USING ENERGY

CHAPTER

2

Putting Energy to Work

As explained in the previous chapter, work is force multiplied by the distance through which it acts. As this definition suggests, the trick in getting energy to do work is to channel it in such a way that it moves something. A simple example is a ship's sail. To get to the other side of a lake, one can either row a boat or put up a sail and let the wind do the work.

A windmill works in much the same way as does a sail, but instead of producing linear movement, it converts the wind's kinetic energy into rotary motion. Windmills have been used for centuries to perform such tasks as pumping water and grinding grain. One problem with a windmill is that it is an "intermittent resource"—it only works when the wind is blowing.

Waterwheels are similar to windmills, though their task is to turn the energy of falling or flowing water into rotary motion. While somewhat more reliable than windmills, early waterwheels had problems of their own. A shop, factory, or mill usually could not depend upon its waterwheel more than 160 days a year because of ice, floods, droughts, and dams that silted up.[21]

Besides their unreliability, another big problem with both windmills and waterwheels is that they are stationary and cannot be used to directly power a vehicle.[22] Enter the steam engine. Water can be boiled to generate high-pressure steam anytime and anywhere. The steam's energy can then be directly converted into rotary motion (with a steam turbine), or can be used to push a piston back and forth. The heat required to produce steam can be

[21]David Freeman Hawke, *Nuts and Bolts of the Past: A History of American Technology, 1776–1860* (New York: Harper & Row, 1988), p. 195.

[22]They can, however, power vehicles indirectly. Windmills and waterwheels (or, at least, water turbines) can run generators to charge batteries that, in turn, power vehicles.

ELECTRICITY—THE MODERN EMANCIPATOR
This early advertisement dramatizes how electricity freed people from ordering their lives around the rising and setting of the sun. The drawing depicts another emancipator from Illinois—Abraham Lincoln. Courtesy of Exelon.

generated by burning wood, alcohol, or carbon-based fuels (i.e., peat, coal, oil, or natural gas); or with controlled *nuclear reactions*.

Internal combustion engines burn fuel directly inside piston cylinders where expanding combustion gases drive the pistons.

Rotary motion created by these various means can be used to run machinery (looms, presses, and drills), turn wheels (cars, trucks, locomotives), drive propellers (boats and airplanes), or to generate electricity.

In 1821, Michael Faraday discovered that moving a magnet near a coil of wire produced a flow of electrons—an *electric current*—within the wire. This is the principle of the *electric generator*: wrap a large coil of wire around a rotor, place the rotor between some strong magnets, turn the rotor, and—presto—electricity!

ELECTRICITY

Electricity is an extremely versatile, portable, and convenient form of power, and about a third of America's primary energy is used to generate it. This proportion is expected to grow as computers and other information-age products continue to expand into more and more areas of our lives. The following sections describe conventional and alternative methods of producing electricity and the pros and cons of each.

GROWING HOME USE OF ELECTRICITY

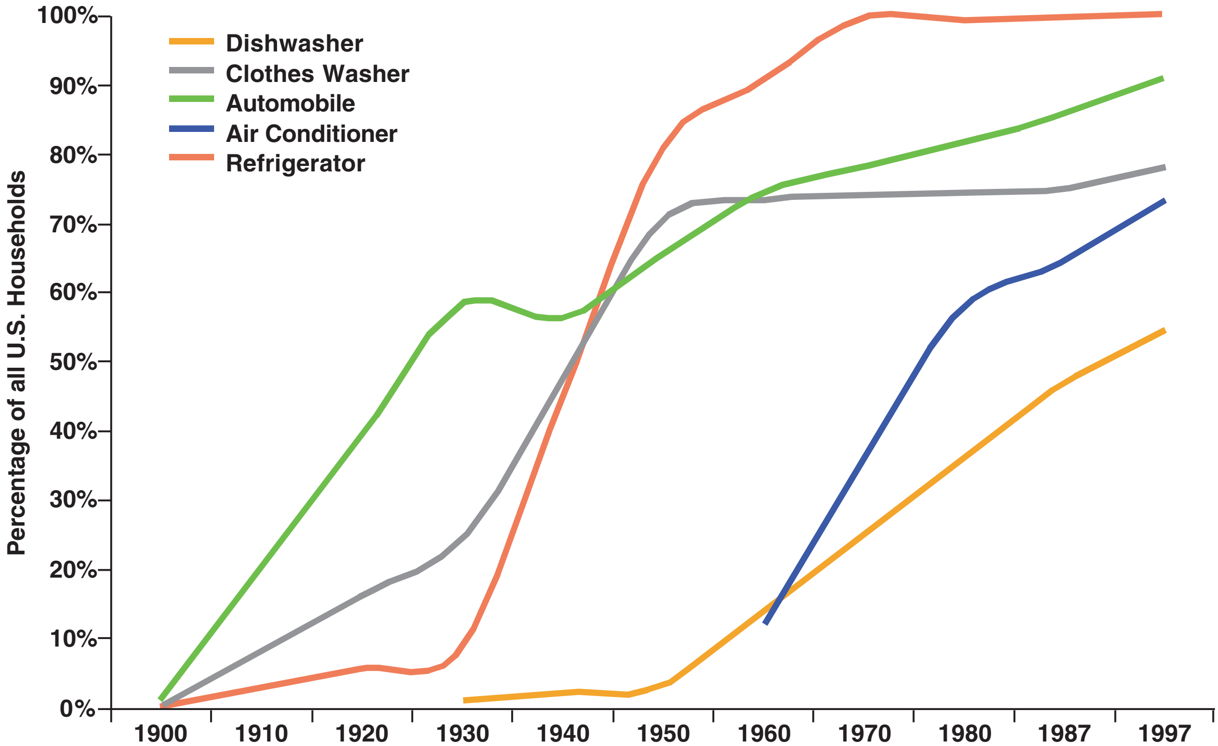
This brief timeline of electricity's home uses shows how new applications of this versatile form of energy have continually emerged to increase efficiency and convenience and to make our lives both more productive and rewarding.

1900s	1910s	1920s	1930s	1940s
• Heater	• Refrigerator	• Air conditioning	• Electric razor	• Electric blanket
• Washing machine	• Electric trains	• Radio	• Can opener	• Dehumidifier
• Vacuum cleaner	• Hair dryer	• Blender	• Garbage disposal	• Electric guitar
• Cloths iron	• Christmas lights			
• Toaster				

1950s	1960s	1970s	1980s	1990s
• Television	• Jacuzzi	• Personal computer	• Dustbuster	• Internet
• TV remote control	• Self-cleaning oven	• VCR	• Rechargeable batteries	• Digital answering
• Dishwasher	• Microwave oven	• Waterbed	• Halogen torchierelamp	• Sony Play Station
	• Security system	• Crockpot	• Cellular telephone	• DVD player
		• Fax machine	• Noise machine	
		• Laser printer		

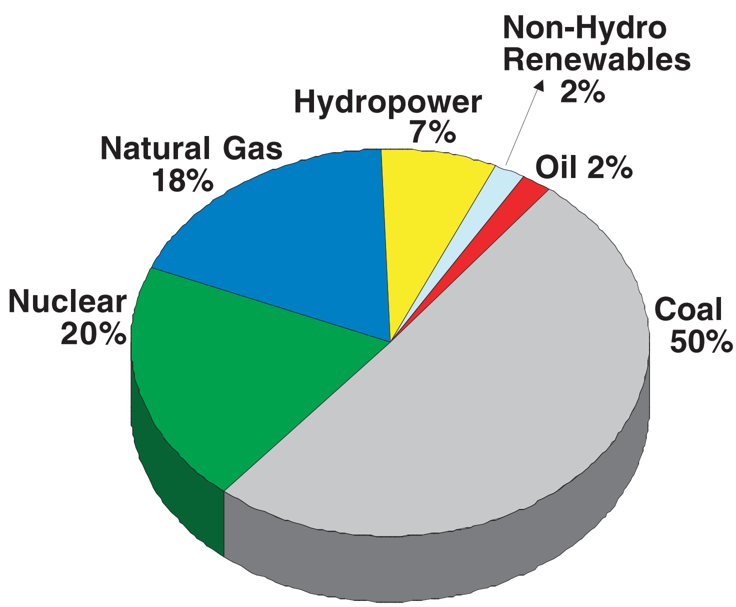
ENERGY USAGE: FROM LUXURY TO NECESSITY

Growing affluence has spread the use of automobiles and major electric appliances to most American households. *Source:* Compiled from *It's Getting Better All the Time: 100 Greatest Trends of the Last 100 Years,* by Stephen Moore and Julian Simon. Copyright 2000 by the Cato Institute. Reprinted by permission.



U.S. ELECTRICITY GENERATION—2002

While coal is still the fuel most often used to generate electricity in the United States, natural gas's market share is growing. Nine percent of United States power is generated by renewables, and only a fourth of that comes from nonhydro sources such as wind, solar, geothermal, and biomass. *Source:* U.S. Energy Information Administration, *Annual Energy Review 2002* (Washington: Department of Energy, 2003), p. 224.



COAL-FIRED PLANTS[23]

The following diagram illustrates the basic operation of a conventional steam plant. Such plants generate most of America's electricity, and most are fueled by coal. In fact, more than half of the country's power comes from coal, the most plentiful carbon-based fuel.

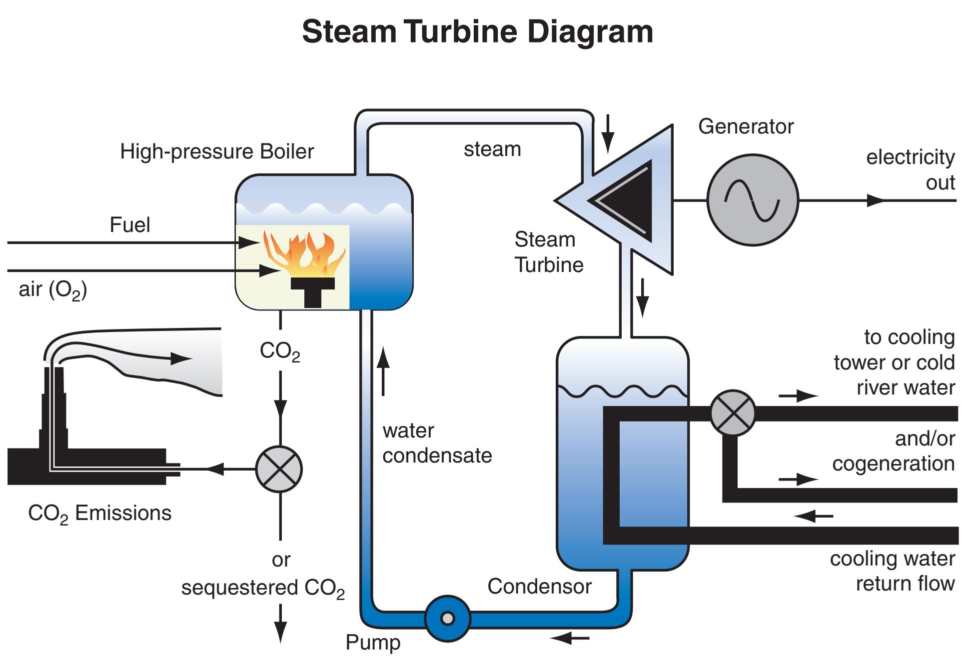
In a typical plant, powdered coal is burned to boil water, converting it into high-pressure, superheated steam. The steam enters a turbine where it expands and drives the turbine's blades. The blades turn a shaft connected to a generator that creates electrical current.

After the steam leaves the turbine, it passes through condensers that cool it back into liquid water. The water is then pumped back into the boiler to repeat the cycle.

