Appendix A

Renewable Energy Technology

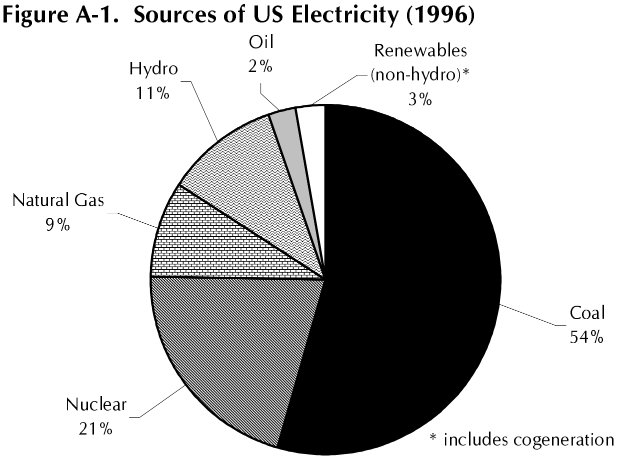
Potential, Costs, and Market

The United States produced about 450 billion kilowatt-hours (kWh) of electricity from renewable energy sources in 1996, about 12 percent of the national total. Hydroelectric generators produced 10 percent of this. Only 2 percent came from other renewable sources powered by biomass, geothermal, wind, or solar energy (figure A-1).*

Solar Energy

Photovoltaics, or solar cells, are the most common solar electric technology. When sunlight hits a semiconductor material, like silicon, it knocks electrons loose from the atoms. These electrons flow in a closed circuit, creating an electrical current. The global photovoltaics industry is growing rapidly, from sales of 23 megawatts (MW) per year in the late 1980s to over 100 MW in 1997. American manufacturers saw annual average growth of 19 percent over the last ten years, with much of their market found abroad. American companies exported $83 million worth of solar panels in 1996.[1] Much of the market is in providing power to people who are "off the grid," or not connected to power lines, especially in developing countries. In the United States, solar cells are increasingly used to power road signs, irrigation pumps, and cellular phone transmitters.

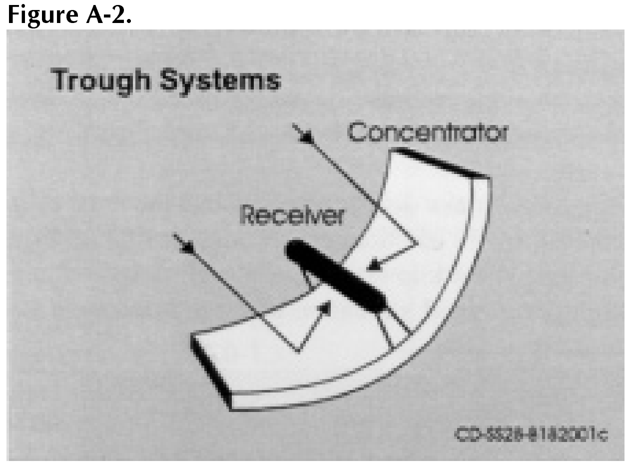
Figure A-1. Sources of US Electricity (1996)



Source: Annual Energy Outlook 1998, Energy Information Agency.

A second type of solar technology uses the sun's energy to heat a fluid. Steam produced using the heated fluid turns a turbine to generate electricity. Such solar thermal electric technology may take any of three configurations: troughs, towers, or dishes.[2] The most common—solar troughs—use curved (parabolic) mirrors in the shape of a trough to heat a fluid in a tube running through the center of the trough (figure A-2). Southern California has 354 MW of solar troughs. Solar towers use mirrors to heat a fluid in a central tower (figure A-3). Two experimental 10 MW "power towers" have been built in California. Solar One operated from 1982–1988,

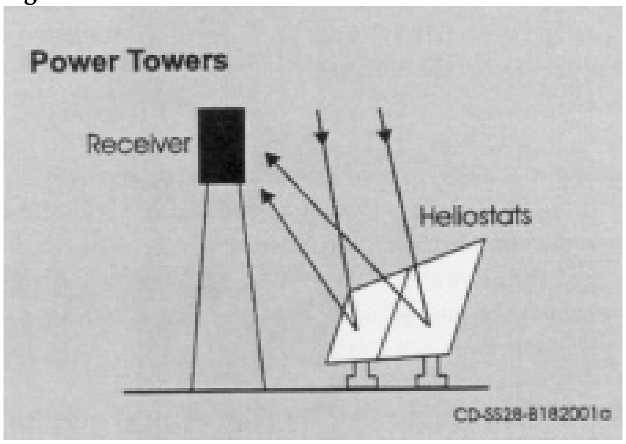
Figure A-2.



Office of Utility Technologies, DOE and Electric Power Research Institute, 1997. *Renewable Energy Technology Characterizations*, October, online at www.eren.doe.gov/utilities/techchar.html.

