tons of soil into the air. A bomb of this type would devastate any city on Earth.

### Fusion in bombs

Just as the fission process used in nuclear power plants was first applied to make bombs, like the fission bombs used by the United States to bomb the Japanese cities of Hiroshima and Nagasaki in 1945 to end World War II, so was fusion.

To create a hydrogen bomb, scientists begin with a quantity of hydrogen. To create a fusion explosion, the hydrogen must be heated until it is as hot as the core of a star. This is done using a fission bomb. The basic design for a hydrogen bomb, then, is to pack hydrogen in a container around a fission bomb. When the fission bomb explodes, it heats the hydrogen enough to start runaway fusion explosions. This fusion explosion can be tens or even thousands of times more powerful than the fission explosion that started it.

The fission bomb that was dropped on Hiroshima was a 20-kiloton bomb, meaning that it had an explosive force equal to that of 20,000 tons of TNT (a chemical explosive). The first fusion bomb exploded with a force equal to that of 10.4 million tons of TNT—some 500 times the power of the Hiroshima bomb. The largest hydrogen bomb ever exploded had a force equal to 50

The mushroom cloud from Mike, one of the largest nuclear blasts ever, during Operation IVY. The blast completely destroyed Elugelab Island. © *Corbis.*

million tons of TNT, about 2,400 times the explosive power of the bomb dropped on Hiroshima.

**Controlled fusion**

Just as they did after the first fission bombs were developed in World War II, scientists began to seek ways to provide peaceful energy with nuclear fusion. The basic process they focused on made use of two forms (isotopes) of hydrogen. (An isotope is a form of an element having fewer or more neutrons in its nucleus than other forms of the same element.) These isotopes, known as "heavy hydrogen" because they contain extra neutrons, are called deuterium and tritium. A normal hydrogen atom's nucleus consists of a single proton, but the nucleus of a deuterium atom contains a proton and a neutron. The nucleus of a tritium atom contains a proton and two neutrons.

Heavy hydrogen is used for two reasons. First, these isotopes fuse at lower temperatures than regular hydrogen does. Second, they are relatively common. About 1 in 6,500 of the hydrogen atoms in natural water are deuterium atoms. Tritium breaks down rapidly, so very little of it is found in nature. It is made artificially by exposing the metal lithium to fast-moving neutrons created in a nuclear reactor.

If a mixture of deuterium and tritium is made hot enough, some of the deuterium nuclei fuse with tritium nuclei. One deuterium nucleus fuses with one tritium nucleus to produce one helium nucleus. (Helium is the gas that is used to fill party balloons.) When this happens, energy is given off in the form of a fast-moving neutron. This also happens in a hydrogen bomb, but it doesn't have to happen as a huge explosion: in theory, it could happen as slowly as one atom at a time.

Some scientists argue that fusion could be the "energy of the future" because its fuel—heavy hydrogen—contains an enormous amount of energy by weight. A bottle-cap full of heavy hydrogen contains the same amount of energy as twenty tons of coal. Further, using such fuel would be relatively safe. The major byproduct is helium, which is harmless. A fusion explosion could not happen because there would not be enough hydrogen, and it would not be not packed together the right way. In fact, keeping a fusion reaction going at all has been difficult for scientists trying to build fusion generators.

Because of the high temperatures needed to keep a fusion reaction going, no container made of any known substance such as steel or titanium can be used as a vessel for the reaction. A fusion reaction would simply melt the container and could not be contained or used. One possible solution is to use magnets to hold the reaction.

Controlled fusion begins with the making of a plasma, a form of gas so hot that the nuclei of all of the atoms have been stripped of their electrons. This leaves each nucleus with a positive electrical charge (usually the positive charge of each nucleus is balanced out by the atom's negative electrons). Because a plasma is charged, it can be held in place, or "bottled," by magnetic fields. Ordinary solid materials cannot be used because the plasma is too hot; even steel would simply turn into a gas at such temperatures, like boiling water turns to steam. The magnetic bottle method was developed early on by the Russian scientists who invented the device called a *tokamak*. "Tokomak" is short for "toroidal magnetic chamber" in Russian, where "toroidal" means doughnut-shaped.

