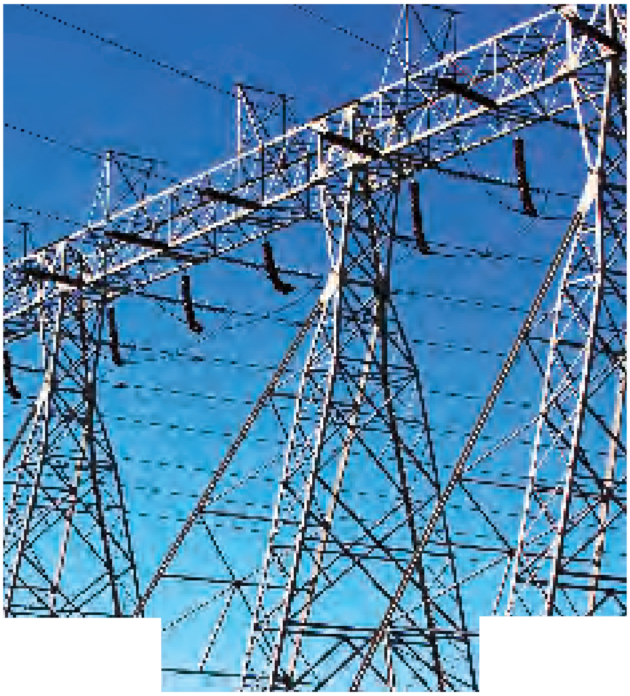
WORLD



BY VIRGINIA HUGHES

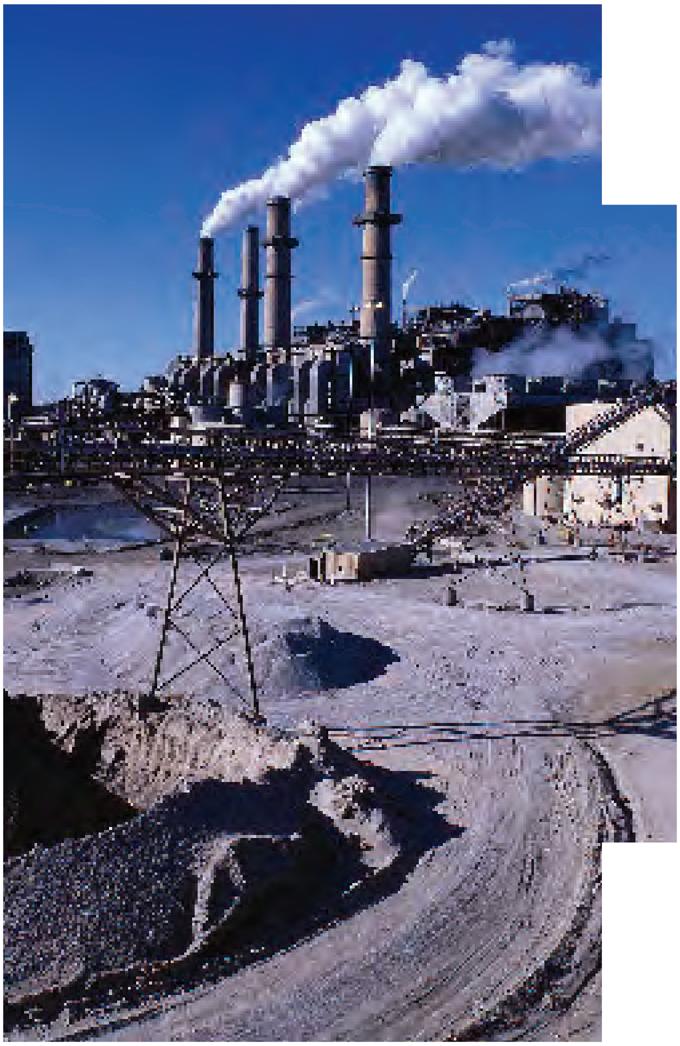
POWER

Coal, natural gas, oil, wind and water can all be made into electricity to feed an enormous grid that satiates the world's hunger for power.