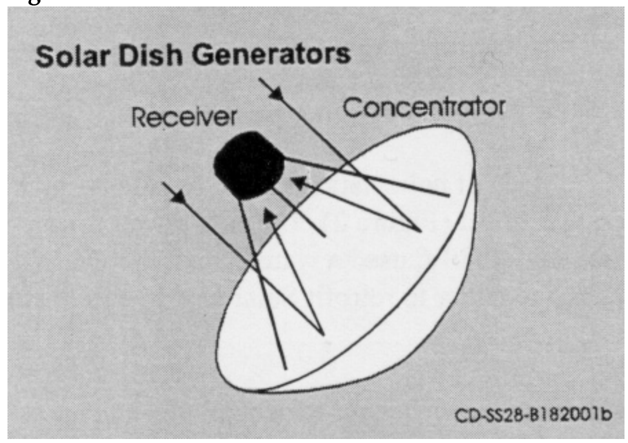
* The capacity of a power plant is typically measured in megawatts (MW), or million watts of generating capacity. Electrical energy is measured in kilowatt hours or megawatt hours (kWh or MWh). A typical American household uses about 10,000 kilowatt-hours per year.

Figure A-3.



Office of Utility Technologies, DOE and Electric Power Research Institute, 1997. *Renewable Energy Technology Characterizations*, October, online at www.eren.doe.gov/utilities/techchar.html.

Figure A-4.



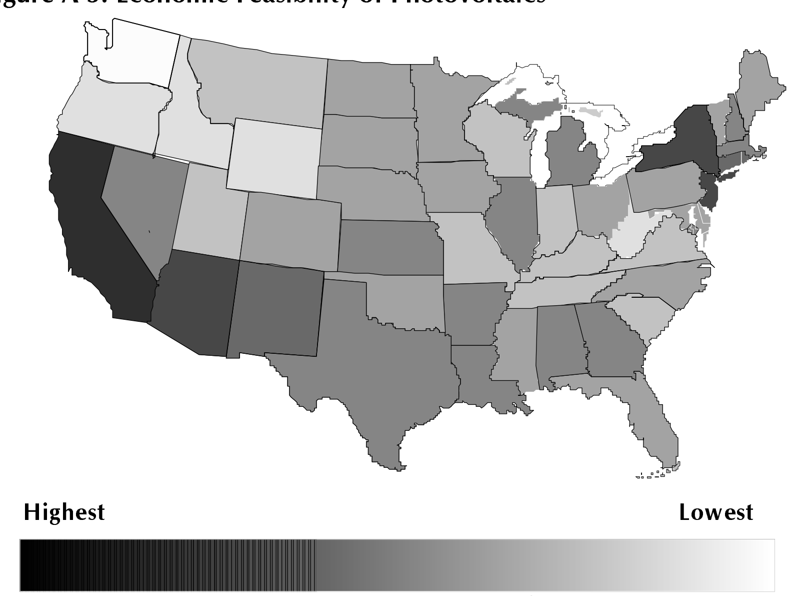
Office of Utility Technologies, DOE and Electric Power Research Institute, 1997. *Renewable Energy Technology Characterizations*, October, online at www.eren.doe.gov/utilities/techchar.html.

while Solar Two began operation in 1996. Solar dish technology uses dish-shaped mirrors to focus the sun's heat (figure A-4). A demonstration solar engine was recently installed at the Pentagon.[3]

Potential. Photovoltaic panels installed on less than 1 percent of the US land area could provide all the electricity the country needs, if there were no transmission constraints.[4] Texas alone receives three times the amount of sunlight needed to power the whole country. Of course, different parts of the country receive different amounts of sunlight, but the variations are not as great as one might expect. The sunny southwest gets only about 35 percent more sun than the northeast.[5]

While solar panels work best in the dry and sunny Southwest, they can be of value in less sunny regions, if electricity is expensive and peak electricity demand occurs when the sun is shining brightest, which is often the case in regions with high air-conditioning use. Power from solar panels is currently much more expensive than that from conventional generators. In many places, though, power prices are very high during periods of peak demand, offering an opportunity for solar power. Figure A-5 shows states where photovoltaics have the greatest value.[6]

Figure A-5. Economic Feasibility of Photovoltaics



Richard Perez, Christy Herig. and Howard Wenger, Valuation Of Demand-Side Commercial PV Systems in the United States. See also NREL web site at http://www.nrel.gov/ncpv/documents/pv_util.html.

Because photovoltaics can be easily sited on existing rooftops and other structures, this technology has great potential. A UCS study found that installing photovoltaics on rooftops and south-facing walls could meet as much as 20 percent of the Boston area's electricity needs.[7]

Solar thermal electric technologies are limited in the United States to the Southwest, because they require strong, direct sunlight and few clouds. Despite this constraint, estimates suggest that solar thermal electric stations covering the area of Edwards Air Force Base in California and the White Sands Missile Range in New Mexico could theoretically meet about a quarter of US electricity needs.[8]

Cost. The price of photovoltaics has declined steadily over time. With increased efficiency and mass production, prices could decrease further. The Electric Power Research Institute and the Department of Energy project a drop in total costs for bulk residential customer installations from $6.72/watt in 1997 to $3.05/watt in 2010 and $1.77/watt in 2020. If, as expected, solar module efficiency increases from 14 percent to 20 percent, utility-scale systems could fall to 6.2¢/kWh in 2020 and 5¢/kWh in 2030.[9]

