DOE/EIA-0603(95)
Distribution Category UC-950

Renewable Energy Annual 1995

December 1995

Energy Information Administration
Office of Coal, Nuclear, Electric and Alternate Fuels
U.S. Department of Energy
Washington, DC 20585

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Preface

This report, *Renewable Energy Annual 1995*, is the first in an expected series of annual reports the Energy Information Administration (EIA) intends to publish to provide a comprehensive assessment of renewable energy. In so doing, this report further documents and explains renewable energy information provided earlier in EIA's *Annual Energy Review 1994*.[1] It covers the following energy sources: biomass, geothermal, wind, and solar. While hydropower is a renewable energy resource, it is also regarded as a "conventional" energy source because it has furnished a significant amount of electricity for more than a century. Hydropower is a mature industry with little growth or change expected, and EIA provides substantial information on hydropower in its electricity publications. Therefore, this report discusses hydropower as it contributes to total renewable energy consumption but does not address hydropower as an individual energy source.[2]

This report includes a feature article, "Environmental Externalities in Electric Power Markets: Acid Rain, Urban Ozone, and Climate Change," that was previously published in EIA's November 1995 *Monthly Energy Review*.[3] The biomass sections of this report include updated information similar to that published in EIA's *Estimates of U.S. Biomass Energy Consumption 1992*.[4] The solar sections include updated information from material previously published in *Solar Collector Manufacturing Activity 1993*.[5] EIA has discontinued publishing the latter two reports.

The Energy Information Administration was established formally by the Department of Energy Organization Act (Public Law 95-91) in 1977. This legislation required EIA to carry out a comprehensive, timely, and accurate program of energy data collection and analysis. It also vested EIA with considerable independence in determining its mission and the data and analysis it chooses to present. After approval by the EIA Administrator, products are not subject to further review. However, because EIA believes that collaborative efforts produce the best results, external reviews of its products—such as this report—are solicited prior to approval both from other offices in the Department of Energy, other Federal agencies, and non-government experts. EIA remains the final judge of product content.

[1]Energy Information Administration, *Annual Energy Review 1994*, DOE/EIA-0384(94) (Washington, DC, July 1995).
[2]For more information on hydropower, see, for example, Energy Information Administration, *Electric Power Annual 1994*, Vol. 1, DOE/EIA-0348(94)/1 (Washington, DC, July 1995).
[3]Energy Information Administration, *Monthly Energy Review*, DOE/EIA-0035(95/11) (Washington, DC, November 1995).
[4]Energy Information Administration, *Estimates of U.S. Biomass Energy Consumption 1992*, DOE/EIA-0548(92) (Washington, DC, May 1994).
[5]Energy Information Administration, *Solar Collector Manufacturing Activity 1993*, DOE/EIA-0174(93) (Washington, DC, August 1994).

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Feature Article

Environmental Externalities in Electric Power Markets: Acid Rain, Urban Ozone, and Climate Change

by John Carlin[1]

Abstract

Electric power plants that burn fossil fuels emit several pollutants linked to the environmental problems of acid rain, urban ozone, and the possibility of global climate change. Damages caused by those emissions are viewed by many economists as "externalities" and an inefficiency of the market when electric power rates do not reflect, nor ratepayers directly pay, the associated social costs. Until recently, efforts to control power plant emissions have focused on the command-and-control approach of setting standards. More recent efforts, including the Clean Air Act Amendments of 1990, have involved incentive-based measures, such as emissions fees and systems of marketable emissions allowances. A few State regulatory bodies are experimenting with methodologies to "price" environmental externalities and incorporate that cost information in deliberations about least-cost ways to meet projected demand for electric power. The spread of these methodologies could be affected by increased competition in the electricity industry, which would allow electric power customers direct access to a variety of electric power providers.

The central theme of the 1991 National Energy Strategy, developed by the U.S. Department of Energy (DOE), was to secure "a more efficient, less vulnerable, and environmentally sustainable energy future."[2] Also, the Energy Policy Act of 1992[3] (EPACT) required DOE to develop a least-cost national energy strategy that considers the economic, energy, environmental, and social costs of various energy technologies. Many observers argue that this requires incorporating all environmental costs of energy production, including the generation of electric power, in the costs of energy. When these costs are not captured by the marketplace, government involvement at the Federal, State, or local level may be proposed to "internalize" them in electric power prices.