Coal comes in four basic forms: *anthracite*, *bituminous*, *subbituminous*, and *lignite*, as shown in the following table.

STEAM TURBINE DIAGRAM

This diagram shows how a steam power plant works. Nuclear plants work in much the same way—the only difference is the way in which water is heated to produce steam. Courtesy of *Power* magazine.



[23]Most of the information for this section on coal comes from Edward Cassedy and Peter Grossman, *Introduction to Energy: Resources, Technology, and Society* (Cambridge, UK: Cambridge University Press, 1998), chapter 6.

Form of Coal	Energy (BTU/lb)	Typical Sulfur Content (%)	Est. U.S. Reserves (billions of tons)
Anthracite	12,500	0.6	7
Bituminous	11,500	2.2	240
Subbituminous	9,500	0.5	180
Lignite	7,000	0.7	40

Adapted from Edward Cassedy and Peter Grossman, *Introduction to Energy: Resources, Technology, and Society,* p. 138, Tables 6.1 and 6.2.

Coal is essentially carbon plus some hydrocarbons and a minor amount of minerals. When coal is burned, heat is produced from the carbon and ash from the minerals. The higher the carbon content, the more heat and less ash that are produced when the coal is burned.

Anthracite has the highest BTU content, but it is also the least plentiful form of coal. Bituminous coal is the most common; its geographically widespread reserves make it readily available to power plants around the country. Unfortunately, it also has the highest sulfur content and releases more sulfur dioxide when burned.

Subbituminous coal has a relatively high BTU content and low sulfur, but 90 percent of its reserves are located in Montana and Wyoming, adding significantly to the cost of transporting it to power plants near major population centers.

Because of its relatively high sulfur content, bituminous coal lost market share to subbituminous coal after passage of the 1990 amendments to the Clean Air Act. Between 1990 and 2002, bituminous production dropped 18 percent (to 566 million short tons from 693 million tons), while subbituminous production rose 82 percent (to 445 million short tons from 244 million).[24]

Lignite, sometimes known as "brown coal," has a lower heating value than subbituminous coal and burns less cleanly. Consequently, it is not as desirable a fuel as are the other types of coal.

Coal use has had a larger effect on the environment than either oil or natural gas, though its impact has decreased with improving technology and stricter regulations. Coal affects the environment in four ways:

1. Extraction — Surface and subsurface mining can significantly alter the landscape and pollute groundwater. In strip mining, the *overburden* (the dirt and rock covering shallow coal seams) must be removed before the coal can be extracted. While under-

[24] U.S. Energy Information Administration, *Annual Energy Review* 2002 (Washington: Department of Energy, 2003), p. 203.

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ground mining results in less damage to the landscape, surface *subsidence* can occur as the tunnels collapse once the coal is removed.

Water seeping into abandoned mines may react with chemicals in the remaining coal to form acids that leach into underground aquifers and drain into rivers and lakes.

These problems can be handled through land reclamation (replacing the topsoil scraped off during strip mining operations) and back-filling empty tunnels to control subsidence.

2. Transportation

The nation's cleanest coal is located in the sparsely-populated West and may need to be moved long distances before it can be used. Railroads transport most of America's coal, but trucks and barges are also commonly used.

Coal also can be transported by pipeline. The coal is ground into powder, then mixed with water to form a slurry that can be pumped. However, this method requires a lot of water, which may not be available near a given mine.

3. Combustion

Burning coal produces pollutants including:

- Sulfur dioxide (SO_2)
- Oxides of nitrogen (NO_x), where x is an integer denoting the particular compound)

- Particulate matter (PM), usually called "particulates"
- Carbon monoxide (CO)

Coal also produces more carbon dioxide (CO_2) per BTU of electricity generated than do other fossil fuels.[25]

Emissions can be controlled in a number of ways. Electrostatic precipitators and filters ("bag houses") remove particulates; "scrubbers" eliminate sulfur dioxide and some nitrogen oxides.

Carbon dioxide removal technologies are still in their infancy, leaving power plant efficiency improvement as the most effective method of reducing CO_2 emissions.

4. Waste Disposal

Unburned ash must be removed from coal-fired plants and dumped. In addition, scrubbers produce large amounts of sludge that present disposal problems.

Currently, most coal ash is sent to landfills. Some is used to backfill mine tunnels, but this is only economical in cases in which the power plant is near the mine. The electric industry is looking for ways to put coal ash to productive use (for instance, the ash may be mined for sulfur and trace metals).

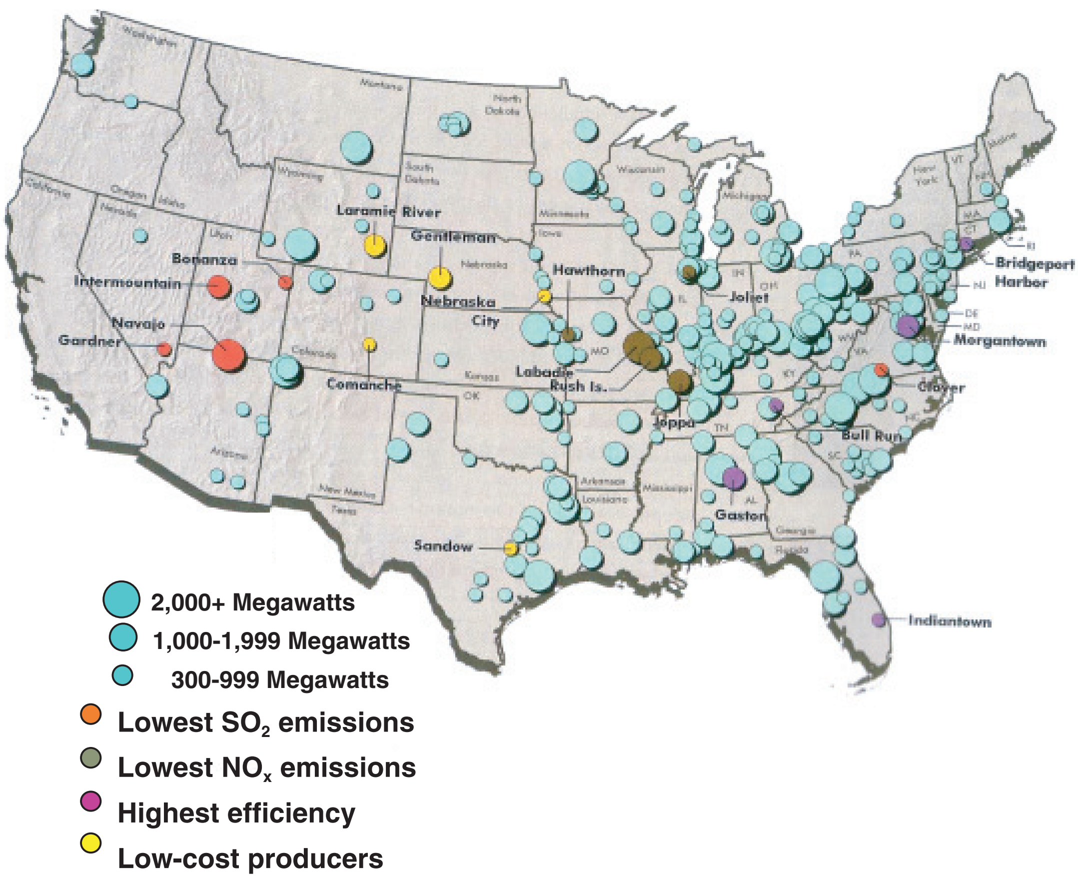
Controlling coal's impact on the environment is expensive. Ultimately, the costs are passed on to consumers in the form of higher prices for both coal and the electricity produced from it. However, as environmentalists point out, these higher prices better reflect the real societal costs of using coal. In the jargon of economics, *negative externalities* (unpaid costs) are being *internalized* (borne by the user). The prices also shift the burden of reducing coal's environmental impact to those who benefit from it.

Despite the higher prices resulting from environmental controls, coal is competitive with other fuels as a primary source of electric power (in 2002, coal-fired plants produced 50 percent of the electricity in the United States).

[25]While carbon dioxide is not a pollutant, it has been associated with global warming, a subject discussed in chapter 6.

COAL-FIRED POWER PLANTS

This chart shows the locations and capacities of the coal-fired plants in the U.S. Most plants are in the East near large population centers. However, most low-sulfur coal deposits are located in the West. *Source:* Bob Schwieger and Melissa Leonard, "First Annual Top Plants Survey," *Power,* August 2002, p. 62. Courtesy of *Power* magazine.



NUCLEAR FISSION

Nuclear power plants produce electricity in much the same way as do traditional power plants. Water is heated to produce steam to drive a turbine that, in turn, spins a generator. The big difference lies in how nuclear plants create the steam.

During *fission*, the nuclei of heavy atoms, typically uranium (^{235}U), are split into lighter nuclear parts. Energy is released in the process. Neutrons from one splitting atom strike other atoms, causing them to split in turn. Because

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more than one neutron is released when an atom is split, the fission reaction becomes multiplied in a *chain reaction*. The amount of fissionable material (like uranium or plutonium) needed to create a self-sustaining chain reaction is called a *critical mass*.[26]

Control rods of neutron-absorbing cadmium or graphite are used to regulate the chain reaction. By inserting or withdrawing the rods, the reaction is either slowed or increased.

The 104 active nuclear power plants in the United States produce about 20 percent of the country's electricity. There are another 350 nuclear plants throughout the rest of the world. Altogether, these plants produce about 18 percent of the world's electric power.

In the United States, the amount of electricity produced by nuclear plants has increased by 25 percent during the 1990s even though the number of nuclear plants fell by eight (from 112 to 104) during this same period.[27] This was made possible by raising the average *capacity utilization factor* of the remaining plants to 89 percent from 69 percent.[28] Put another way, the amount of time that the units were running versus their theoretical maximum rose by one-third.

Part of this improvement was due to better technology and techniques. But another reason was a change in *incentives*. Under traditional public utility regulation, the rewards that plant-owning utilities received were not tied to their performance. Firms simply received from customers, in addition to their

[26]An amount of mass that is more than that required to achieve a chain reaction that is *exactly* self-sustaining is called "super-critical." Anything less is called "sub-critical."

[27]U.S. Energy Information Administration, *Annual Energy Review* 2002, p. 257.

[28]Ibid., p. 224.

operating costs, an allowed rate of return based on the plant's "book value" (original cost minus depreciation). Under deregulation, nuclear plants now earn more money when they produce more power, so better performance means higher returns to shareholders.

In 1979, an accident occurred at the Three Mile Island (TMI) nuclear plant near Harrisburg, Pennsylvania. Although no one was injured and no harmful levels of radioactive emissions were released, the operating utility nearly went bankrupt paying for the cleanup. After the incident, public opinion turned solidly against the nuclear power industry. Nuclear power was dealt an additional blow in 1986 when a terrible accident at the Chernobyl plant in the Soviet Union killed 31 people immediately and exposed an estimated 4,000 more to high doses of radiation.

Containment vessels built around American reactors are designed to be an ultimate safeguard against any incidents. The vessel at TMI worked as designed; but tragically, Chernobyl, built under far lower safety standards than are the norm in western countries, had no such last line of defense.

Advances in technology offer the possibility that future reactors can be made inherently safe from meltdown, but existing reactors of older design will remain in operation for many years. While the U.S. industry has taken steps to reduce the possibility of human error, some analysts argue that accidents due to operator mistakes are inevitable.