Solar thermal electric technologies are also likely to undergo large price reductions. Projections show a decline in prices for electricity from parabolic troughs from 17.3¢/kWh in 1998 to 6.8¢/kWh in 2030. For hybrid solar dishes, using natural gas to provide supplemental energy, the projected decrease is from 17.9¢/kWh in the year 2000 to 5.2¢/kWh by 2030. Electricity from power towers could reach as low as 4.2¢/kWh in that time frame, dropping from 13.6¢/kWh in 2000.[10]

Market. The market for photovoltaics is limited by high costs relative to other renewable as well as conventional technologies. Even at 1998 prices, however, there are niche markets where these systems can compete. In remote applications, such as off-grid homes, outdoor lighting, communications towers, and water pumping, photovoltaics can be less expensive than building transmission lines to connect with conventional generation. Even in urban areas, photovoltaics may be cost-effective in locations where installation allows expensive transmission and distribution system investments to be deferred or avoided.[11]

The market for photovoltaics is expected to take off when the price of an installed module declines to about $3 per watt. At that price, the total US market for photovoltaics may reach 9,000 MW.[12] Photovoltaic production is expected to grow by 20 percent per year, aiming in part at the 10 million single-family homes located in regions of the United States that have above-average sunshine and suitably tilted roofs with unshaded access to direct sunlight. This market alone has a long-run potential of over 30,000 MW.[13]

Impacts. Solar energy is the most environmentally benign energy source available, since solar technologies produce no air or water pollution, do not deplete natural resources, and do not endanger public health or safety.

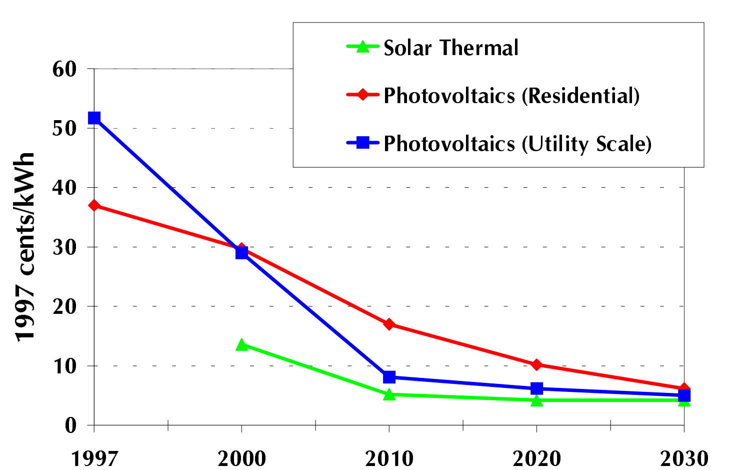
The few environmental impacts are minor or easily controlled. The manufacture of photovoltaic panels, for example, involves the use of toxic materials like cadmium and arsenic. Because this takes place in a closed factory, the toxics can be controlled; pollutants are not released intentionally as they are from a coal-burning power plant. Processes to recycle materials used in thin-film solar panels will need to be developed, but these are unlikely to pose problems.

Land use is an issue for centralized solar thermal power plants. These technologies require about 7.5 acres of mirrors per megawatt, or one square mile for an 85 MW plant. However, as noted earlier, large amounts of electricity could be produced on a small area of desert.

Wind Energy

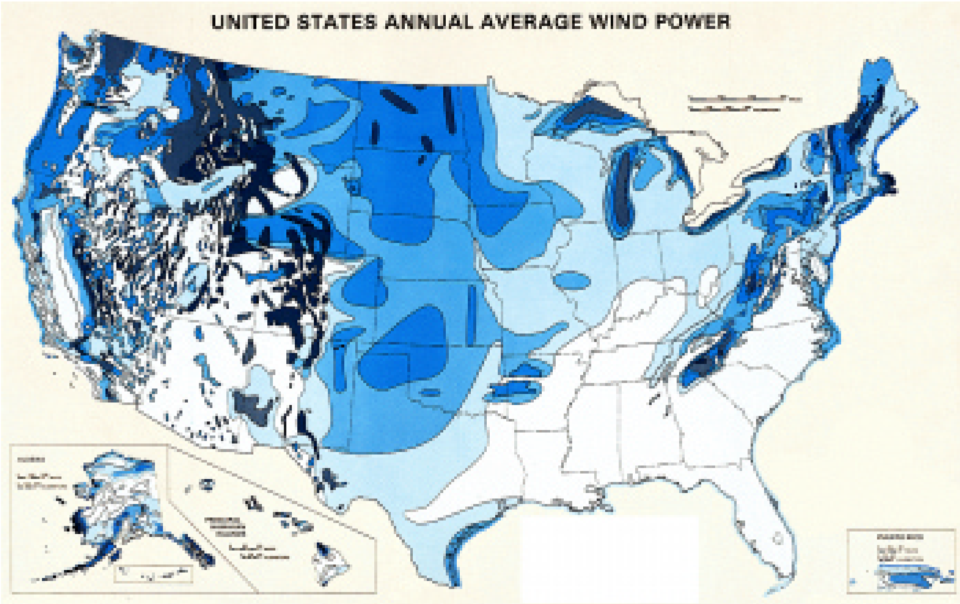
Wind turbines convert the force of moving air into electricity. Like an airplane, the wind turns the blades using lift. Almost all wind turbines have blades rotating about a horizontal axis. They range in the United States from small 200-watt machines used on

Figure A-6. Solar Cost Projections



Office of Utility Technologies, DOE and Electric Power Research Institute, 1997. *Renewable Energy Technology Characterizations*, October, online at www.eren.doe.gov/utilities/techchar.html.