THE TRILLION-DOLLAR ELECTRICAL INDUSTRY that keeps milk from spoiling, mechanical hearts pumping and the Internet abuzz would never have been possible if, in 1831, English physicist Michael Faraday hadn't noticed a tiny movement in his cluttered laboratory.

Eleven years earlier, Danish scientist Hans Christian Oersted had shown that electrical current flowing through a wire caused a compass needle to swing about—that is, that flowing electricity could create a magnetic force. But Faraday wondered if the opposite was true: Could magnets create electricity?

To find out, he placed a wire near a magnetic source, hoping to see that the magnet induced a current in the wire (which was attached to a current-detecting meter). To his great frustration, nothing happened. But one day,



Coal is transported from mines (photos above) to coal-fired power plants, which produce the majority of the world's power.

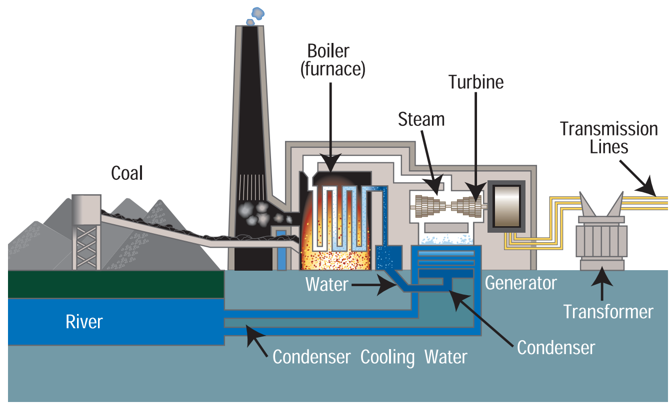
just as he was turning off his laboratory magnet, Faraday happened to notice the current meter's pointer flicker. Curious, he turned the magnet back on, and saw the pointer flicker again, this time in the opposite direction. With a few more tinkerings, Faraday discovered a physical law that would change the world: A change in magnetic force can induce electricity.

In 2004, global electricity generation was 16.4 trillion kilowatt-hours, according to the U.S. Department of Energy. (For comparison, a 100-watt light bulb operated for 10 hours uses one kilowatt-hour.) And Faraday's law of induction underlies every non-battery electrical power generator in the world, including coal- and gas-fired power plants, hydroelectric dams and nuclear reactors. At the heart of each, metal coils rotating between large magnets induce electrical currents to flow into an enormous power "grid" that doles it out to our lamps and refrigerators. The difference between the various types of power plants lies in how to get those coils moving.

From Rock to Grid

About 87 percent of the world's energy consumption starts by digging up fossil fuels such as oil, natural gas and coal. Coal—million-year-old fossilized rocks of mostly carbon, with traces of sulfur and heavy metals—is abundant in many places throughout the world, most famously in China (with more than 21,000 mines), the United States, Australia, Germany and Siberia. The world consumes 5.3 billion tons of coal each year, and about 75 percent of that is used to make electricity.

Once uprooted at a coal mine, the rocks are transported by rail to individual power plants, where they are pulverized into a fine powder and thrown into a furnace. To burn the precise combination of carbon and oxygen that produces the most heat, extra air is blown into the furnace, creating a vacuum so strong that, according to Michigan State University chemical engineer Carl Lira, "when you walk into the plant, the door immediately slams shut behind you."



Once mined, coal is burned to heat water into steam. The steam then drives a turbine to ultimately produce electricity.

The coal and oxygen, once burned, turn into carbon dioxide and heat. The carbon dioxide is discarded, along with excess nitrogen and oxygen, creating the familiar smoke billowing from chimneys on top of the plant.