This article discusses the emissions resulting from the generation of electricity by utilities and their role in contributing to the environmental problems of acid rain, urban ozone, and climate change. It then discusses the general concept of environmental externalities and assesses the means that have been devised to ameliorate them. The article analyzes the emissions-control requirements for electric utilities of the Clean Air Act Amendments of 1990 (CAAA)[4] and concludes with a brief examination of State initiatives directed at addressing environmental externalities associated with electric power generation. The article does not purport to analyze all externality costs and benefits associated with electric power generation or suggest what actual externality costs are or should be.

Air Emissions from Electric Power Plants

Pursuant to the provisions of the Clean Air Act of 1970[5] and its amendments, the Environmental Protection Agency (EPA) identified six common "criteria air pollutants" that are found all over the United States: volatile organic compounds (VOCs), nitrogen oxides (NO_x), carbon monoxide (CO), particulate matter less than 10 microns in diameter (PM_{10}), sulfur dioxide (SO_2), and lead. These pollutants are all subject to limits established by EPA in the National Ambient Air Quality Standards (NAAQS). Fossil-fired electric power plants emit all (though only trace amounts of lead)

[1]The author is an industry analyst in the Office of Coal, Nuclear, Electric and Alternate Fuels at the Energy Information Administration (EIA). He gratefully acknowledges the contributions of Russell Lee of the Oak Ridge National Laboratory. Comments may be directed to Mr. Carlin at 202-426-1146.

[2]U.S. Department of Energy, *National Energy Strategy*, DOE/S–0082P (Washington, DC, February 1991), p. 2.

[3]Public Law 102-486, 42 U.S.C. 13201, "Energy Policy Act of 1992" (Enacted October 24, 1992).

[4]Public Law 101–549, 42 U.S.C. 7401, "Clean Air Act Amendments of 1990" (Enacted November 15, 1990).

[5]Public Law 91-604, 42 U.S.C. 1857, "Clean Air Act" (Enacted December 31, 1970).

as byproducts of electricity generation. Several of these pollutants contribute to acid rain and urban smog, and some may contribute to global climate change.

In addition to the criteria pollutants, many State public utility commissions (PUCs) have been examining carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) as well. Those gases are greenhouse gases, which accumulate in the atmosphere, block infrared radiation to outer space, and reradiate the captured heat to the atmosphere. Many scientists believe that the resultant augmentation of the atmosphere's natural warming effect will ultimately change the Earth's climate.

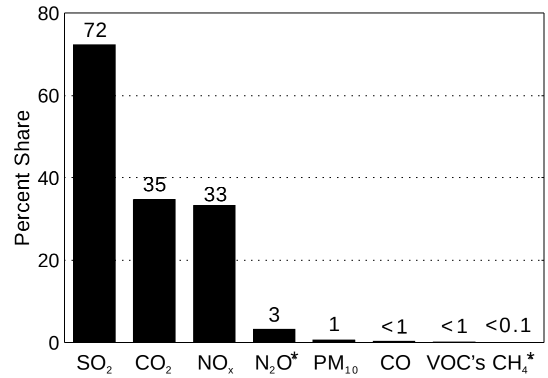
The composition of emissions from electric power plants is, in part, a function of the completeness of the combustion process. The primary fuels burned in electric power plants (coal, natural gas, and distillate or residual oils) are carbon-hydrogen compounds that produce CO_2 and water vapor byproducts when completely combusted (oxidized).

However, combustion is seldom complete, and incomplete combustion yields unburned fuel molecules, smoke particles (primarily carbon), and partially oxidized carbon as CO. Nitrogen oxides result from the combustion of hydrocarbons in the presence of air, which is 21 percent oxygen and 78 percent nitrogen. During combustion, portions of both the atmospheric nitrogen and the fuel-bound nitrogen react with oxygen to form NO and NO_2. These compounds are referred to collectively as nitrogen oxides.[6]

Fossil fuels also contain varying amounts of sulfur, which is oxidized to sulfur dioxide (SO_2) during combustion. The level of SO_2 emitted is a function of the type of fuel burned and the control equipment used rather than the combustion process. Sulfur is present in virtually all coals and fuel oils at levels ranging from trace amounts to 6 percent by weight.[7]

Electric utility power plants currently account for only a small percentage of U.S. total particulate emissions (Figure FE1) because control devices, such as baghouse filters and electrostatic precipitators, remove most of the particulates from power plant waste gases. Similarly, electric utility power plants contribute only small percentages of total emissions of VOCs, CO, N_2O, and CH_4.[8] On the other hand, 72 percent, 35 percent, and 33 percent of total emissions of SO_2,[9] CO_2,[10] and NO_x,[11] respectively, come from utility power plants.