Figure A-7.



CLASSES OF WIND POWER DENSITY

Wind Power Class		Density at 10m (33ft) W/m²	Speed at 10m(33ft) m/s	mph	Density at 50m (164ft) W/m²	Speed at 50m(164ft) m/s	mph
1		0-100	0-4.4	0-9.8	0-200	0-5.6	0-12.5
2		100-150	4.4-5.1	9.8-11.5	200-300	5.6-6.4	12.5-14.3
3		150-200	5.1-5.6	11.5-12.5	300-400	6.4-7.0	14.3-15.7
4		200-250	5.6-6.0	12.5-13.4	400-500	7.0-7.5	15.7-16.8
5-7		250-1000	6.0-9.4	13.4-21.1	500-2000	7.5-11.9	16.8-26.6

D.L. Elliott and M.N. Schwartz, *Wind Energy Potential in the United States*, DOE, Pacific Northwest Labs, 1991, online at www.nrel.gov/wind/potential.html.

sailboats to 750 kW turbines with 46-meter blades mounted on 60-meter tall towers. Some wind turbines of 1 MW and larger are being installed in Europe.[14]

Wind power is the most rapidly growing source of energy in the world, increasing 20 percent per year since 1990.[15] Power producers installed over 1,500 MW of wind turbines around the world in 1997. Germany's installed base rose to 2,080 MW of wind, surpassing the United States as the world leader in wind power generation. In China, India, Denmark, and Spain, wind power is also growing rapidly. Most US wind power development has been in California, but since 1993 new large-scale wind turbines have been installed in Colorado, Iowa, Michigan, Minnesota, Texas, Vermont, and Wyoming.

Potential. A study by the Pacific Northwest Laboratory estimated the total theoretical potential for wind at about 40 times annual US consumption.[16] The study excluded areas where siting wind turbines would be especially difficult, like cities, national parks, and environmentally sensitive areas. About 6 percent of the total land area in the lower 48 states has wind speeds of 13 mph or more and is potentially available for wind turbine installation. Estimates indicate that annual wind power output from these areas could be 4,400 billion kWh—1.5 times total US electricity demand. The study found that 12 states in the middle of the country have most of the wind energy potential, enough to produce nearly four times the amount of electricity consumed by the nation in 1990, if there were no constraints on transmission. North Dakota alone could supply over a third of the nation's power needs.

The study concludes that to provide 20 percent of the nation's electricity, wind development would require only about 0.6 percent of the land of the lower 48 states. Furthermore, since wind turbines must be spaced widely so as not to interfere with each other, less than 5 percent of this land would be occupied by turbines, electrical equipment, and access roads, leaving the rest of the land available to existing land use, such as farming and ranching.

The distance from existing power lines is also a key factor determining the cost-effective potential of wind power, since new long-distance transmission lines can cost as much as $200,000 per mile. In 1995, the Department of Energy assessed the US wind potential based on distance from existing power lines, using a GIS-based method that the Union of Concerned Scientists pioneered in *Powering the Midwest*. The DOE found that 153,000 square miles of land within 5 miles of existing transmission lines had the potential for wind development. That land could accommodate 464,000 average MW—more than the total US generation capacity in 1993. Within 10 miles of power lines, enough wind turbines could be sited to provide more than twice the power needs of the country—as much as 6,430 million MWh.[17]

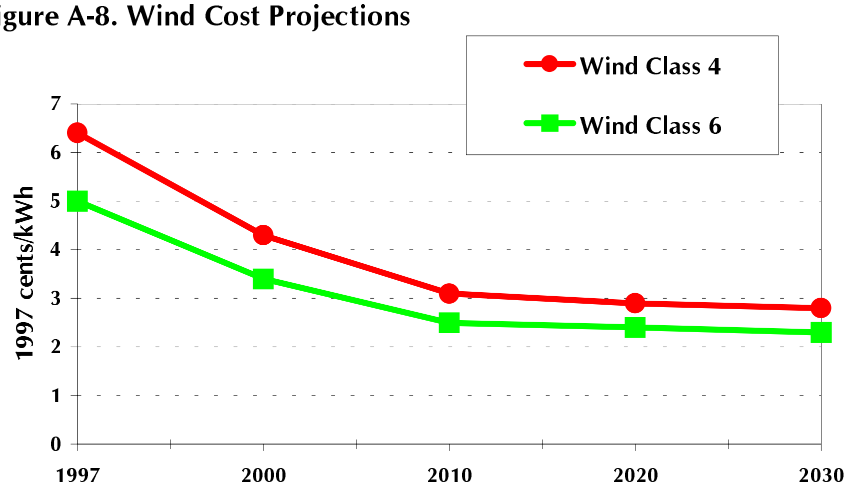
Costs. Wind costs have declined from 25¢/kWh in 1981 to less than 5¢/kWh in 1998. Installation and operations costs are likely to continue falling as performance increases. Improvements in wind technology should enable turbines to take advantage of a wider range of wind speeds, thereby producing power in both slower and faster winds. Construction costs are projected to fall from $1,000/kW in 1998 to $635/kW in 2030, with generation prices falling as low as 2.3 cents per kWh. These improvements will be driven by research and development on aerodynamics and materials, leading to more efficient, lighter weight systems with improved components, placed on taller towers. Manufacturing improvements and increased volume of production will have a strong effect on reducing costs as the market grows.[18]