"Almost three-quarters of the air that you put through the burner comes out the other side," Lira says. The heat, however, is used to turn water, pumped into the plant from nearby reservoirs, into high-pressure steam. (The water that's pumped into the boiler is first treated with softeners and anti-corrosive chemicals to remove all of the minerals that could clog the pipes, just like the crud that tap water, once boiled, leaves at the bottom of a teakettle.) The steam is then shot through a series of steel pipes that lead to the large blades of a giant pinwheel, called a turbine. "The overall process is to make the water into steam, use the steam to drive the turbine, condense the water back into liquid, and then pump it back into the boiler again in as much of a closed loop as you can," Lira explains.

When first made, the steam is pressurized at about 850 pounds per square inch (for comparison, your car tires are kept at about 30 psi). This high-pressure steam is then pushed through uniquely shaped, small-diameter nozzles, which causes the pressure of the steam to drop and the velocity to rise. The high-velocity steam is then powerful enough to push blades of the turbine. Lira says the process is akin to blowing on a pinwheel with a straw. "If you blow through a straw, you end up with a much stronger gust than if you just blew on the wheel without the straw."

The turbine blades, once set in motion, turn a shaft that causes large coils of wire to rotate inside of large magnets. This "dynamo" thus induces electricity on a large scale in much the same way that Faraday did on his laboratory table-

Capturing Carbon

Coal, when burned, releases more carbon dioxide into the atmosphere than anything else on Earth. But since coal is also the cheapest and most abundant source of energy in many parts of the world, engineers are now developing technology that traps the carbon dioxide emitted from traditional coal-fueled power plants and pumps it deep into the ground.

"When people talk about how filthy and dirty coal is, there's something wrong," says chemical engineer Gary Rochelle of the University of Texas at Austin, whose research focuses on carbon-capture technology. "It's not the coal, but the old plants that are filthy and dirty."

Rochelle's team is working on a process that captures carbon dioxide by first dissolving it in a liquid chemical solution containing ammonia. Then, a series of other chemical reactions isolate pure carbon dioxide from the solution, and compress it into liquid form. Finally, the liquid carbon dioxide is pumped 3,000 to 5,000 feet underground, "and it stays down there forever," he says. This is an especially practical solution in places that have already been drilled for oil or natural gas.

What are the drawbacks to using carbon-capture power plants? For one thing, they're about 30 percent less efficient, according to Rochelle. If a normal coal-burning plant was designed to produce about 800 megawatts, then a carbon-capture plant that burned the same amount of coal would only produce about 560 megawatts. "That's a major hit," he says. "Nobody's going to do that voluntarily."

Another problem is scale. The typical carbon-fueled power plant produces about 800 megawatts, and the largest carbon-capture systems built so far, Rochelle says, produce only about 30 megawatts. That's because the "scrubber"—the cylindrical, steel vessel where the ammonia solution first comes in contact with the emitted gases—has to be about 60 feet in diameter. "So we still need to learn how to build big plants," says Rochelle, who estimates it will take at least five more years of research.

When the Lights Go Out

Most of us take electricity for granted—until we don't have it. Given the size and complexity of the power grid, what causes the electricity to suddenly shut off?

The power distribution grid is simply all of the power plants in a particular region and the wires that connect them. Because a power grid cannot store power, to be most efficient it must supply exactly enough to satisfy demand—no more, no less.

The interconnectivity of the grid makes it dependable: If a power company needs to take a tower offline for maintenance, for instance, then the others in the grid can crank up production to pick up the slack. But the grid can be a curse in times of overuse.

During an especially hot summer, homes and businesses supplied by a particular power plant may all be blasting their air conditioners, so that the demand exceeds the capacity of the plant. The plant may temporarily lower voltage to conserve power—called a "brownout"—or, to prevent serious damages, may shut down completely (much like a household fuse).

To meet the region's energy demand, nearby power plants will try to "spin up" production. But if the homes and businesses connected to these plants are also demanding excess power, these plants will also disconnect from the grid and exacerbate the problem even further. In a serious blackout, dozens of power plants might shut down in this kind of "cascading failure," leaving millions of people in the dark.

top. The current is then distributed away from the power plant and into the world at large. For this power "grid," we can thank 19th-century American inventor Thomas Edison.