Potentially, the biggest problem with nuclear power is the management and disposal of the tons of radioactive wastes produced every year. Nuclear plants produce far less waste than do coal plants. A 1,000-MW nuclear-electric plant, for example, produces about one metric ton of waste per year, versus one *million* tons from a similarly sized coal plant. However, nuclear waste is far more dangerous. Many of the waste products are highly toxic and remain radioactive anywhere from less than one year to millions of years. On the other hand, toxicity is generally inversely proportional to half-life, and some scientists argue that after about 1,000 years most of the waste would be no more dangerous than uranium ore.

Further complicating the storage problem is that the wastes initially generate large amounts of heat. Spent fuel currently is stored at the plants in pools of water that absorb the radiation and dissipate the heat. Heat production drops quickly as the wastes age.

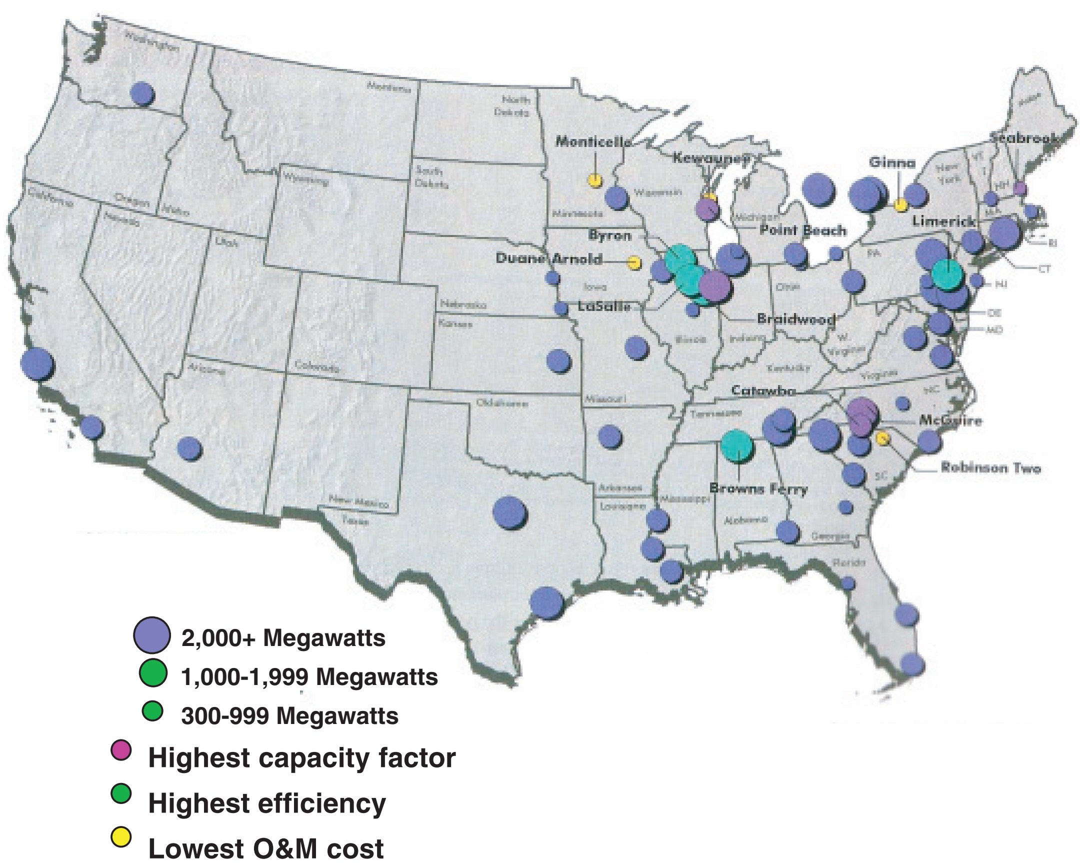
Geological isolation is the only viable long-term disposal solution currently available. This means storing the wastes in highly stable geologic formations that have remained seismically inactive for millions of years. Such formations exist both on land and beneath the oceans, but transporting spent fuel to these sites must be done with care. Terrorists could try to sabotage storage sites or, more likely, attack convoys hauling the materials.

The so-called NIMBY (Not In My Back Yard) syndrome is just as important as are the geological issues in locating a suitable site for waste disposal. Not surprisingly, people are reluctant to live near a nuclear waste dump. Billions of dollars have gone into building a permanent storage facility for high-level radioactive wastes at Yucca Mountain, Nevada. The facility, run by the Department of Energy, was to have opened in 1998, but the project is behind schedule. Even after construction is complete, however, political opposition from Nevada's citizens and politicians may keep the facility's doors shut.

For years, nuclear engineers have argued that spent fuel should be reprocessed to extract any unconsumed uranium along with the plutonium, neptunium, and lawrencium created during fission. These extracted elements could then be fed back into power plants as fuel. While *pyroprocessing* may be technically feasible, current reactors are not capable of using the low-grade fuel thus created.

NUCLEAR POWER PLANTS

This chart shows the locations and sizes of the nation's nuclear power plants. Most of the facilities are located east of the Mississippi River and near large population centers. *Source:* Bob Schwieger and Melissa Leonard, "First Annual Top Plants Survey," *Power,* August 2002, p. 44. Courtesy of *Power* magazine.



Nuclear power plants are much more expensive to build than conventional plants, but their operating and maintenance (O&M) costs are less. It is possible, however, that nuclear power would not be viable without the type of government support that began in the 1950s and 1960s. This support has taken a number of forms, including:

- Direct subsidies. Beginning in 1957, the U.S. Atomic Energy Commission (now the U.S. Nuclear Regulatory Commission) helped pay some of the construction costs of plants built by private utility companies.
- Research and development. Since the establishment of the U.S. Department of Energy in 1977, the government has spent more than $20 billion on nuclear power research and development. In fact, the first commercial reactor was based on reactors designed for use in U.S. Navy submarines.
- Accident liability limits granted to power companies under the Price-Anderson Act of 1957, as amended.

NATURAL GAS PLANTS

Natural gas is the cleanest of the fossil fuels. It leaves no residue and produces less pollution than either oil or coal.

Natural gas is used in both gas turbine and steam generating plants. The most efficient way to use it is in a *combined-cycle* system. In such plants, fuel is burned in a combustion chamber to produce hot, high-pressure gases that pass directly through a gas turbine that, in turn, powers a generator. The still-hot gases are then sent to a waste heat boiler where they heat water to produce steam. The steam turns a turbine that is connected to a second generator. Spent steam is piped to a condenser where it is cooled back into water. The water is pumped back into the boiler, repeating the cycle.

Natural gas became the fuel of choice for new electric generation in the 1980s and 1990s due to falling gas prices and significant efficiencies in gas-fired combined-cycle technologies. As recently as 2001, energy forecasters were predicting that the market share of gas would double in the next two decades.[29]

However, the prices paid for natural gas by power generators have increased by over 50 percent since 2000, while coal prices have dropped. The Energy Information Administration now forecasts that coal growth in the U.S. will be nearly equal to that of gas through 2025.[30]

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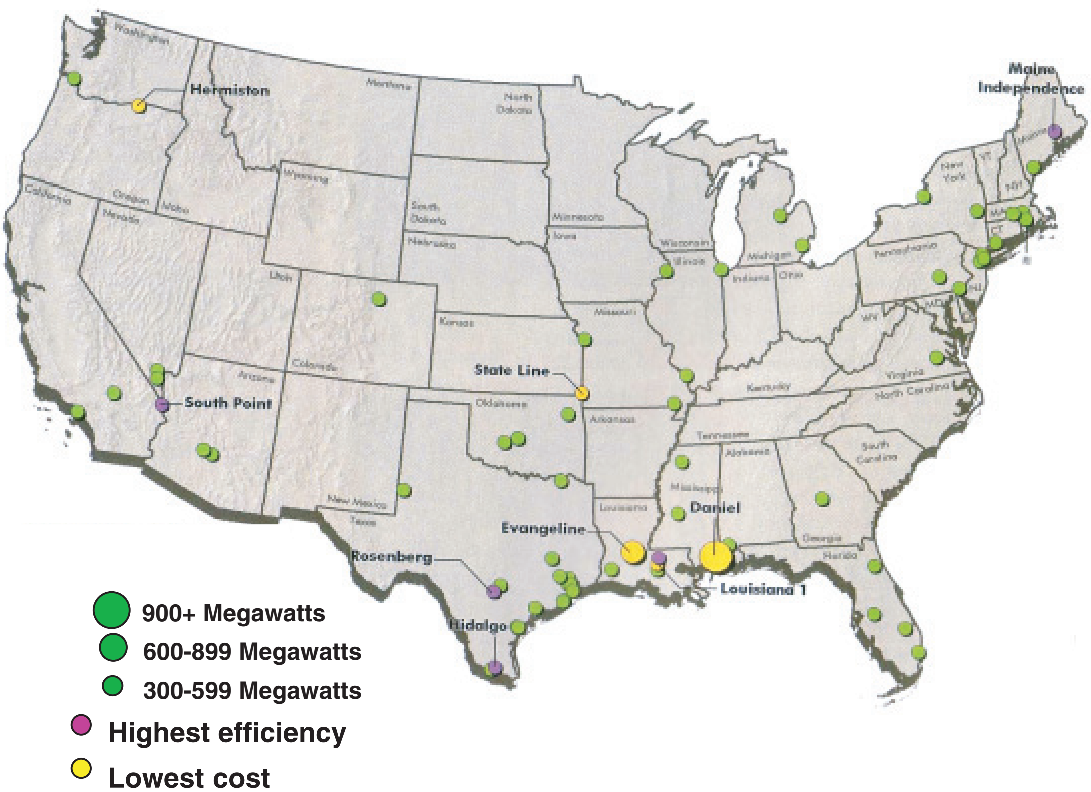
[29]National Energy Policy Development Group, *National Energy Policy* (Washington: Government Printing Office, 2001), p. 1–7.

[30]U.S. Energy Information Administration, *Annual Energy Outlook* 2004 (Washington: Department of Energy, 2004), pp. 82–83, 135.

NATURAL GAS COMBINED-CYCLE POWER PLANTS

Gas-fired combined cycle power plants, the newest plants in the country, are located in the nation's fastest growing areas. *Source:* Bob Schwieger and Melissa Leonard, "First Annual Top Plants Survey," *Power,* August 2002, p. 38. Courtesy of *Power* magazine.



HYDROELECTRIC PLANTS

Hydroelectric plants produce electricity by releasing falling water through turbines that drive generators. Despite the fact that hydroelectric plants produce no pollution, they have fallen out of favor with many in the environmental community who point out that dams disrupt local ecology, place large tracts of land (often including wildlife habitat) under water, and interfere with the migration of indigenous fish.

Currently, hydroelectric plants produce about 7 percent of both America's and the world's electricity. The following table shows estimates of hydroelectric generating capacities that could technically be exploited versus those al-

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ready being used. These numbers are somewhat misleading because only about half of this capacity would be economical to use. Presumably, most (if not all) of the portion that has already been exploited comes from the economic half.

VIABLE HYDROPOWER SITES—POTENTIAL AND EXPLOITED

Region	Technically Exploitable Potential (gigawatts)	Already Exploited (gigawatts)	% Used
Asia	610	98	16
South Asia		45	
China		33	
Japan		20	
Latin America	432	96	22
South America		85	
Central America		11	
Africa	358	17	5
North America	356	148	42
Canada		58	
United States		90	
Former USSR	250	62	25
Europe	163	145	89
Eastern Europe		17	
Western Europe		128	
Oceania	45	12	27
World Total	2,214	577	25

Source: Edward Cassedy, *Prospects for Sustainable Energy: A Critical Assessment* (Cambridge, UK: Cambridge University Press, 2000), p. 137.