A tokomak is a steel chamber shaped like a hollow doughnut. Plasma is held inside the doughnut by magnetic fields and heated. When it is hot enough, fusion begins. The magnetic fields are supposed to keep the plasma from touching the inside walls of the reactor. So far, the main problem with tokamaks is that the plasma leaks out of the magnetic fields when the fusion reaction begins so that the reaction can be kept going for only a few seconds. Only if this problem can be overcome can tokamak containers house useable fusion reactions. Several large tokomaks have been built, but none has produced as much energy as it takes to run.

On June 28, 2005, six partners (China, Japan, South Korea, Russia, the United States, and the European Union) agreed on a site for a tokomak to be called the International Thermonuclear Experimental Reactor (ITER). ITER will be built in Cadarache, north of Marseille, France. This is a multi-billion-dollar project designed to make possible experiments that the sponsors hope will lead to a greater understanding of fusion reactions and eventually to electricity-producing fusion power plants. In December 2005, the ITER site was prepared for construction of the reactor. Its designers currently plan for operation to begin in 2016.

Another way of keeping plasma hot enough for fusion to happen is "inertial confinement." This uses powerful laser beams to blast a tiny pellet of hydrogen fuel from all sides at once, turning it into hot plasma before it can expand and cool. While this method has worked for experimental purposes, scientists doubt whether it can ever be a feasible source of commercial power.

To be a useful power source, a fusion reactor would not only have to make more energy than it uses, but it would have to make that energy more cheaply than other sources of energy can be made. But there seems to be only a small chance that fusion can be made to produce large amounts of power, at any price, for many years to come.

### Cold fusion

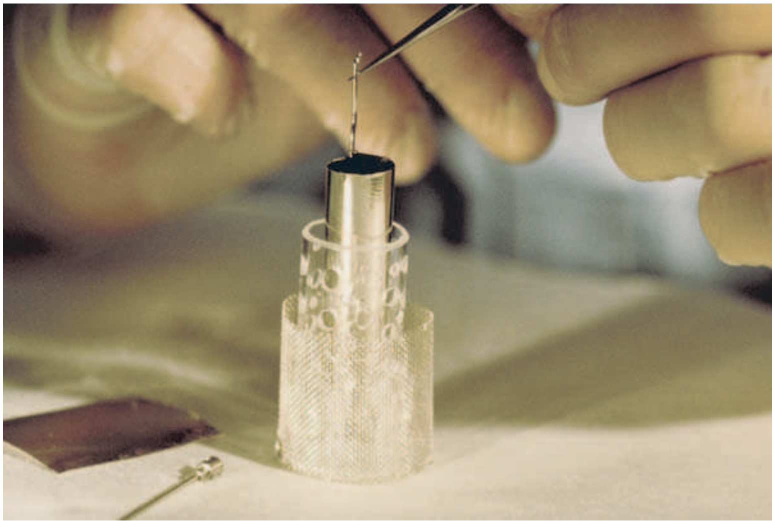
Because it is so hard to control the star-like temperatures needed for "hot" fusion, some scientists have looked for ways to make fusion happen at low temperatures. This is sometimes called "cold" fusion, a term coined in 1986 by Dr. Paul Palmer of Utah's Brigham Young University. As with zero point energy, all physicists agree that certain forms of cold fusion do happen, but most do not think that cold fusion can ever be a practical source of energy.

The history of cold fusion began in the nineteenth century, when scientists recognized the unique ability of the metals palladium and titanium to absorb hydrogen, much as sponges absorb water. In the twentieth century, scientists thought that these elements might be able to hold deuterium atoms so close together that a fusion reaction would result even at low temperatures. Later, two German scientists claimed to have performed an experiment using palladium that transformed hydrogen into helium at room temperature. However, they later took back their claim, admitting that the helium had probably come from the surrounding air.

### The Pons-Fleischmann announcement

In the following decades, a few scientists around the world continued to experiment with ways to produce fusion at low temperatures. None succeeded, but by the 1980s, after the energy shortages of the 1970s, a few scientists still worked on the premise that cold fusion held out hope for a future of clean, safe, abundant energy. In 1984, Stanley Pons of the University of Utah and Martin Fleischmann from England's University of Southampton began conducting cold fusion experiments at the University of Utah. On March 23, 1989, Pons and Fleischmann held a press conference at which they made an announcement that startled the world. They claimed that they had successfully carried out a cold fusion experiment that produced excess heat that could be explained only by a fusion reaction, not by chemical processes (such as metal combining with oxygen). At long last, the dream of being able to produce energy on a commercial scale from a bucket of water seemed to be just around the corner.