By 1878, 31-year-old Edison was famous in America for inventing the telegraph, phonograph and a rudimentary telephone. In early September, while visiting a manufacturing plant in Connecticut, Edison saw "arc lights" powered by a noisy dynamo, where arcs of white light were made when electricity hopped between a series of carbon electrodes. Edison was inspired by the arc process: What if he could make, like the chain of electrodes, mass-produced lamps, distributed throughout a community but powered by a centralized source? By the end of December, Edison had made a mini-grid on the property of his laboratory in Menlo Park, N.J. He invited New York City planners to come by for dinner, and dazzled them with the bright lights that illuminated the grounds and dining hall. They granted him permission to dig up city streets, and two years later he switched on a grid that, via wires buried underground, powered 400 lamps across Manhattan.

Today, every major city has its own power grid. One problem with the grid system is that it can't store electricity. So if generated power isn't used, it's wasted. For that reason, the grids of nearby cities are usually linked; if one region is only using a relatively small amount of power, it can be sold to a nearby region that needs it. This mass linkage sometimes presents its own problems; a blackout started in one city, for instance, may easily spread to others. (See sidebar this page.)

From a Different Kind of Rock

Coal-fired power plants produce the bulk of the world's electricity, but not all. About 6 percent of the world's power (and 80 percent of France's) is generated by nuclear reactors, making steam not with fossil fuels, but fission fuels.

In a "pressurized water reactor," a common reactor in nuclear power stations, heat is created by splitting (fission-

In a nuclear power plant (photos page 12), a nuclear reaction is used to heat water into steam and drive turbines. Solar panels can harness the sun's energy to generate power (below).

ing) uranium atoms. Uranium is found in several forms, but only U-235—meaning that the number of neutrons and protons in its nucleus add up to 235—is fissile. To be useful in a reactor, U-235 rock is first formed into half-inch-wide pellets, which are then stacked inside of thin, pencil-like zirconium tubes about 2 feet long. The pencils are then grouped into 50-pound fuel bundles, about the size of a fire log. Each "fire log" has enough energy to supply 100 homes with electricity for one year. Because a nuclear reaction releases so much potent energy, one reactor could go for a year or more without stopping. (This is why military ships that stay at sea for long periods use nuclear power.)

The U-235 atoms inside of the fuel logs are then struck by subatomic particles called neutrons, which split apart the uranium and release huge amounts of energy. Just as in a coal-burning plant, this heat is used to make steam that will move the blades of a turbine.

Nuclear technology accelerated in the 1960s, as part of weapons research in the United States and the Soviet Union during the Cold War. Today there are 439 nuclear power plants in 31 countries. But because of its controversial past, the idea of nuclear plants leaves a bad taste in the public's mouth in some parts of the world. In fact, due to strict licensing regulations and political pressure, only a handful of new nuclear facilities have been built in the United States and England in the last few decades.

"It is heavily regulated, as it should be," says Christopher Harrop, a project director with the international nuclear consultancy AMEC. In both countries, he explains, companies must get a reactor design pre-licensed by governmental nuclear regulatory commissions (NRCs) before any building takes place. The process is expensive, and takes many years.

In the United Kingdom, the Nuclear Installations Inspectorate is currently reviewing four designs for nuclear reactors. Once the designs are approved, the sponsoring companies can submit applications to build reactors on specific sites. Between now and 2009, the U.S. NRC will review 21 such applications for new nuclear power plants.

Nuclear power is growing, especially in the Far East countries like India and China. Harrop, who has developed nuclear plants in China, says that though they have a lot of coal, it's usually low-quality coal that must often be transported long distances.