Markets. Wind competes as a bulk power source and its price is expected to remain higher than the price of natural gas for the near future. Thus changes in the market for wind are likely to depend on how quickly a market develops for environmentally friendlier "green power" and on the extent to which policy supports wind power. Policy decisions about renewal of the 1.5¢/kWh production tax credit, currently set to expire in July 1999, the adoption of renewables portfolio standards, and the extent to which transmission prices penalize intermittent sources like wind will have an enormous impact on wind markets. Market projections for wind range widely. The US Energy Information Administration, forecasting business as usual, projects an increase from 1998 capacity of 1,850 MW to 3,330 MW by 2010. On the other hand, *Energy Innovations*, a study by the Union of Concerned Scientists and others projects market potential at 44,480 MW by 2010, if strong measures are taken to achieve a 10 percent reduction in carbon emissions from 1990 levels by that date.[19]

Impacts. Wind power produces no air or water pollution, involves no toxic or hazardous substances (other than the lubricants commonly found in large machines), and poses no threat to public safety. A serious potential obstacle facing the wind industry, however, is public concern about their impacts on wilderness areas and about the visibility of wind turbines. In forests, wind development may clear some trees and cut new roads. Near populated areas, wind projects may run into opposition from people who regard them as unsightly, or who fear their presence will reduce property values. However, recent studies of the first commercial wind development in New England, as well as a number of studies in Europe, have shown greater public acceptance after construction than before.[20]

One of the most misunderstood aspects of wind power is its use of land. Wind turbines occupy only a small fraction of the land area across which they are sited. The rest can be used for other purposes or left in its natural state. For this reason, wind power development is ideally suited to farming areas. Farmers can plant or allow grazing right to the base of turbine towers. In fact, landowners can derive substantial benefits in increased income and land value by leasing

Figure A-8. Wind Cost Projections



Office of Utility Technologies, DOE and Electric Power Research Institute, 1997. *Renewable Energy Technology Characterizations*, October, online at www.eren.doe.gov/utilities/techchar.html.

land for wind turbines. Consequently, the areas with the greatest potential for wind power development are in the Great Plains, where wind is plentiful and vast stretches of farmland could support hundreds of thousands of wind turbines.

Bird deaths have been a significant problem for wind turbines at only two locations: Altamont Pass in California and Tarifa, Spain. Studies show that bird deaths can be reduced by minimizing perches on and around the wind machines, as by using tubular rather than lattice towers, and new turbines with larger and slower moving blades. Recently, a Danish company announced plans to replace 750 smaller wind turbines at Altamont with only 100 larger new machines.[21] This should greatly reduce the number of injuries there.

Biomass Energy

Biomass energy is energy from plants and organic material. Although the most common form is wood, which can be burned, biomass also includes wastes, like paper, sawdust, and yard clippings; methane, from decomposing trash, sewage, and manure; and crops grown specifically for energy use. For the foreseeable future, biomass energy has the greatest potential of all renewables. Currently in the United States, the combustion of biomass wastes, such as in paper and lumber mills, provides 7,300 MW of power and generates 42 billion kWh of electricity a year, about 1.4 percent of the nation's electricity. Municipal solid waste, considered a renewable source by the US Department of Energy, contributes another 3,000 MW and 20 billion kWh.[22]

Most biomass used for electricity production is simply burned in power plants, much like coal. Most fuel for these plants is produced as waste in other processes, like farming and wood processing. Although this approach is straightforward and familiar, new approaches are needed to take advantage of the full potential for biomass energy.

A process called gasification offers higher efficiency and cleaner power production than simple combustion. A gasification system heats the biomass fuel under pressure until it gives off volatile gases. A high-efficiency gas turbine then burns these gases. While this approach has been proven at a small scale, it is still being tested at a large scale. The US Department of Energy has converted the McNeil Generating Station in Vermont to a 10 MW gasification system using wood waste and is also testing a gasification plant in Hawaii, using sugar cane waste.[23] If successful, these demonstrations could lead to a wider acceptance of utility-scale biomass plants.