In their experiment, Pons and Fleischmann used a double-walled vacuum flask to reduce heat conduction. They filled the flask with "heavy water," water made with the deuterium isotope of hydrogen replacing ordinary hydrogen (the "H" in the chemical formula for water, $H_2O$). They inserted a piece of palladium metal in the heavy water and applied an electrical current. According to their results, nothing happened for a period of weeks. The energy input and energy output of the system were steady, and the temperature of the water stayed at 86°F (30°C). Then the temperature suddenly rose to 122°F (50°C), without any increase in the input power. The water remained at that temperature for two days before



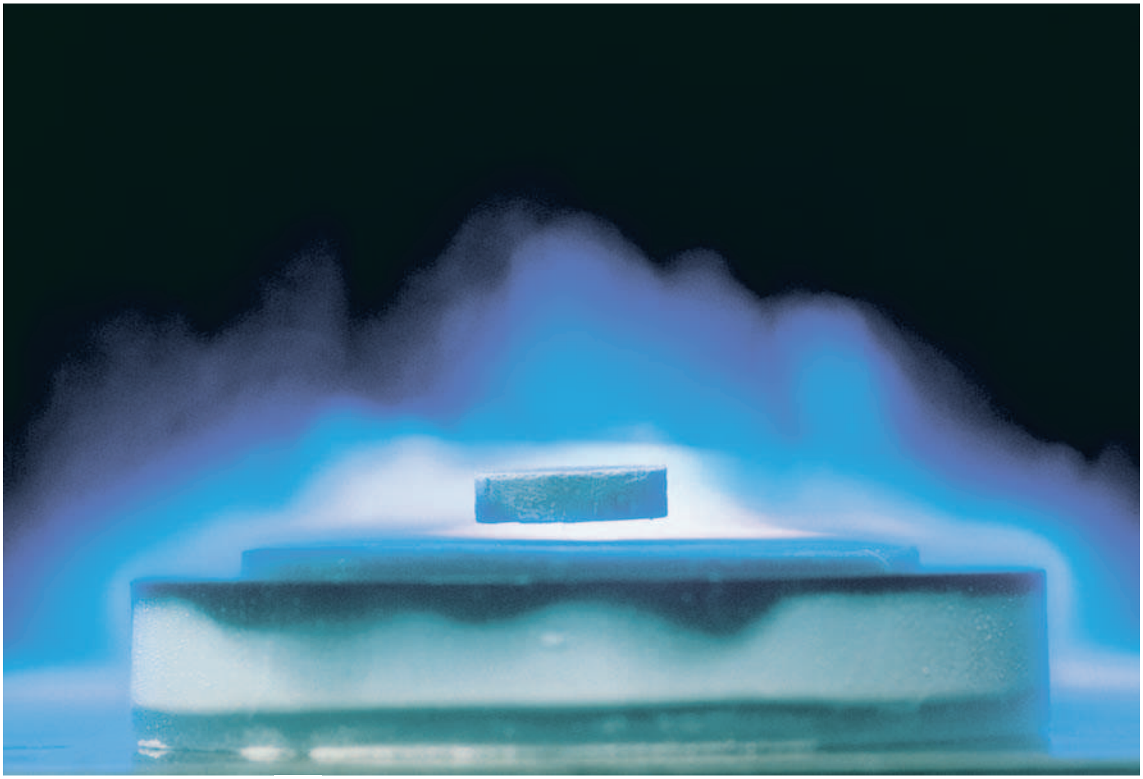
"Cold fusion" palladium and platinum electrodes, part of a French experiment to investigate the results of Fleischmann & Pons, who claimed to have created sustained cold fusion energy production in a simple electrolytic cell. *Philippe Plailly/Photo Researchers, Inc.*

decreasing again. This happened more than once. During these power bursts, the energy output was about twenty times greater than the energy input.

Because of the simplicity of the Pons-Fleischmann design, groups of scientists around the world attempted to duplicate their results. For weeks, the topic of cold fusion was on the front pages of newspapers. Some scientists initially reported that they were able to duplicate the Utah experiments, while others failed. What resulted was a mix of claims, theories, explanations, accusations, and arguments that the press dubbed "fusion confusion."

Since 1989, many scientists claim to have produced cold fusion. In some experiments, excess heat is generated. The expected by-products of cold fusion—neutrons, tritium, and charged particles—have been reported. Other laboratories have found the production of an isotope of helium, another potential by-product of fusion. They have also reported isotopes of such elements as silver and rhodium, again suggesting that something is happening at an atomic level.