Oil-Fired Plants

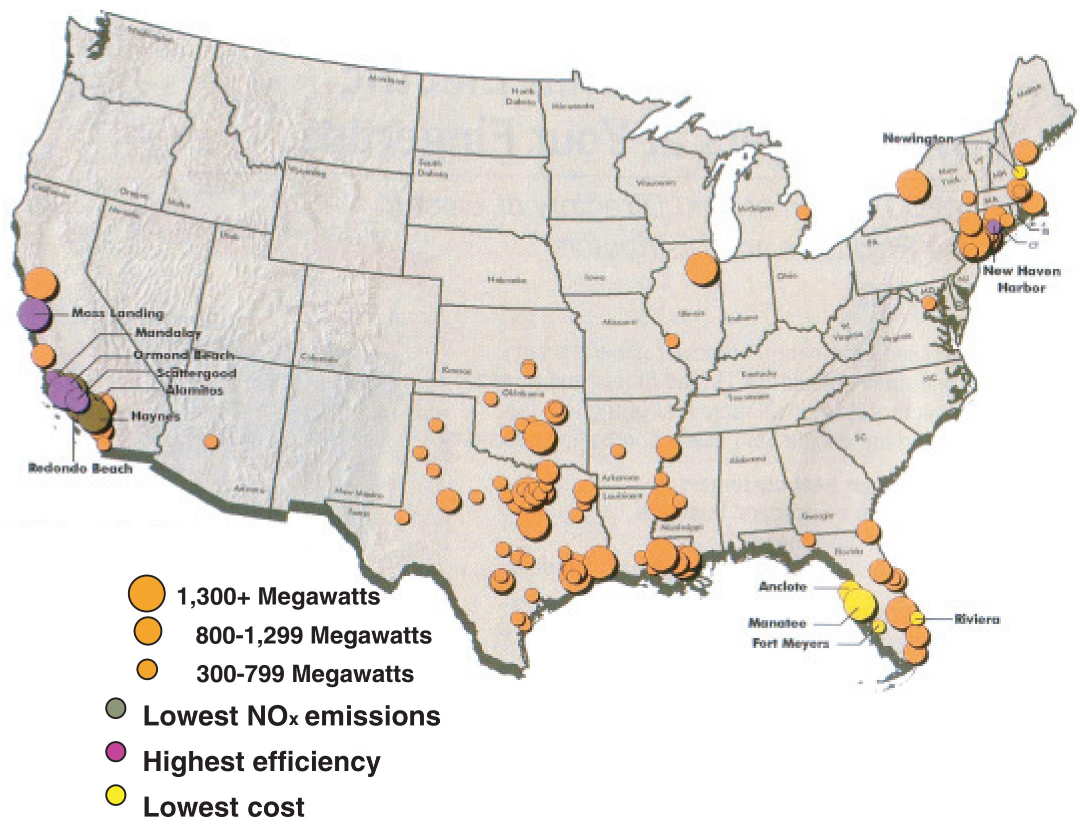
Most oil-fired plants work in much the same way as coal-fired steam plants, although petroleum (like natural gas) can also be used to power turbine generators.

While 39 percent of America's overall energy came from oil in 2002, less than 3 percent of the country's electricity was generated from oil-fired plants.[31]

Oil resources are less plentiful and generally more expensive than coal, but oil has a lower environmental impact. It burns more completely than coal and leaves no ash to be hauled away. It also produces fewer emissions per unit

Oil/Gas Steam Power Plants

Steam plants that can be fueled by either oil or gas are older and less efficient than the newer combined-cycle facilities. Most are used only during high-demand peak periods as swing capacity, and most use gas rather than oil in order to meet air quality regulations. *Source:* Bob Schwieger and Melissa Leonard, "First Annual Top Plants Survey," *Power,* August 2002, p. 54. Courtesy of *Power* magazine.



[31]U.S. Energy Information Administration, *Annual Energy Review* 2002, pp. 9, 225.

of energy generated. Oil wells leave a much smaller footprint than do coal mines, and advances in directional drilling have significantly reduced this footprint even more.[32]

Oil is cheaper to transport than coal because it can be more easily pumped through pipelines.

WIND POWER

Wind power is favored by many environmentalists as the best alternative to power generation from carbon-based fuels. Modern wind turbines use blades, modeled after airplane propellers, to turn electric generators.

Power output is proportional to the cube of the wind speed, and directly proportional to the area swept by the turbine's blades. A typical unit has a blade diameter of about 33 meters (108 feet) and has a capacity of 400 kilowatts. However, General Electric (GE) has developed 3.6-MW turbines designed for offshore use.

Installation costs run about $1,000 per rated kilowatt, not counting transmission lines. This cost and the turbines' operating availability of about 95 percent compare favorably with conventional power plants. However, because turbines work only when the wind is blowing, annual production under even the best conditions is generally only about 20 percent to 35 percent of rated capacity.[33] Adjusting for these numbers, the installed cost of a turbine is closer to $3,000 to $5,000 per kilowatt.

Denmark is the world's leader in wind-power technology; nearly 15 percent of that country's electricity comes from wind turbines. In addition, Denmark supplies state-of-the-art turbines to countries around the world including the United States. Backing from the Danish government has, in part, accounted for the prominence of wind power there. In February 2002, however, the government announced that it was ending its subsidies due to the high cost.

Several areas in the United States boast wind conditions suitable for the operation of *wind farms*, including Iowa, Kansas, North Dakota, and South Dakota. The consistent winds in California's Altamont Pass near San Francisco have made it the country's leading site. California took the lead in wind power in this country with an aggressive tax credit program during the early 1980s. While

[32]Directional drilling techniques allow a drill bit to be guided from the wellhead to oil reservoirs not directly below the wellhead. These techniques are especially useful for offshore production and production in environmentally sensitive areas because they enable multiple well bores to fan out in many directions from a single platform.

[33]Chris Namovicz, *Update to the* NEMS *Wind Model*, presentation to the NEMS/AEO 2003 Conference in Washington, D.C., on March 18, 2003. See www.eia.doe.gov/oiaf/aeo/conf/pdf/namovicz.pdf, slide 15.

some early "tax farmers" used the tax breaks to cash in on failed wind farms, by 1993 wind power supplied more than one percent of the state's electricity.[34]

Problems with wind power include:

- *Location*. Areas with favorable wind conditions are not always near demand centers, and the value of the power produced by remote wind farms may not be worth the cost of building transmission lines.
- *Unreliability*. The intermittent nature of the wind makes turbines unsuitable as primary power sources, at least until significant advances in storage technology are made.
- *Land use*. For wind farms to produce significant amounts of energy, they must incorporate hundreds of turbines requiring large tracts of land (though each turbine's small footprint does allow the land to be used for agriculture or grazing). Assuming that the wind blew all the time, it would take *twenty-five hundred* 400-kW wind turbines to replace one traditional 1,000-MW power plant. Given that the wind does not blow all the time, however, and assuming a capacity factor of 33 percent, it would take 7,500 turbines to replace a traditional plant! By a similar calculation, it would take 835 of GE's 3.6-MW turbines installed offshore to replace a regular facility.

WIND POWER: THEN AND NOW

Machines that convert wind energy into electricity are not new. At the left is an illustration of an experimental wind station from an 1891 issue of *Scientific American.* To its right, a picture of a standard model from the late 20th century. Courtesy of Enron Corp.

[34]Christopher Flavin and Nicholas Lenssen, *Power Surge: Guide to the Coming Energy Revolution* (New York: W. W. Norton, 1994), p. 119.

- *Aesthetics*. Some people object to wind farms because they block their view of nature. Sunlight filtering through rotating turbine blades can also produce an irritating stroboscopic effect.
- *Harm to wildlife*. Birds are killed when they fly into the rotors. The kills, while relatively small in number, may be significant for endangered species such as golden eagles. Of particular concern have been such prime wind areas as Altamont Pass, California and Tarifa, Spain.
- *Noise* (not a factor if the turbines are installed in remote areas).
- *Safety*. Wind turbines can throw ice that builds up on the blades, and the blades themselves can come loose. Blade and turbine maintenance often must be performed at dangerous heights.

At least some of the objections to wind power, such as land use, aesthetics, and noise, might be overcome by placing windmills offshore. However, a proposal to site 170 turbines five miles off the coast of Massachusetts was attacked on the basis that it "would 'industrialize' the area, interfere with local fishing, destroy a 'place of pristine relaxation' for boaters and drive away tourists," according to an article in *The Wall Street Journal*.[35] While the United Kingdom and other coastal European countries have moved ahead with offshore projects, the United States has yet to launch one of its own.

GEOTHERMAL ENERGY

The Earth's core is a vast and essentially unlimited source of heat. Most of this heat is at depths that are currently beyond our reach, but some exists near the surface. Water in these zones can be extremely hot (up to 2,200°F) and under

PhotoDisc

[35]John Fialka, "Florida Utility Finds It's Not Easy Even Trying to Be Green," *The Wall Street Journal*, April 4, 2002, p. A20.

very high pressure. If wells are drilled into these formations, the water can be brought to the surface and used to drive turbines. If water does not exist naturally in such hot formations, it can be pumped in through injection wells and then back out after it has been heated.

The steam and water produced in this manner often contain salts and minerals that pit and corrode turbine blades. Equipment operating under these conditions is subject to frequent breakdowns and high maintenance costs.

Along with salts, the water from geothermal wells, commonly called brine, may contain toxic elements such as lead, arsenic, boron, mercury, and gases such as hydrogen sulfide, which is extremely toxic. The brine may be handled by re-injecting it into the ground. Water re-injection would also eliminate any land subsidence that might otherwise occur.

One problem with geothermal energy is its limited availability. There are few areas on Earth suitable for geothermal power generation. In the United States, geothermal power production is centered in a few western states, and plants are often located in environmentally sensitive areas such as national parks. Another problem is that geothermal sites tend to cool down with use.

Country	Geothermal Generating Capacity in 1998 (megawatts)
USA	2,850
Philippines	1,850
Italy	770
Mexico	740
Indonesia	590
Japan	530
New Zealand	350
Iceland	140
Costa Rica	120
El Salvador	110
Nicaragua	70
Kenya	40
China	30
Turkey	20
Portugal (Azores)	10
Russia	10
Other	10
Total	**8,240**

Source: Ernest McFarland, "Geothermal Energy," in John Zumerchik, ed., *Macmillan Encyclopedia of Energy,* 3 vols. (New York: Macmillan Reference USA, 2001), vol. 2, Table 1, p. 576.

MICROTURBINES

Microturbines are small combustion turbines about the size of a refrigerator. They can produce anywhere from 25 to 500 kilowatts—enough to power 25 to 500 homes. Although they are typically fueled by natural gas, the turbines can also run on diesel. The use of microturbines and other remote devices is known as *distributed generation*.

Microturbines fill an important niche by providing power to areas far away from existing power grids. In developing countries especially, micro power can help bridge the technology gap between the old and new worlds. However, some experts like Johannes Pfeifenberger believe that, "[e]ven with the continued technological progress of distributed resources,. . . the base-load and intermediate-load markets most likely [will] remain dominated by central station power plants."[36] This is because of:

- Economies of scale in development costs (siting, permits, and fuel contract negotiations are less expensive when handled in quantity). Moreover, it takes far fewer resources to build a single 1000-MW generator than two thousand 500-kW units.
- Economies of scale in control, operations, and maintenance.
- Load balancing (i.e., by pooling many customers, the chances of coincidental peak loading is reduced).
- Modular designs that improve plant operating flexibility and allow them to grow with demand.
- Decreasing cost of pollution controls.[37]

In the late 1800s, during the early years of the American electrical power industry, *isolated plants*—"systems designed to light a single building and operated from a 'powerhouse' in the basement"[38]—dominated the market. Such small stations were fast, easy, and cheap to build, and provided quick returns on investment.