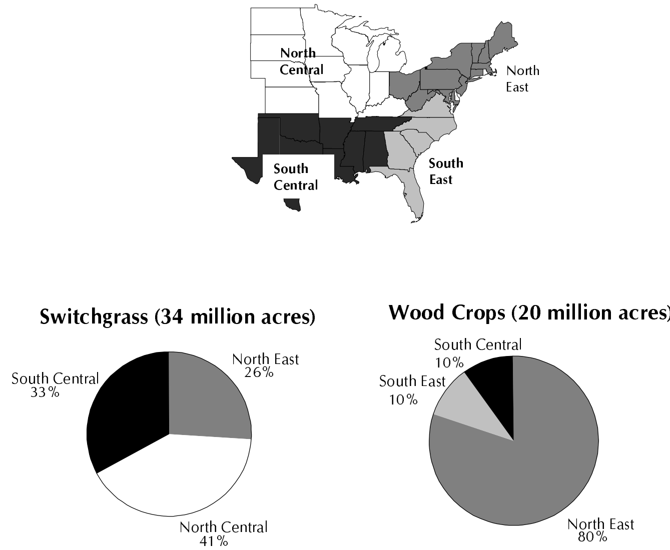
Full development of this technology also requires larger amounts of biomass fuels. Under current economic conditions, waste wood, agriculture residue, and municipal solid waste make the most sense as fuels, since they would otherwise face disposal costs. But expanding biomass generation requires farms and plantations that produce crops solely for energy production. Fast-growing native species like switchgrass, poplar, and willow can grow on land that is idle, subject to erosion, or ill-suited for food crops.

Potential. About 100 million acres of cropland are idle in any given year, some as part of federal conservation programs. Another 150 million acres of pasture, range, and forest has "medium to high" potential for conversion to cropland, according to the US Department of Agriculture. Overall, around 200 million acres of cropland might be suitable and available for energy or "power" crops, without irrigation and without competing with food crops.[24] This land base would be capable of producing one billion tons of biomass every year. Recoverable biomass wastes could contribute 375 million tons annually—during 1997 only half of this was used. In theory, then, biomass could produce over 2 trillion kWh of electricity a year—about 70 percent of US consumption.

On the other hand, some of the biomass resource could be used to make liquid fuels for transportation. If used entirely for transportation, the 1.4 billion-ton total could produce about 150 billion gallons of ethanol or 200 billion gallons of methanol, roughly equivalent to all the fuel currently used in cars and light trucks.

Costs. Biomass is generally cost-effective when residues are available at a low or negative cost. It is also cost-effective when it can serve two purposes at once: producing heat as well electricity, or producing electricity in addition to ethanol or animal feed or industrial chemicals. However, power crops are not yet cost-effective, either for farmers to grow or for power producers to use, mainly because subsidies favor food

Figure A-10. Biomass Production Regions



Source: Cost, Noel D. et al. 1990. Forest Biomass Resource of the United States. USDA Forest Service. Aug. 18, 1994. Available on-line at : www.rredc.nrel.gov/biomass/bricmaps.html

crops and fossil fuels and because the environmental benefits of biomass are not formally valued.

Biomass power is currently produced by small combustion power plants, with an average size of 20 MW. Most of this is operated by the wood industry in combined heat and power applications. These small plants have higher capital costs and lower efficiencies than larger steam plants, resulting in electricity costs in the 8–12¢/kWh range.

The Department of Energy and the Electric Power Research Institute expect the next generation of biomass power plants to substantially reduce these high costs and efficiency disadvantages (see figure A-9). Several processes could result in lower costs:

- cofiring biomass in existing coal-fired power plants
- using high-efficiency gasification with combined cycle gas turbines
- improving efficiency in larger combustion plants, allowing biomass to take advantage of economies of scale

Technologies under development may be competitive in the future The Whole Tree Energy system burns whole trees at once, saving the effort of processing the wood. Integrated gasification fuel cell systems combine biomass gasifiers with new high-efficiency fuel cells. Small modular systems use gasifiers with microturbines, allowing the electrical generator to go the source of biomass, rather than shipping the biomass to the generator.

Markets. The Department of Energy envisions liquid biofuel use growing to over 20 percent of car and light truck use by 2010 and over 50 percent by 2030. The DOE also hopes to raise biomass electric generating capacity to 12,000 MW by the year 2000 and 22,000 MW by 2010. The Electric Power Research Institute believes that as much as 50,000 MW—approximately 8 percent of US generating capacity—could be in place by the year 2010, with twice that amount by 2030.[25]

Researchers at Oak Ridge National Laboratory, the US Department of Agriculture, and the University of Maryland have estimated the economic potential for energy crops like switchgrass, willow, and poplar in a number of states.[26] They found that switchgrass and wood raised on 54 million acres of land and used in biomass gasification/gas turbine systems could produce 630 billion kWh, for about 4.5¢/kWh. This is equal to a fifth of total US electricity production.

Power crop cultivation and energy production might be split among regions as shown in figure A-10. Switchgrass production would be grown in the North Central, South Central, and Northeastern states. The Northeast would lead wood crop production, with 16 million acres of willow trees.[27]

Impacts. Conventional biomass combustion systems produce some air emissions similar to coal-fired power plants, but little sulfur dioxide, carbon dioxide, or toxic metals. The most serious problem is particulate emissions, which must be controlled with special pollution-control devices like electrostatic precipitators. More advanced biomass energy technologies, such as the gasifier/combustion turbine combination, are likely to have emissions comparable to natural gas power plants.