"It's an open market—everyone's building [nuclear plants] in China right now," he says. "They've been building them since 1985 … and haven't really stopped, whereas the U.K. and the USA have stopped." Part of the reason for that, he says, is that a nuclear plant takes about seven years to build, which is difficult in the ever-changing political climate in the U.S. and the U.K. "When the Chinese declare a 12-year plan, chances are the plan will go ahead because it's not open for political discussion every five years," he explains.

As for the dangers of nuclear power, advocates say the safety statistics speak for themselves. Because of respiratory diseases and coal-mining accidents, power generated by fossil fuels kills more people every year than the accumulated radiological effects of all fissile reactions in the past. Bruce Power, in Ontario—Canada's first private nuclear plant—cites that someone who eats one banana a day for a month will receive the same amount of radiation from naturally occurring potassium-40 as someone who spends a year living next to their site. "It's a very safe industry," Harrop says, "but there is still this public perception of danger of what you cannot see, touch, feel. I don't think that's completely gone away. Here in the United Kingdom, there's now a large public debate about using nuclear power," he says. "It's on TV most of the time, on everybody's minds. It's something that people are ready to discuss."

Renewables

Both fission fuels and fossil fuels are nonrenewable energy sources—a finite amount of uranium, natural gas and coal is buried deep within the Earth. Moreover, the use of both fission and fossil fuels brings a host of environmental problems. Nuclear plants produce thousands of tons of radioactive waste every year, and nobody really knows the safest way to dispose of it. (Most of it now goes to "cooling bays"—underground Olympic-size swimming pools filled with water—and stays there for at least 10 years.) And coal, along with being the largest single source of fuel for worldwide electricity generation, is also the largest single source of carbon dioxide emissions—which many climatologists say is the primary cause of the planet's recent warming. Some engineers are working on technologies that will trap these dirty emissions from existing plants, and pump them back into the ground. But others are turning their focus to renewable forms of energy, such as the long-established hydroelectric dam or, increasingly, solar farms and wind farms.

Renewable energy accounts for about 7 percent of power generation worldwide. And the bulk of this comes in the form of hydroelectric dams, where the pressure from water trapped in pipes, when released, can turn huge turbines. Solar and wind power, though now representing only a fraction of the world's power generation, are two of the fastest growing energy sectors, especially in Europe.

In Southern California, the Mojave Desert's unyielding sunlight, pouring down on miles of empty space, seems the perfect place to harness the sun's energy. At the end of 2005, a startup company and two large utility companies announced they would build the largest solar power plant in the world there, with a 500-megawatt energy capacity that would rival coal-burning plants.

With construction scheduled to begin in mid-2008, the 4,500-acre farm will have 20,000, 40-foot-tall curved dishes that each use a mirror array to focus the sun's energy onto a Stirling engine—an oil-barrel-sized heat engine filled with hydrogen. The 1,350-degree-Fahrenheit heat makes the hydrogen expand, and this drives the engine's four pistons. The pistons move a drive shaft, which then powers an electrical generator.

But the renewable commodity getting the most press of late is wind. Denmark is at the forefront of the industry, with one-fifth of its power generated by wind. (The United States, in contrast, relies on wind for just one-half of 1 percent of its power.) In places with steady breezes—usually on a coast or barren plain—wind turns the turbine blades, which then turn a rotor shaft and an electrical generator at the top of the tower. Wind turbines are only practical in places where wind speed is at least 10 miles per hour, without too many sudden powerful bursts.

Keith Lovegrove, energy engineer and the solar thermal group leader at Australian National University, in Canberra, says that the solar and wind technologies are already huge industries, and that a "renewable revolution" is absolutely feasible in the coming years. "A decade from now it will be very noticeable for everybody, but still a small percentage. In two decades, it will be quite a significant percentage," he says. That said, Lovegrove admits that renewable energy on its own doesn't make sense everywhere. "If you live in a part of the world with no wind and no sun, then you're in a bit of trouble," he says.