Thomas Edison, however, was convinced that the future lay with *central power stations*. He realized that an isolated powerhouse would have to be built with enough capacity to handle its building's peak load. This meant that most of the system's capacity was unneeded for much of the time. Edison reasoned that by pooling users and connecting them to a centralized generating station, the peaks and valleys of demand would even out, and the capacity of the single station could be far less than the sum of the total capacities of the individual powerhouses.

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[36]Johannes Pfeifenberger, "What's in the Cards for Distributed Resources?," *The Energy Journal, Distributed Resources Special Issue*, International Association for Energy Economics, 1997, p. 15.

[37]Ibid., p. 5.

[38]Forrest McDonald, *Insull* (Chicago: University of Chicago Press, 1962), p. 26.

Benefits of Micropower

Benefit	Description
Modularity	By adding or removing units, micropower system size can be adjusted to match demand.
Short lead time	Small-scale power can be planned, sited, and built more quickly than larger systems, reducing the risks of overshooting demand, longer construction periods, and technological obsolescence.
Reliability and Resilience	Small plants are unlikely to all fail at once. They have shorter outages, are easier to repair, and are more geographically dispersed. Factories and computer facilities often use microturbines for backup in case of a loss of power from the regular service provider.
Avoided plant and grid construction, and losses	Microturbines can be placed at the site where power is needed, thus eliminating the need to construct expensive power transmission lines (although the need for a fuel distribution system to supply the microturbines remains). Local siting also eliminates grid power losses.
Avoided emissions and other environmental impacts	Small-scale power generally emits lower amounts of particulates, sulfur dioxide and nitrogen oxides, and heavy metals, and has a lower cumulative environmental impact on land and on water supply and quality.

Source: Adapted from Seth Dunn, *Micropower: The Next Electrical Era,* Worldwatch Paper 151, Washington, July 2000, p. 33, Table 5.

Around 1910, Samuel Insull, the father of the modern power generation industry and a protégé of Thomas Edison, ran a series of studies on the use of isolated powerhouses located in Illinois. As his biographer, Forrest McDonald explained, Insull found that, "For all Illinois outside of Cook County, the combined demand for power was just over 300,000 kilowatts, and various users had installed about 437,000 kilowatts to cover it, though they never used more than about 225,000 kilowatts at the same time. If they were connected as an integrated system, they could easily be served with a total capacity, including abundant reserve, of about 270,000 kilowatts, thus saving more than half of the $43,000,000 that was invested in power supply in the area. The waste of fuel under the existing systemless arrangement was incalculable, but Insull believed that at least three to four times as much coal as necessary was being burned."[39]

The pattern of starting with remote power plants and gradually shifting to central power stations is being repeated in developing countries today.

Proponents of micropower argue that with today's technology, *distributed* does not have to mean *isolated*. Distributed power sources can be tied into the local grid. When home or business owners do not need their generators' total capacity, excess power can flow into the grid and be sold at a profit. Once

[39]Ibid. 142.

enough distributed power supplies are tied to a grid, the need for central plants could actually disappear. Under such a scenario, utilities would not sell power, but instead would sell access to the grid just as internet providers now sell access to the world-wide web.

SOLAR POWER

Photovoltaics, or solar cells, convert sunlight directly into electricity. When photons strike certain semiconductor materials, such as silicon, they dislodge electrons. These free electrons collect on the specially-treated front surface of the solar cell, creating a potential difference between it and the back surface. Wires attached to each of the cell's faces conduct the current. Individual cells can be combined in panels to increase voltage.

Because solar cells only work when the sun shines, they must either be used together with storage devices or as supplements to conventional facilities.

Photovoltaics have provided energy for spacecraft and for remote devices such as floating buoys. However, because of their high cost, they are still not practical for large-scale power generation.

Total grid-connected solar power generation in the United States is currently only about 60 megawatts with perhaps another 120 megawatts not connected to the grid.[40] This totals to less than half the capacity of a traditional mid-sized plant. The few central solar generation facilities in operation are experimental and use large tracts of land. With current technology, about 100 square feet of photovoltaic (PV) panels are required to generate one kilowatt of electricity in bright sunlight. It would take hundreds of square miles of solar panels to replace an average nuclear power plant.

About 10,000 square miles (26,000 km^2) of PV panels would produce enough electricity to supply all U.S. electrical and non-electrical energy needs, while 85,000 square miles (220,000 km^2) would be needed to supply the world with power. By contrast, as an article in *Science* pointed out, "all the PV cells shipped from 1982 to 1998 would only cover [about] 3 km^2," or about 1.16 square miles.[41]

Some scientists suggest that the size of the solar power footprint could be reduced by as much as 75 percent by placing satellites in space to collect sunlight, convert it into electricity, and then beam the power to the Earth's surface in the form of microwaves.[42]

[40]U.S. Energy Information Administration, *Annual Energy Outlook* 2004 (Washington: Department of Energy, 2004), p. 156. Communication from EIA to authors, March 16, 2004.

[41]Martin Hoffert, et al, "Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet," *Science*, November 2002, p. 984.

[42]Ibid.

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Currently, researchers are concentrating on two aspects of the solar cell technology: making solar cells less expensive, and making them more efficient. Unfortunately, high efficiency and low cost tend to be mutually exclusive.

Another way of harnessing solar power is to use an array of mirrors to concentrate, or focus, sunlight onto water flowing through a metal pipe. The resulting steam can then be used to drive a turbine.

BIOMASS

Biomass energy is derived from plants or animal wastes. Wood, a form of biomass, was the first fuel used by humans, long before coal or any of the hydrocarbons. Wood was used for heating caves and later homes, and, much later, for powering steam engines. Usually it was not used in a renewable manner, and many forests were cut down faster than they grew back. Vast oak forests in California's Central Valley, for example, were cut down to fuel early locomotives.[43]

Today, wood and other biomass is more often, but not always, a renewable energy source, and often the biomass used for fuel is the byproduct of other processes. Biomass power accounts for about two-thirds of the nonhydroelectric renewable energy generated in the United States, producing about 3 percent of the country's electrical power. Counting both electric and nonelectric usage, biomass accounts for approximately 4 percent of U.S. and 7 percent of the world's total primary energy use.

[43]Environmentalists have complained that most uses of biomass around the world "are neither renewable nor sustainable." Christopher Flavin and Nicholas Lenssen, *Power Surge*, p. 177.

PhotoDisc

Biomass is a very broad term that covers many primary sources, electric generation technologies, and alternative fuels for transportation. It includes crops grown specifically for energy purposes (so-called *energy crops*) and residue or waste materials, also called *opportunity crops*. Energy crops include fast-growing trees (e.g., eucalyptus) and corn (used for ethanol production). Opportunity crops are more varied and include lumber mill waste, paper mill residues, food crop residues (both field harvesting residue and food processing residue), forest thinnings (e.g., to reduce fire risk), and animal wastes.

Currently in the United States, nearly all biomass electric power generation—probably 90 percent to 95 percent—is based on wood type fuels. Examples include wood waste from pulp, paper, and lumber mills. Examples of biomass not derived from wood include agricultural wastes such as sugar cane bagasse, rice and nut hulls, and fruit pits.

Biomass fuels can be either burned directly to produce steam to drive electric generators, or first converted to a solid, liquid, or gas fuel. Conversion may be by thermal, chemical, or biological processes, or some combination of these methods. Biological processes, like fermentation, covert biomass materials into fuel forms, such as natural gas or gasoline substitutes. Thermal processes like gasification decompose the biomass into combustible gaseous fuels similar to natural gas.

Electric power generation and heating are the main uses of biomass in the United States. A small amount of biomass is converted to ethanol fuel for transportation. Beyond electrical power generation, biomass fuels are used for industrial, commercial and residential heat. The primary wood products industries dominate in the use of biomass heat, with pulp and paper applications surpassing sawmill and lumber applications within the sector. Since the 1970s, the pulp and paper industry has increasingly used leftover materials as fuel to generate steam and power for the paper making process.

During the 1980s, many wood-fired, and a smaller number of municipal-waste-fired, electric power plants were constructed. In several cases, electric utilities built wood-fired power plants or converted existing coal-fired power plants to burn wood and mixtures of wood and coal.

Cofiring—mixing biomass with coal—is the most economical, near-term technology for biomass, with a potential of approximately 7,000 MWe in the United States.[44] The potential economic benefits of cofiring include reduced coal consumption, reduced SO_2, and NO_x emissions, and additional revenue received from wood waste disposal. Negative impacts include increased costs, reduced efficiencies, and potential lost power due to the lower heat density of the biomass. Some biomass fuels also produce increased emissions of hydrogen chloride and heavy metals such as lead, cadmium, and mercury. Reduced marketability of the resulting fly ash may also be a factor.

Another constraint on biomass cofiring is emerging as more coal-fired plants are required to adopt selective catalytic reduction (SCR) as a NO_x control technology. The catalysts used in SCR may be poisoned when exposed to alkali-containing flue gas from biomass.

Plants and trees are able to turn only about 1 percent to 3 percent of the sun's energy into usable fuel, and only a fraction of that can be turned into work by burning them. Even less energy would be produced if the plant matter were first converted into methanol or bio-diesel and then burned. Considering that solar cells' energy efficiency ranges from 15 percent to 20 percent, it is clear that more energy can be produced by covering the ground with photovoltaics than with trees.[45]

There is little reason, therefore, to grow crops specifically for the purpose of energy production, although cultivation of dedicated energy crops is increasing rapidly in some areas due to heavy government subsidies. On the other hand, using residue biomass that would otherwise be wasted does make economic sense, and, in fact, opportunity fuels by far account for most of the energy use of biomass in the developed world.

While biomass is the oldest fuel known to man, the technologies to grow and harvest biomass continue to improve and mature. In addition to the gasification of biomass to produce natural gas and transportation fuels, even more advanced systems, similar to petroleum refineries, can produce a wide variety of products simultaneously, including electricity, plastics and pharmaceuticals, and heat. These "biorefineries" can also produce useful products from the ash and can use a wide variety of biomass materials as input.

[44]MWe and MWt are used to measure plant capacity. MWe indicates megawatts of electrical output, and MWt megawatts of thermal output.

[45]Bjørn Lomborg, *The Skeptical Environmentalist: Measuring the Real State of the World* (Cambridge, UK: Cambridge University Press, 2001), p. 134.

TIDAL POWER

Electric power can be generated from the water flow caused by rising and falling tides. Only a few experimental tidal plants exist in the world today, although a number of suitable locations have been identified. In general, such plants cost significantly more to build than do conventional facilities, and they provide only intermittent service (i.e., when the tide is either coming in or going out).

Tidal power has been used for centuries. As far back as 1734, a mill in Chelsea, Massachusetts used four tide-driven waterwheels to grind spices. It is estimated that under optimum conditions the installation may have generated as much as 50 horsepower.[46] As with wind power, however, tidal power could not survive the introduction of inexpensive electricity generated from carbon-based fuels.[47]

FUEL CELLS

Fuel cells work on the same principles as do storage batteries, except that free electrons are provided by the continuous flow of some fuel-like hydrogen rather than by the corrosion of an electrode.

Fuel cells are efficient and clean; their only effluent is pure water.[48] They have few moving parts and are therefore quiet, reliable, and maintenance free. Like microturbines, fuel cells have found a niche in providing distributed power for remote sites and in serving as power backups.

Also, because fuel cells are so reliable, some companies are using them to power critical computer systems. Momentary power surges and declines, which can cause significant computer problems, are common in today's grid systems. The trade journal, *Public Utilities Fortnightly*, reported that "In 1997, the First National Bank of Omaha switched from the grid to fuel cells after experiencing a costly computer crash at its data processing center."[49]

One of the main drawbacks in using fuel cells is their high cost, which is about $5,200 per kilowatt of capacity as compared to $1,300 to $1,500 per kilowatt for a diesel generator.[50] Another drawback is the difficulty in supplying the hydrogen fuel that powers all fuel cells.