Using biomass as a fuel can greatly reduce emissions of the heat-trapping gases that cause global warming. The carbon dioxide released when biomass is burned is reabsorbed into plants grown to produce more biomass fuels. Thus, in a sustainable fuel cycle, there would be almost no net emissions of carbon dioxide.[28]

Power crops have significant environmental impacts if they are grown in the same unsustainable way that most food crops are grown today, with heavy doses of chemicals and energy. But they can be grown quite differently, so that they improve soil and water quality, reduce erosion, and create animal habitat. Energy crops using fast-growing and hearty native species like switchgrass, willow, and poplar require little if any applications of fertilizers or pesticides. Since trees would grow for several years before being harvested, their roots and leaf litter could help stabilize the soil. Planting varieties that regenerate when cut would minimize the need for disruptive tilling and would be especially beneficial on cropland or rangeland prone to erosion and flooding. Perennial grasses harvested like hay could play a similar role; soil losses with a crop such as switchgrass, for example, would be negligible compared with losses of annual crops such as corn.

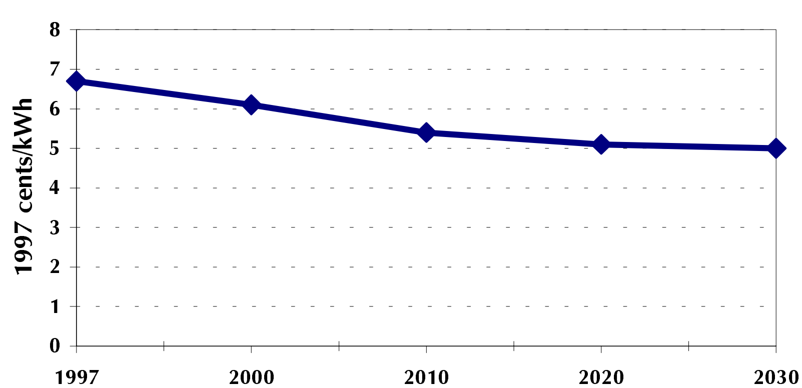
Geothermal Energy

Geothermal energy uses the heat under the earth's crust to produce steam, heat, and power. The US geothermal industry is concentrated in California and Nevada, although the world leader is Iceland, where almost every building is heated by hot springs. With a 3,000 MW capacity, geothermal plants produce about 5 percent of California's electricity. Geothermal plants also produce 460 MW (thermal) of steam and heat for direct use, displacing the use of 1.2 million barrels of oil per year. Worldwide capacity in 1990 was 5,800 MW electric and 11,300 MW thermal.[29]

Geothermal energy in the United States produced about 16 billion kWh of electricity in 1995, making it the third largest renewable energy source, after hydroelectric and biomass generation. Geothermal energy is not replenished, but considering the vast quantity of energy available, it is virtually inexhaustible. The US Geological Survey estimates that the amount of energy from geothermal heat that is accessible amounts to at least 14 times more than all proven and unproven coal reserves in the United States.

Much of this energy, however, is in forms that cannot be captured economically with today's technology. So far, only hydrothermal resources—boiling hot water and steam coming straight out of the ground—have been tapped. Steam reservoirs are the easiest to use for electricity production, but they are rare, and most—like the Geysers in California—have already been exploited. New development is focusing on hot water (150°C or more). Hot water plants have been built in California, Hawaii, and Nevada. The US Geological Survey estimates hot water systems could provide 23,000 MW of power for 30 years at an affordable cost—enough for 23 million people.[30] Hot water and steam are also used directly for industrial processes, enhanced oil recovery, and district heating. Most new plants are closed loop, returning the steam and hot water to the ground after use. Older plants tend to be open loop, venting the steam to the air after use.

Figure A-9. Biomass Gasification Cost Projection



Office of Utility Technologies, DOE and Electric Power Research Institute, 1997. *Renewable Energy Technology Characterizations*, October, online at www.eren.doe.gov/utilities/techchar.html.

Geothermal heat can also be harnessed using “hot dry rock” technology, which involves drilling deep wells and pumping water down the hole to extract the heat. Since this approach uses hot underground rocks wherever they occur, the potential is enormous, accounting for most of the geothermal resource potential in the United States. While research continues, costs are so far not competitive with traditional resources.

The Department of Energy expects little growth in electrical production from geothermal power plants between now and 2020, as new power plants offset the decline in output from the installation at the Geysers. In an optimistic scenario or with a renewables portfolio standard, geothermal power production could double by 2020.[31]

Impacts. Geothermal plants draw heat from the earth and use it to run steam turbines. Many existing geothermal plants using hot steam directly from the earth and vent it to the air afterwards. These open-loop systems can generate solid wastes as well as noxious fumes. Metals, minerals, and gases are brought to the surface with the geothermal steam. Open-loop systems release carbon dioxide as well, although only about 5 percent of that emitted by a coal- or oil-fired power plant. Open-loop systems can also deplete the water and geothermal resource. Closed-loop systems are almost totally benign, since gases or fluids removed from the well are not exposed to the atmosphere and are usually injected back into the ground after being run through a heat exchanger. Although this technology is more expensive than conventional open-loop systems, in some cases it may reduce scrubber and solid waste disposal costs enough to provide a significant economic advantage.