To a nonscientist, it all sounds pretty convincing. Yet most scientists do not accept that cold fusion has been achieved. There is, to begin with, no theory that would explain it. The minority who argue for cold fusion point out that even though science cannot explain cold fusion, that does not prove that it is not real. They note, for example, that when superconductivity (the flow of electricity through very cold metals with zero loss) was first discovered in the early twentieth century, there was no theory to



Demonstration of magnetic levitation of one of the new high-temperature superconductors yttrium-barium-copper oxide (Y-Ba2-Cu3-O7-x). The small, cylindrical magnet floats freely above a nitrogen-cooled, cylindrical specimen of a superconducting ceramic. The glowing vapor is from liquid nitrogen, which maintains the ceramic within its superconducting temperature range. *David Parker/Photo Researchers, Inc.*

explain it until decades later. This is true, but in the case of cold fusion, the observations themselves are in doubt. The case for cold fusion is not as certain as a mere list of all the positive reports makes it sound.

First, there have also been many failed cold-fusion experiments. Second, the production of energy by a system is not proof that nuclear reactions are happening; chemical reactions could be supplying the energy. Third, the production of "excess heat" by a system—often reported by scientists working with cold fusion setups—does not necessarily mean that more energy is coming out of the system *over the lifetime of the experiment* than goes into it. Fourth, there are many possible sources of measurement error when looking for fusion by-products. Extra helium, for example, may come from the air; silver or rhodium (supposedly detected in extremely small amounts) may come from contaminated instruments; neutrons may come from cosmic rays or radioactive elements such as uranium.

A supercooled superconductor creates magnetic levitation, as well as steam, due to its low temperature. *Charles O'Rear/Corbis.*

As of early 2006, seventeen years after the Pons-Fleischmann announcement, there was still no widely accepted proof that nuclear fusion is happening in the devices built by cold-fusion researchers. The scientific community as a whole has not been convinced that cold fusion is real. That is, they are not convinced that any kind of cold fusion that produces more energy than goes into it is real. There is agreement among physicists that energy-consuming forms of cold fusion do exist. In particular, the phenomenon called "muon-catalyzed fusion" is well-established. Muons are particles that can briefly substitute for electrons in atoms. When they do this they shield the atomic nuclei from each other, reducing the electrical force that keeps them apart and so allowing them to be fused by lower-velocity collisions (cooler temperatures). Muons, however, have a limited lifetime—about 2.2 millionths of a second—and more energy is needed to produce them than they can release through fusion.

In the 1990s, the U.S. Department of Energy suspended funding for cold fusion research. In 2004 it conducted a study in which it concluded that research since 1989 had produced nothing new of substance. Japan continues to fund cold fusion research.

### Sonofusion

Claims of another kind of "desktop" fusion (fusion that can be produced by inexpensive, simple equipment rather than multi-billion dollar tokomaks) surfaced in 2002. Physicist Rusi Taleyarkhan of Purdue University published a study claiming to have produced fusion using sonoluminescence. Sonoluminescence—the word means, literally, "sound-light"—occurs in some liquids when they are hit by intense sound waves. Tiny, short-lived bubbles appear in the liquid and then collapse. When each bubble collapses, very high temperatures and pressures occur inside it and a tiny flash of light is given off. Temperatures of thousands of degrees are generated in these collapsing bubbles, but physicists are not sure just how hot they are. If the temperature were high enough, it could cause fusion. Most physicists however currently argue that temperatures can not reach this high level.

Dr. Taleyarkhan ran his first experiments at the Oak Ridge National Laboratory in Tennessee, a laboratory owned by the U.S. government. He used a liquid chemical called acetone. The normal hydrogen atoms in the acetone that Taleyarkhan used had been replaced with atoms of deuterium, one of the heavy forms of hydrogen. He hoped that super-high temperatures in collapsing sonoluminescence bubbles would make the deuterium atoms fuse. To see whether fusion was really happening, he placed detectors around his acetone setup to count fast-moving neutrons. Neutrons would prove that fusion was occurring. Taleyarkhan believed that he counted enough neutrons to prove the presence of fusion.