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[46]Wilson Clark, *Energy for Survival: The Alternative to Extinction* (Garden City, NY: Anchor Books, 1974), p. 331.

[47]Ibid.

[48]If hydrogen fuel is provided by a reformer, a device that breaks a hydrocarbon fuel such as natural gas or gasoline into hydrogen and carbon dioxide, then carbon dioxide is also emitted.

[49]Ruth Kretshmer and Kenneth Hundrieser, "Reliability: What Level and What Price?," *Public Utilities Fortnightly*, November 1, 2001, p. 15.

[50]U.S. Energy Information Administration, *Assumptions to the Annual Energy Outlook*, February 2004, p. 35.

Despite these problems, fuel cells have generated interest among auto makers and even some oil companies. This attention brings with it additional focus on both wind and solar power. Some hope that these environmentally friendly or green power sources can provide the electricity required to extract the hydrogen that fuel cells need from either water or methane.

Some of the enthusiasm over fuel cells has begun to die down, however. Part of this may be due to the pall that fell over the high-tech sector when the dot-com bubble burst on Wall Street in 2001.

According to the International Energy Agency, "fuel cells are . . . projected to make a modest contribution to global energy supply after 2020, mostly in small decentralized power plants. . . Fuel cells in vehicles are expected to become economically attractive only towards the end of the projection period. As a result, they will power only a small fraction of the vehicle fleet in 2030."[51]

Fuel Cell Technologies

Type	Description
Alkaline Fuel Cell	Uses a potassium hydroxide electrolyte and operates at 400°F. Alkaline fuel cells have the highest electrical efficiency (70 percent), but are too costly for commercial use. These types of fuel cells are used aboard NASA space shuttles.
Proton Exchange Membrane Fuel Cell (PEM)	Uses a polymer membrane electrolyte and can generate anywhere from a few watts to hundreds of kilowatts. Their relatively low operating temperatures (about 200°F) make these fuel cells suitable for residential and automotive applications. PEM fuel cells include the Direct Methanol Fuel Cell that extracts its hydrogen fuel directly from methanol (eliminating the need for a reformer[52]).
Phosphoric Acid Fuel Cell	Uses a phosphoric acid electrolyte and operates at 400°F. This type of fuel cell was the first to be employed in commercial stationary power generation. Because of its flexibility, the cell is suitable for use by hotels, hospitals, airport terminals, and even locomotives and buses.
Molten Carbonate Fuel Cell	Uses a potassium/lithium carbonate electrolyte and operates at about 1,200°F. Molten carbonate fuel cells have electrical efficiencies of 50–55 percent. Suitable for megawatt-size applications such as commercial buildings and institutions.
Solid Oxide Fuel Cell	Uses a zirconium dioxide ceramic electrolyte that allows the highest operating temperature (1800°F) of all types of fuel cell (higher temperatures generally mean higher efficiencies).

Source: Adapted from Carl Levesque, "How Soon is Now? Looking for Fuel Cell Technology's Future," *Public Utilities Fortnightly,* Vol. 139, No. 20, November 1, 2001, p. 25.

[51] International Energy Agency, *World Energy Outlook*: 2002 (Paris: OECD/IEA, 2002), p. 30.

[52] A reformer is a device that extracts hydrogen (and carbon dioxide) from hydrocarbon fuels such as methane and gasoline.

NUCLEAR FUSION

Like fission, nuclear fusion converts some of the mass in an atom's nucleus into energy. While fission accomplishes this by splitting nuclei, fusion does it by joining two nuclei. The sun is essentially a huge nuclear-fusion reactor.

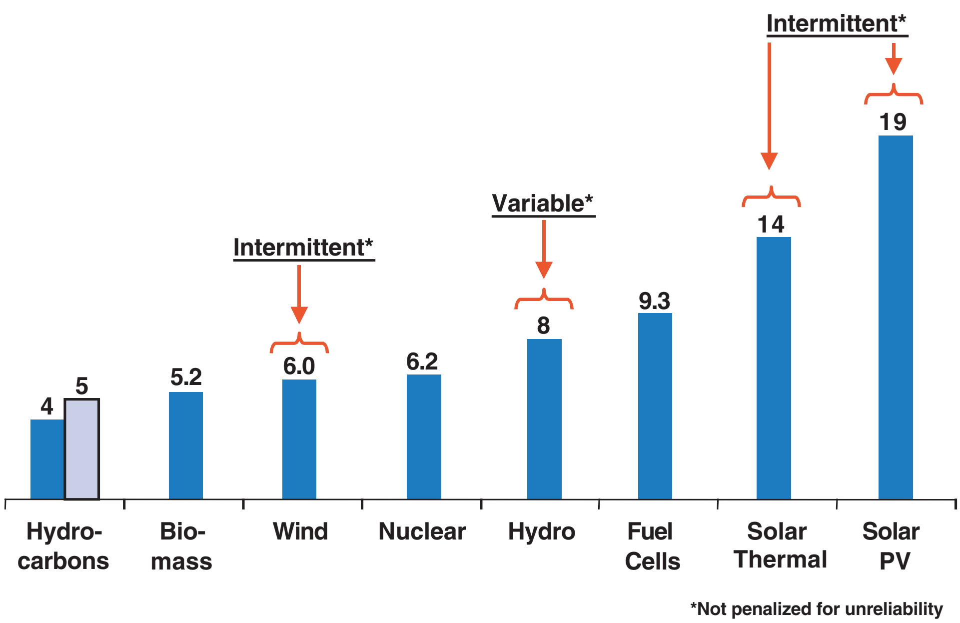
Despite decades of research, no one has yet been able to create a sustained fusion reaction in the laboratory, and scientists do not expect to be able to construct an operating demonstration plant before 2020. If such plants are possible, they offer the promise of a clean and nearly inexhaustible supply of energy.

COMPARATIVE GENERATION COSTS

Which energy technology generates electricity at the least cost? Answering this question is difficult because of constantly changing fuel, maintenance, and regulation costs and because of differences in government subsidies and

COMPARISON OF POWER GENERATION COSTS FOR NEW CAPACITY (CENTS PER KILOWATT HOUR)

Electricity generated from oil, natural gas, or coal is cheaper than that generated from renewable resources. Fossil-fuel plants are also more reliable and have more flexibility in size and location.[53]



[53]U.S. Energy Information Administration, *Annual Energy Outlook* 2003 reference case aeo2003. d110502c. See Appendix F.

tax treatment. Many assumptions must be made, but the U.S. Energy Information Administration estimates that given current technology, hydrocarbon-fired generation is the cheapest and solar the most expensive.

However, availability is as important as the cost of production. The market places a higher value on technology that can reliably produce power at the instant it is needed. "Dispatchability" (industry jargon for the ability to deliver power on demand) is essential to satisfy customers. The availability of both wind and solar power varies from moment to moment, while hydropower, which is ultimately dependent on rainfall, varies by season and year. Thus the costs shown in the previous illustration understate the true costs of the less reliable technologies.

Power Transmission

Electrical power is carried from generation plants over high-voltage wires. The use of high voltages reduces line losses over large distances. Before the power can be used at a home or business, its voltage must be reduced by a device known as a *transformer*.

Transmission lines are controlled by SCADA (supervisory control and data acquisition) systems consisting of remote sensors that transmit data about the lines and the power flowing through them to a central control station.

In the United States, transmission lines are interconnected to form *grids*. Linking the transmission lines together in this way allows power plants to back each other up in case of problems. As the map below illustrates, there are ten separate grids that supply power within the continental United States, Canada, and a portion of Baja California Norte, Mexico. With few exceptions, the grids themselves are not interconnected.

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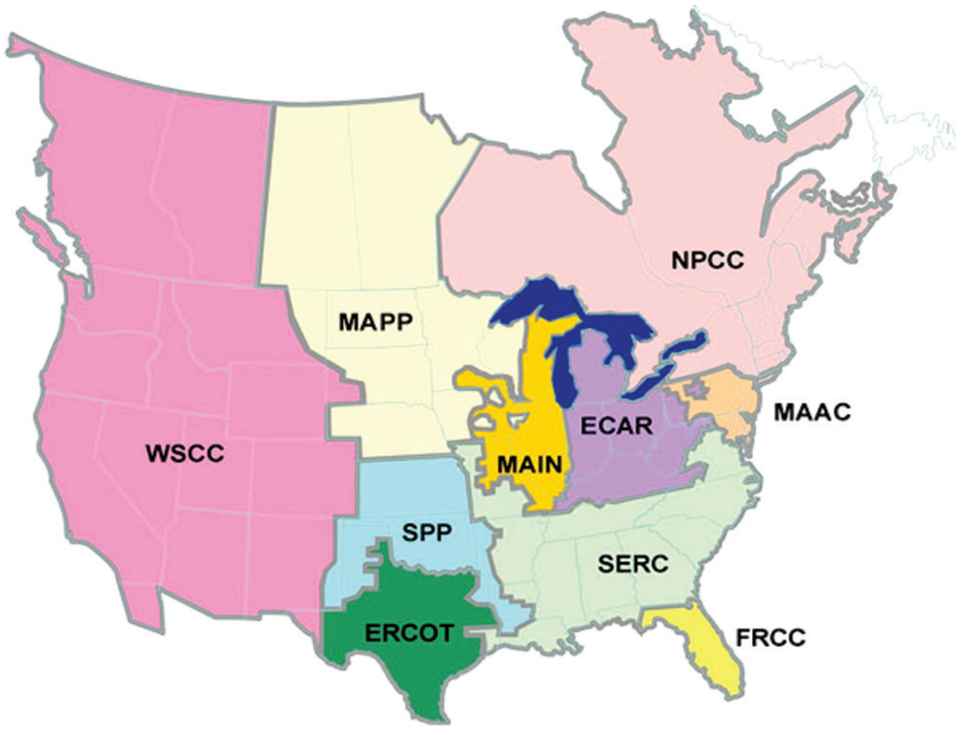
Power transmission has long been considered to be a *natural monopoly*. The belief is that building two or more sets of competing transmission lines each capable of supplying power to every home or factory in a town would be wasteful and would result in higher prices to consumers. In order to avoid such duplication, government authorities typically grant monopoly rights to a single transmission company and then regulate the company's business decisions and the rates that it charges its customers.[54]

NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

A series of power outages, led by the northeast blackout of 1965, resulted in the 1968 formation of the North American Electric Reliability Council (NERC) and its ten Regional Reliability Councils (see Appendix F). Copyright 2004 by the North American Electric Reliability Council. Reprinted with permission.



[54]Industry leaders a century or more ago successfully obtained what became known as the *regulatory covenant*—franchise protection from would-be competitors in return for maximum rates based on a cost-plus determination. Robert Bradley, Jr., "The Origins and Development of Electric Power Regulation," in Peter Grossman and Daniel Cole, eds., *The End of a Natural Monopoly: Deregulation and Competition in the Electric Power Industry* (New York: JAI, 2003), pp. 43–75.

Still, electric distribution companies directly competed in dozens of American cities as late as the 1960s.[55] Economists such as Walter Primeaux see benefits to open competition between so-called public utilities. Economists also recognize the imperfections of *public-utility regulation*, where one firm is given a legal monopoly and all but guaranteed cost recovery at varying levels of performance.[56]

Transportation

Transportation accounts for more than a quarter of America's energy consumption and about a fifth of world energy use. The sections that follow discuss not only the primary power plant used in today's vehicles—the internal combustion engine—but also possible alternatives to the engine and to its most common fuels, gasoline and diesel.