Hydroelectric Energy

Hydroelectric power uses the energy of moving water to drive water turbines, producing electricity. Large systems rely on dams to block rivers, storing huge amounts of water. The water is passed through the turbines when power is needed. Smaller "run-of-the-river" systems let the water flow through continuously. Most energy production comes from large dams. In the United States, hydropower has grown from 56,000 MW in 1970 to about 80,000 MW today. As a portion of the electricity supply, however, it has fallen to 10 percent, down from 14 percent 20 years ago. Still, US hydropower plants produce the energy equivalent of 500 million barrels of oil per year. In some parts of the country, hydropower is the dominant generator. It provides 63 percent of power used along the west coast and two-thirds of the power in the Pacific Northwest, from 58 hydroelectric dams.

Potential. In theory, there remains great potential for further hydropower development in the United States. The Federal Energy Regulatory Commission has catalogued 7,243 sites, which could provide 147,000 MW of hydropower capacity. As of 1991, less then half of this had been developed, with another 3,300 MW capacity planned or under construction (most of it in expansions or upgrades of existing facilities). Thus, the potential exists for the United States to just about double its current hydropower capacity. The majority of this expansion potential lies in western states, where most previous hydropower development has taken place.[32]

But most of this resource is unlikely to be developed. Environmental laws like the 1968 National Wild and Scenic Rivers Act preclude building dams on stretches of many virgin rivers, eliminating about 40 percent of the potential. An additional 19 percent of potential sites are under a development moratorium until their final status can be decided. According to a 1990 report by national laboratory scientists, only 22,000 MW of the undeveloped hydropower resource is economically viable and of this only 8,000 MW is likely to be developed because of “regulatory complexities and institutional and jurisdictional overlaps” in the hydropower licensing process.[33]

As a result, most of the potential for expanding hydropower involves upgrading existing facilities rather than building new ones. Possibly 6,000 MW in improvements could be made at large dams. The 2,500 small hydro plants currently in operation could also be expanded. These plants account for a tiny fraction of the 70,000 dams that block and divert our rivers. An estimated 4,600 MW of capacity could be added at existing small dams, especially at the more than 3,000 facilities that were abandoned in the 1950s and ’60s.[34]

Although it is unlikely, hydropower capacity could be affected if any existing dams were denied licenses when they come up for relicensing. Since hydro facilities have long lives, many dams are quite old. The Grand Coulee dam, for example, has been in operation since 1942. The federal government issues licenses for all dams for a 30- to 50-year period. In 1993, over 200 licenses were due for renewal, amounting to 2,000 MW of capacity. Relicensing will require some dam owners to find ways to reduce environmental impacts.

Costs. As with other renewable technologies, capital costs for hydroelectric plants are high, while operating costs are low, although costs vary widely according to design and location. Large dams in the Pacific Northwest are so inexpensive to operate that commercial electric rates there are as low as 1.5¢/kWh. New large-scale hydro plants can be built for between $500 and $2,500 per kW, while small plants average around $2,000 per kW. Repowering of existing dams is a much cheaper option, usually less than $100 per kW. Operation and maintenance costs are about one-tenth of a cent per kWh.[35]

Impacts. Although hydropower is inexpensive and nonpolluting, the environmental impacts of hydropower can be serious. The most obvious effect is that fish are blocked from moving up and down the river, but there are many more problems. Most problems of hydropower come from large dams with reservoirs. Small run-of-the-river hydro plants produce fewer environmental impacts.

In the Pacific Northwest, large federally-owned dams have blocked the migration of coho, chinook, and sockeye salmon from the ocean to their upstream spawning grounds.[36] Some steps are being taken to help the fish around the dams, such as putting them in barges or building fish ladders, but this has helped only a little. Also, when young fish head downriver to the ocean, they can be chewed up in the turbines of the dam. The salmon population in the Northwest currently seems headed for extinction, falling from a population of 16 million to 300,000.

When land is inundated by the creation of reservoirs, habitat and productive land can be destroyed. This land is often composed of wetlands, which are important wildlife habitats, and low-lying flood plains, often the most fertile cropland in the area. In addition, population density is often higher along rivers, leading to mass dislocation of urban centers.

A related problem has occurred in Canada. The stones and soil in areas now under water contained naturally occurring mercury and other metals. When the land was flooded, the mercury dissolved into the water and was absorbed by fish. The creatures that eat the fish, from bears and eagles to the native Cree people, are suffering from mercury poisoning.

Hydropower affects water quality in other ways as well. Water falling over spillways can force air bubbles into the water, which can be absorbed into fish tissue, ultimately killing the fish. When dams slow rivers, the water can become stratified, with warm water on top and cold water on the bottom. Since the cold water is not exposed to the surface it loses its oxygen so that fish can no longer live in it. And, as illustrated by the Colorado River in the Grand Canyon, fast-moving rivers can fill up with sediment when they are slowed down. During 1997, the Department of Interior flushed huge amounts of water out of dams in an attempt to clear away the sediment.

Another important habitat disruption comes from operating the dam to meet electric demand. Water is stored up behind the dam and released through the turbines when power demand is greatest. This causes water levels to fluctuate widely on both sides of the dam, stranding fish in shallow waters and drying out habitat. There are many competing pressures on dam operators—to produce power, to provide water for recreational use on the reservoir and downstream, to provide drinking and irrigation water, to allow Native Americans to carry out traditional religious practices, and to preserve habitat for fish and plant species. In most cases, nature loses out to boaters and electricity customers.

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