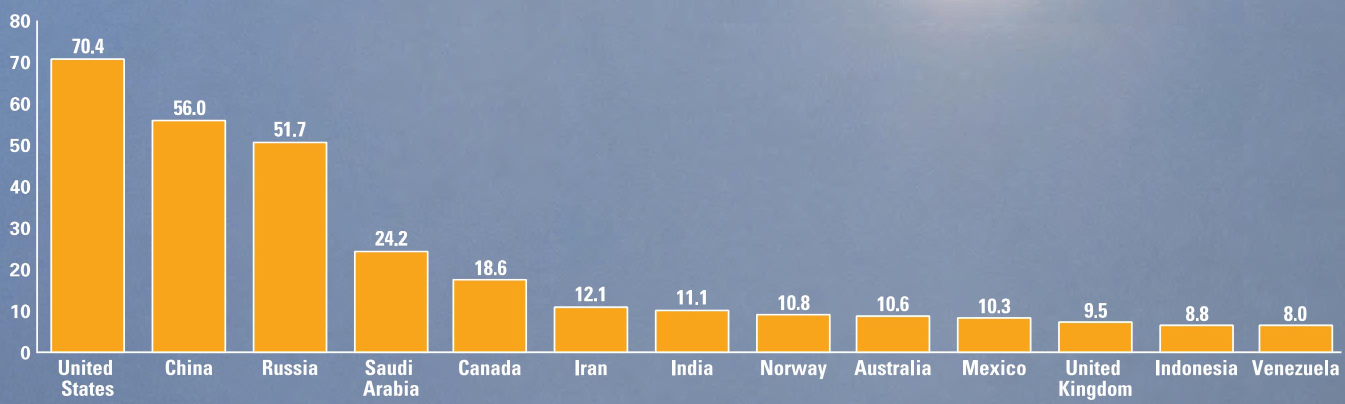
The choice of which kind of alternative energy source to invest in comes down to basic economics. "Countries develop power strategies around the fuel source that they have," Harrop explains, "because that's their basic economic driver." The United States, for now, has a lot of coal, while Europe's supply is running dry. The recent growth in the wind industry has thus largely been because of initiatives in Western Europe, Lovegrove says. "But even they see a limit to what they can do with wind, so they look to places like Spain and even northern Africa for solar plants."

As our fossil fuels diminish, a combination of many types of energy may be the ultimate solution.

Power Generation

Worldwide energy production by region

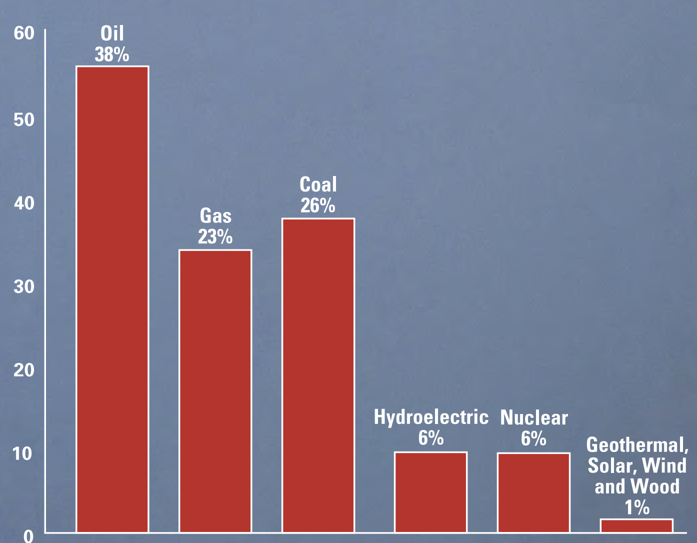
(U.S. Department of Energy 2004 figures)



**Measured in Quadrillion British Thermal Units (BTU). A BTU is the amount of heat energy needed to raise the temperature of 1 pound of water by 1 degree Fahrenheit.

Worldwide energy production by type

(U.S. Department of Energy 2004 figures)



Source: http://en.wikipedia.org/wiki/Image:2004_Worldwide_Energy_Sources_graph.png