Internal Combustion Engine

Much of the world's oil is used to move people and goods, and most of that is consumed by internal combustion engines. When the gasoline-fueled automobile first appeared, it was hailed as a great boon to the environment. That may seem strange today, but at the turn of the century horses and oxen powered most vehicles. Fueling a nation's draft animals requires that much land be placed under agriculture—resulting in a loss of natural habitat. In the early 1900s, "it took about 2 hectares [almost 5 acres] of land to feed a horse—as much as was needed by eight people. . . . In 1920, a quarter of American farmland was planted to oats, the energy source of horse-based transport."[57]

Worse, animal power turned city streets into filthy breeding grounds for disease, reeking of manure and urine and swarming with flies. San Francisco's ordinances still include a law that bans the piling of horse manure more than six feet high at street corners. Another legacy of horse power is the custom that a gentlemen walks to the outside when escorting a lady down a sidewalk. This was done to shield the lady's dress from any muck that might be thrown up by passing carriages.

[55]Walter Primeaux, Jr., "Total Deregulation of Electric Utilities: A Viable Policy Choice," in Robert Poole, ed., *Unnatural Monopolies: The Case for Deregulating Public Utilities* (Lexington, MA: Lexington Books, 1985), p. 128.

[56]The difficulties of regulation include determining when costs are *reasonable* and when new investments are *prudent* given the incentive of utilities to incur greater costs (such as salaries) and "pad" or "gold plate" the rate base (physical assets) to earn more profits.

[57]J. R. McNeill, *Something New Under the Sun*, p. 310.

TRANSPORTATION IN TRANSITION

This scene from a midwestern street around 1910 shows transportation in transition from the horse-and-buggy era to the age of the horseless carriage. The smoke of the early automobiles was considered much less polluting than the excrement and carcasses of horses on the street. *Source:* John Jakle and Keith Sculle, *The Gas Station in America* (Baltimore: John Hopkins, 1994), p. 207.

In addition to the tons of waste that had to be scraped off city streets and carted away each day, the bodies of thousands of dead horses had to be disposed of. "A big city had to clear 10,000 to 15,000 horse carcasses from the streets every year."[58] Early autos were noisy and belched smoke, but at least they kept the streets clean.

Today's engines are far more powerful, efficient, and cleaner than their ancestors. No other power plant can yet match the gasoline engine's combination of convenience, power, and low cost. Consider that a fifteen-gallon gas

Corbis

[58]Ibid.

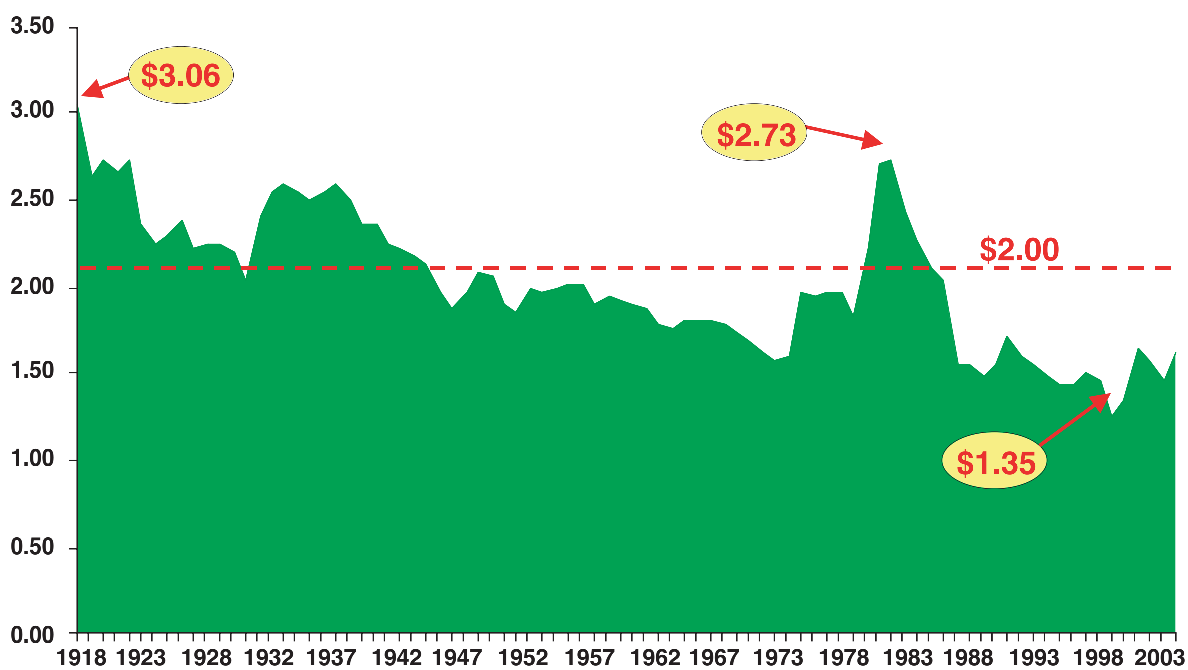
tank gives the average car a range of more than 300 miles. When the tank is empty, it can be quickly filled at any one of tens of thousands of service stations across the country.

Despite occasional spikes, the price of gasoline has, on average, declined over the past 80 years (after adjusting for the decreasing purchasing power of the dollar due to monetary inflation). This decline is even more impressive when two key factors are considered. First, the quality of gasoline has improved greatly over the decades. Second, local, state, and federal retail motor fuels taxes have increased more than the rate of inflation.

In the United States, motorists pay an average tax of over $0.40 per gallon or 25–30 percent of the pump price. As high as this is, motorists in Canada pay more than $0.60 per gallon, motorists in Spain and Australia pay more than a dollar per gallon, and drivers in some European countries pay more than two dollars in taxes per gallon, giving them the most expensive motor fuel in the world.[59] Because Americans drive greater distances than do Europeans, and in larger

U.S. RETAIL GASOLINE PRICES 1917–2003 ($/GALLON IN 2003 DOLLARS)

Average U.S. gasoline prices have remained steady or declined over the decades despite motor fuel taxes that have risen more than the rate of inflation. *Source:* See Appendix F.



[59]International Energy Agency, *Energy Prices and Taxes, First Quarter* 2003. (Paris: OECD/IEA, 2003).

vehicles that use more fuel per mile traveled, it has been more difficult politically to raise taxes in the United States than it has on the other side of the Atlantic.

ELECTRIC CARS

Electric cars are not a new idea. In the late 1800s, most American automobiles in regular production were electric. In fact, according to historian David Kirsch, "the Electric Vehicle Company was both the largest vehicle manufacturer and the largest owner and operator of motor vehicles in the United States."[60] The cars were quiet, easy to operate, and could travel about 40 to 60 miles before needing to be recharged.

EARLY ELECTRIC VEHICLE ADVERTISEMENT

This advertisement highlights the attractions of early electric vehicles. *Source:* Advertising Ephemera Collection, Emergence of Advertising On-line Project.

[60]David Kirsch, *The Electric Vehicle and the Burden of History* (New Brunswick, NJ: Rutgers University Press, 2000), p. 31.

Electrics soon fell out of favor with the driving public, however. Gasoline engines replaced electric motors as the power plant of choice because of their greater power and range. By 1914, internal combustion engines powered 99 percent of the 568,000 vehicles manufactured in America.[61]

While there have been advances in storage battery technology, batteries have not kept pace with the higher demands consumers place on cars.[62] Today's electrics (also called zero emissions vehicles, or ZEVs) can move faster than their early predecessors and offer more in the way of amenities, but their range is still limited to between 50 and 150 miles after five-hour battery charges.[63]

The vast majority of the auto trips most people make are within a few miles of their homes. Were range the only limitation, then, an electric would make an acceptable second or third car for those who can afford more than one vehicle. Unfortunately, ZEVs have other serious shortcomings:

- They can cost two or three times as much as comparable conventional vehicles, although ZEV proponents hope that mass production will eventually result in lower prices.
- In order to stretch their driving range, manufacturers have had to build ZEVs out of lightweight materials. Consequently, they do not stand up as well to collisions as do their heavier, gasoline-powered rivals.
- Typical ZEVs have load capacities of about half of those of conventional vehicles.
- The cars' batteries are expensive (about 20 percent of the cost of a vehicle) and must be replaced every four to six years.[64]
- The batteries contain toxic chemicals, including lead, and their disposal creates serious waste management problems.
- While the cars themselves do not pollute, the power plants that supply the electricity needed to recharge their batteries do. Some environmentalists have dubbed ZEVs "Emission Elsewhere Vehicles."[65]

Despite these limitations, in 1990 the California Air Resources Board's Low-Emission Vehicle Program mandated that by 2003 ten percent of all new cars sold in the state had to be electric. CARB relaxed the requirement

[61] Ibid. 15.

[62] The lead-acid battery is still the most cost-effective battery for cars even though it has been around for a century and a half.

[63] Edward Cassedy, *Prospects for Sustainable Energy*, p. 165.

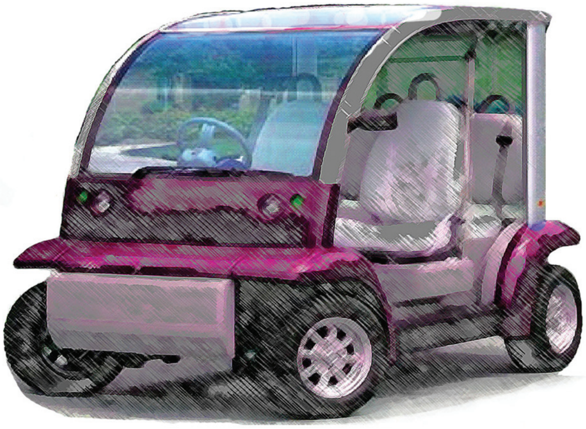
[64] Ibid., p. 164.

[65] Amory Lovins, quoted in *Alternative Fuels: Myths and Strategies*, American Petroleum Institute, August 8, 1995, p. 3.

ELECTRIC VEHICLES: THEN AND NOW

Electric vehicles are still a niche product after a century of development. The similarity between early and some modern electrics underscores a lack of progress relative to vehicles powered by the internal combustion engine. *Source:* (a) Colorado Historical Society, Denver Art Museum. Denver Public Library. (b, c) illustration by Jean Spitzner.

(a)



(b)

(c)

several times, and, in January 2001, gave auto makers credits toward the 10 percent ZEV goal for partial zero emission vehicles (PZEVs), advanced technology zero emission vehicles (AT-ZEVs), and super-ultra-low-emission vehicles (SULEVs).[66]

Critics point out that these vehicles are so expensive that the only way that automakers can sell even this reduced number is to price them well

[66]U.S. Energy Information Administration, *Annual Energy Outlook* 2002 (Washington: Department of Energy, 2002), p. 17.

below cost. This means that the price of regular cars must go up to offset manufacturers' losses on the sale of electric vehicles. As a result, some consumers may be forced to drive their old cars longer than they ordinarily would. The net result could actually be dirtier air because older cars tend to be less efficient than new ones. In fact, it could well be that auto emissions could be reduced far more and with much less cost simply by helping owners of old, heavily-polluting cars replace their vehicles with newer, cleaner models.

Another possible unintended consequence of California's program may be more traffic deaths; older cars and ZEVs are not as safe as new conventional automobiles.

Despite such problems, California's Low-Emission Vehicle Program has been adopted by several other states, including New York and Massachusetts—states with dense traffic and associated air quality problems.