Taleyarkhan's work was real science, but that doesn't mean it couldn't be wrong. Some other scientists criticized the details of his work. For example, fusion was not the only possible source of the neutrons that Taleyarkhan was measuring; he was shooting neutrons at the acetone to make bubbles form faster. Therefore, to detect fusion, Taleyarkhan had to measure not just whether there were **any** neutrons coming out of the experimental setup, but whether there were **extra** neutrons coming out—a much trickier problem.

Much as with cold fusion, hopes run high for sonofusion. But as of early 2006, no one had been able to duplicate Taleyarkhan's results. However, in early 2006 he announced that he was about to publish new results in the journal *Physics Review Letters*, an important science journal. Most physicists argue that Taleyarkhan is making an honest mistake in his experiments. The scientific process of presenting evidence and testing new ideas will eventually show whether he is correct.

## SOLAR POWER SATELLITES

Solar cells or photovoltaic cells, devices that turn sunlight directly into electricity, work best in outer space. The sun is brighter there because there is no air to block any light, and solar cells can be stationed outside the Earth's shadow so they see the sun all the time. In fact, solar cells were first used, in the 1950s, to power space satellites. Some people have argued that we should use solar cells in space to generate power for the Earth. They say that we should build large arrays of solar cells in orbit around the Earth—solar power satellites.

But there is a problem: it is impossible to run power lines from a satellite to the Earth. Any wire or cable would snap under its own weight long before it was long enough to reach from the Earth's surface into space. Therefore, supporters of solar power satellites propose to beam the power to Earth in the form of radio waves. The kind of radio waves that would be used are "microwaves", the same kind that are used to cook food in microwave ovens.

The system would look like this: a large, flat array of solar cells would orbit the Earth at a height of about 22,000 miles (36,000 km). At that height, it takes a satellite 24 hours to circle the Earth. Since the Earth is spinning once every 24 hours, a satellite at that height (circling in the same direction as the Earth is turning) looks from the ground like it is standing still in the sky (geostationary, that is, remaining above the same point over the ground). Satellites of this kind are used to broadcast satellite TV signals. Also, a satellite that far from the Earth can be positioned so that the Earth's shadow never falls across it and breaks the supply of sunlight.

This giant array of solar cells would make electricity, turn it into radio waves, and beam the radio waves at Earth. A large antenna on the ground would pick up the radio waves and turn them into electricity again. The power would then be transmitted to users through power lines, just as power from ordinary generating plants is.

There are no basic scientific problems with this idea: everything about it uses machines that we already know how to make. The great problem is cost. A solar-cell array and microwave radio transmitter of the size needed would weigh many tons. The cost of launching all that machinery with rockets would be huge—far greater than the cost of building solar power stations, windmills, and other sources of renewable power right here on Earth. Although there is nothing basically wrong with the idea of solar power stations, they would be difficult to finance and build. Only wealthy and technologically advanced governments could currently fund such an effort. Only Japan has announced intentions to at least explore the possibility, but not until 2040.

## NO MAGIC BULLETS

Hot fusion and solar power satellites are based on solid science, but there seems to be no current way to make them practical or affordable, at least for the foreseeable future. Cold fusion, sonofusion, and zero point energy, on the other hand, are based on scientific claims that most scientists currently reject. And perpetual motion is a complete fake that is not possible because of the well-tested laws of thermodynamics. Accordingly, there is probably not going to be any near-term "magic bullet" for our energy problems. We already know what tools we have to choose from: fossil fuels, nuclear power, and renewable energy sources such as the wind and sun, geothermal power, biofuels, wave or tide energy, and hydroelectric power.

There is intense disagreement in our society over what the right energy choices are that are both possible and affordable. For example, some people claim that it would be madness to not develop nuclear power on a huge scale, and others say it would be a disaster to do so. Some say that renewable energy can supply all our needs, and others that such energy sources can not meet increasing energy demands. There is no easy answer to the energy problem; even the best answers developed in the near future may be complicated, dangerous, and expensive. However, one thing is certain: **all** ways of making energy harm the Earth to some extent. Therefore, no matter where our energy comes from, we should not waste it. Living a more energy-efficient life is as easy as reaching out to turn off the nearest unneeded light.

Even as scientists and engineers are working on more efficient refrigerators, cars, computers, lights, and other devices, we can all save a significant amount of energy just by turning off lights, computers, and other devices whenever we aren't using them. Over time, we all make many choices about how much energy to use and how to use it. A more energy-efficient world is a world that is easier to supply with energy, whatever the source.

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