Even with these looming mandates, Ford Motor Company abandoned its two lines of Think! electric vehicles (see the above figure) in August 2002. After spending $123 million on development, the company concluded that there simply were not enough customers interested in the vehicles.[67]

HYBRIDS

Hybrid Electric Vehicles (HEVs) offer a viable alternative to all-electric cars. Hybrids are powered by an internal combustion engine and driven by one or more electric motors. Although a number of configurations are possible, typically the gas engine runs a generator that powers an electric motor at each of the car's wheels. An electric battery provides back-up power for entering traffic and passing, and is recharged by the generator when the vehicle is idling or operating at cruising speeds.

Although HEVs aren't true zero emission vehicles, they do offer a number of advantages over all-electric cars, including:

- Better acceleration
- Lower cost
- Greater range (500 to 700 miles)

[67]Micheline Maynard, "Ford Abandons Venture in Making Electric Cars," *New York Times*, August 31, 2002, p. B1.

- No need for lengthy battery recharges
- Fewer batteries to replace
- Fueled by readily available gasoline or diesel

HEVs also have some advantages over traditional cars:

- Lower emissions
- Significantly better gas mileage
- Greater range
- Similar or better performance

There are several reasons why hybrids are more efficient than conventional cars. First, their own internal combustion engines can be much smaller (and therefore lighter) because they need to be sized only for average operating conditions. Any additional needs are supplied by the battery.

Hybrids also recover some of the kinetic energy that is normally lost when braking. When traditional cars brake, they convert kinetic energy into heat, whereas hybrids use regenerative braking. During braking, the electric motors are switched to work as generators (a generator is essentially a motor working in reverse). The torque required to turn these generators is converted into electrical energy, which is fed back into the storage battery.

Finally, like ZEVs, HEVs rely on lightweight materials to reduce their overall weight.

In the near term, hybrids offer a much more realistic alternative to traditional cars than do all-electric vehicles.

ALTERNATIVE FUELS

LPG and CNG[68]

Liquefied Petroleum Gas (LPG) together with *Compressed Natural Gas* (CNG) are the most common alternatives to gasoline and diesel used in the United States. Both fuels produce fewer emissions than gasoline and about 25 percent less carbon dioxide (CO_2).[69] Until recent years, both fuels were less expensive than gasoline.

[68]CNG, the abbreviation for *compressed natural gas*, has been copyrighted by the company, Consolidated Natural Gas.

[69]T. Y. Chang, R. H. Hammerle, S. M. Japar, and I. T. Salmeen, "Alternative Transportation Fuels and Air Quality," *Environmental Science and Technology*, Vol. 25, no. 7 (1991), p. 1194.

LPG and CNG-fueled vehicles have found a number of market niches. Theme parks with heavy foot traffic sometimes use natural gas-powered carts to avoid the fumes that would be produced were the carts fueled with gasoline or diesel instead. Farmers have used LPG from on-site storage tanks rather than install gasoline pumps to refuel their vehicles. Fleets whose vehicles travel regular routes have also found natural gas to be an economical alternative to traditional fuels.

On the down side, the Department of Energy estimates that new natural gas vehicles (NGVs) can cost anywhere from $2,500 to $5,000 more than conventional vehicles, while LPG-fueled cars cost about $2,500 more.[70] In addition, these alternative-fuel vehicles (AFVs) are less reliable and less convenient to refuel. Finally, because both fuels contain less energy by volume than does gasoline, larger tanks are needed. In fact, a cubic foot of compressed natural gas contains only about one quarter of the BTUs that are in a cubic foot of gasoline. Tanks on an NGV can take up nearly all the available cargo space, while holding only about 150 miles worth of fuel.

Despite these drawbacks, the federal government and some states have promoted the use of AFVs through subsidies and tax breaks. In 2000, for example, Arizona began offering its citizens a lump-sum rebate of 40 percent of the price of a new AFV. Thousands of people took advantage of the program to purchase taxpayer-subsidized trucks. The program was abruptly ended seven months and $500 million dollars after it began.[71]

The environment may actually be worse off as a result because the program encouraged the purchase of trucks, which use more fuel than do regular cars. Worse, participants only needed to promise to use 100 gallons of alternative fuel a year in their vehicles in order to qualify, so many of the new trucks ended up burning mostly gasoline.

In Albuquerque, New Mexico, the police department purchased 15 natural gas-powered squad cars for $25,000 each with a grant from the federal government. As Sean Paige reported in *Reason* magazine, "The autos have only about half the range of conventional patrol cars, they perform sluggishly, and they can be refueled at only one location in town." Still, the department's fleet coordinator said, "We couldn't turn down what was basically a free car."[72]

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[70]U.S. Department of Energy, *Taking an Alternative Route* (Washington: Department of Energy, 2001), pp. 18, 19.

[71]Sean Paige, "The Great Pickup Stick-Up," *Reason*, June 2001, p. 43.

[72]Ibid. 47.

ETHANOL

Ethanol is an alcohol produced from the fermentation of sugar. In the United States, it is typically made from corn. Benefits of ethanol over gasoline include:

- Lower carbon dioxide emissions (though other emissions are comparable)
- Non-toxic
- Renewable supply

Problems with ethanol include:

- About 20 percent less BTU content by volume.
- Cannot be transported through existing pipelines.
- Significantly more expensive to produce.
- Requires that a significant amount of land be placed under cultivation. Along with this would come an additional load on the fresh water supply, increased use of fertilizers (which could end up in streams and rivers), and loss of forestland and other natural habitat.
- Creating ethanol may consume more energy than is contained in the ethanol. This point is controversial, and probably cannot be resolved as long as the government subsidizes production of the fuel. If producing ethanol on the free market yields a net monetary profit, then it will likely yield a net energy profit as well (see the section, *Energy Economics* in the next chapter).
- Ethanol-fueled vehicles cost several hundred dollars more than comparable conventional vehicles.

> *"The fuel of choice during the early days of the automobile industry appears to have been none other than ethanol. . . . The availability of gasoline was very limited and its distribution system was not yet in place. Ethanol, by contrast, derived from the fermentation of sugars and starches, was a well established industry, and a relatively abundant supply of it was available. It is reported that in 1908, when Henry Ford began the production of the famous Model T, which was to establish the automobile as we now know it, he consulted with Thomas Edison whether to use gasoline or ethanol as the fuel for the new model vehicle. Edison advised Ford to choose gasoline."*[73]
>
> **John Ingersoll**

[73]John Ingersoll, *Natural Gas Vehicles* (Lilburn, GA: Fairmont, 1996), p. 20.

EARLY ETHANOL ADVERTISEMENT

This advertisement for a 1902 French auto, cycle, and boat show, features alcohol as the fuel of choice. *Source:* Reproduced in John Ingersoll, *Natural Gas Vehicles* p. 21.

METHANOL

Methanol also is an alcohol, but, unlike ethanol, it is highly toxic. It can be made from coal, natural gas, wood, and biomass. Methanol's advantages over gasoline are:

- Lower carbon dioxide emissions (other emissions are comparable)
- Renewable supply

Its disadvantages include:

- Cannot be transported through existing pipelines
- Somewhat more expensive to produce
- More toxic
- About 50 percent less BTU content by volume, requiring larger fuel tanks and resulting in less vehicle cargo and passenger space
- More corrosive (harder on auto parts)
- Lower vehicle resale value
- More frequent vehicle oil changes
- Higher vehicle cost (several hundred dollars more)

In the 1970s and 1980s, methanol attracted government support as "the most promising alternative to motor vehicle fuel" for the United States.[74] The California Energy Commission promoted the fuel as a way to increase energy security by reducing dependence on petroleum imports while, at the same time, decreasing air emissions. Methanol's attraction faded in the 1990s as reformulated gasoline and improvements in vehicle technology significantly and affordably reduced emissions with no inconvenience to motorists.[75]

HYDROGEN

From an environmental standpoint, hydrogen is nearly an ideal fuel because its only products of combustion are water and some nitrogen oxides. Unfortunately, hydrogen is very reactive and does not exist in a pure state on Earth.

[74] *Methanol: Fuel of the Future, Hearing before the Subcommittee on Fossil and Synthetic Fuels*, 99th Cong, 1st sess., (Washington: Government Printing Office, 1986), pp. 43, 80, 114.

[75] Robert Bradley, Jr., "The Increasing Sustainability of Conventional Energy," *Cato Policy Analysis*, No. 341, April 22, 1999, p. 24.

Hydrogen is therefore considered to be an *energy carrier* (like a battery), rather than an *energy source*. Hydrogen cannot replace fossil fuels, nuclear power, or any other primary energy source. In fact, energy from these sources must be expended to produce hydrogen.

Hydrogen usually is extracted from hydrocarbons although it can also be generated by *water electrolysis*, a process that consumes a lot of electricity.

If the electricity used to produce hydrogen is generated by burning coal or hydrocarbons, there would be little environmental benefit over the use of reformulated gasoline. Significant emission reductions would be achieved only if the electricity were to be produced by solar or wind power, a hydroelectric facility, or a nuclear plant.

There may prove to be a symbiotic relationship between hydrogen fuel use and both solar and wind power. One of the chief problems with these sources of electricity is that they are intermittent—they only work when the sun is shining or the wind is blowing. This makes them unsuitable as power sources for customers who require a steady supply of electricity. However, the sporadic nature of these sources is less of a problem for the purpose of hydrogen production.

Hydrogen can also be extracted from hydrocarbons such as methane or gasoline. Another promising method involves mixing borax with water to form sodium borohydride, and passing the mixture through a catalyst chamber to produce hydrogen.[76]

NASA scientist Friedemann Freund has suggested that there may be vast amounts of hydrogen existing in the top 12 miles of Earth's crust.[77] If this hydrogen can be economically extracted (i.e., if the hydrogen that is extracted contains more energy than must be expended to produce it), it may provide a nearly inexhaustible source of clean energy.

One problem with using hydrogen as a fuel is a phenomenon known as *hydrogen embrittlement*. Under high pressure and temperature, hydrogen, the smallest of the atoms, can flow into the intermolecular spaces in steel. When this occurs, the metal can become brittle and susceptible to fracture.

Also, as with other alternative fuels, there is no distribution network for hydrogen, so refilling the tank would present a problem.

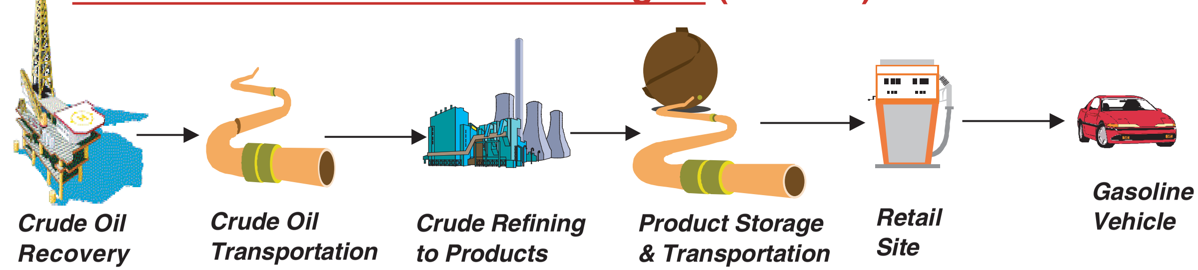
[76]Julie Wakefield, "The Ultimate Clean Fuel," *Scientific American*, May 2002, p. 36.

[77]John Bluck, "Hydrogen-Fed Bacteria May Exist Beyond Earth," NASA *News*, April 3, 2002.

Wells-to-Wheels Comparison

This diagram shows the flow of energy resources from the wells or mines to consumers, and illustrate the different infrastructures involved for conventional (current) and hydrogen technologies.

Gasoline Internal Combustion Engine (Present)



Hydrogen Fuel Cell from Electricity (Hypothetical)