Figure FE1. Electric Utilities' Share of Total U.S. Emissions of Eight Air Pollutants, 1993



SO_2 = sulfur dioxide, NO_x = nitrogen oxides, CO_2 = carbon dioxide, N_2O = nitrous oxide, PM_{10} = particulate matter with diameter less than 10 microns, VOCs = volatile organic compounds, CO = carbon monoxide, CH_4 = methane.

* 1992 data.

Notes: • Approximately 37 percent of all methane emitted into the environment comes from landfills. • Nitrous oxide emissions are only from coal-fired plants. • PM_{10} data are for primary particulates only.

Sources: **CO_2, N_2O, CH_4:** Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 1987-1992* (Washington, DC, November 1994), pp. 9, 12, 25, 33, 45, 48. **SO_2, NO_x, PM_{10}, VOCs, CO:** Environmental Protection Agency, *National Air Quality and Emissions Trends, 1990-1993,*EPA-454/R-94-027 (Research Triangle Park, NC, October 1994), pp. 2-8, 2-9, and 2-10.

DOE has increasingly recognized that the lack of accurate and consistent (across fuel types) information on external costs distorts Federal energy research decisions and PUC decisions about emission control technologies. In 1991, DOE and the Commission of the European Communities committed to a joint study to develop comparative analytical methodologies to determine the external costs of the major fuels. Preliminary emissions data from the application of these methodologies by Oak Ridge National Laboratory indicate that substitut-

[6]B. Nebel, *Environmental Science: The Way the World Works* (Englewood Cliffs, NJ: Prentice Hall, 1990), p. 307.

[7]IEA Coal Research, *Coal Specifications—Impact on Power Station Performance,* IEACR/52 (London, England, January 1993), p. 21.

[8]Particulate, CO, and VOC emissions are much more significant at biomass electric generating plants.

[9]U.S. Environmental Protection Agency, *National Air Pollutant Emission Trends, 1900–1993,* EPA 454/R–94–027 (Research Triangle Park, NC, October 1994), Table A–4.

[10]Energy Information Administration, *Emissions of Greenhouse Gases in the United States 1987-1992*, DOE/EIA–0573 (Washington, DC, November 1994), Tables 4 and 5.

[11]*National Air Pollutant Emission Trends,* Table A-2.

ing any major fuel for coal (or using clean-coal technology) reduces emissions of the key pollutants SO_2, NO_x, and CO_2 (Table FE1).[12]

Table FE1. Estimated Emissions from Electric Power Generation
(Tons per Gigawatthour)

Fuel	SO_2	NO_x	PM_{10}	CO_2	VOCs
Eastern Coal . . .	1.74	2.90	0.10	1,000	0.06
Western Coal . . .	0.81	2.20	0.06	1,039	0.09
Gas	0.003	0.57	0.02	640	0.05
Biomass	0.06	1.25	0.11	[a]0	0.61
Oil	0.51	0.63	0.02	840	0.03
Wind	0	0	0	0	0
Geothermal	0	0	0	0	0
Hydro	0	0	0	0	0
Solar	0	0	0	0	0
Nuclear	0	0	0	0	0

[a]Net emissions.

SO_2 = sulfur dioxide, NO_x = nitrogen oxides, PM_{10} = particulate matter with diameter less than 10 microns, CO_2 = carbon dioxide, VOCs = volatile organic compounds.

Note: The values have been derived from preliminary data for the Department of Energy Fuel Cycle Study (ORNL/RFF). These estimates are technology and location specific, and should only be used to give an order of magnitude estimate of relative damages.

Source: Oak Ridge National Laboratory, *The Impact of Environmental Externality Requirements on Renewable Energy* (Oak Ridge, TN, July 1994).

Environmental Problems Related to Electric Power Plant Emissions

Electric power plant emissions are factors in three major environmental issues: acid rain, urban air quality, and global climate change. These issues are discussed below.

Acid rain. Acid rain refers to rain, fog, mist, or snow that is more acidic than normal. The acidity of precipitation is stated in terms of its pH level, which describes the concentration of hydrogen ions along a scale (from 0 to 14) that defines the continuum from acid to base. The pH scale is logarithmic; pH levels of 4.0 and 3.0, for example, are 10 and 100 times more acidic, respectively, than a pH level of 5.0. Although a pH level of 7.0 is neutral, unpolluted rainfall is normally slightly acidic (pH=5.6). Acid rain is defined as any precipitation with a pH of 5.5 or less.

Chemical analysis of data collected by means of cloud sampling and experimentation reveals the presence of sulfuric acid and nitric acid in precipitation in the United States (Figure FE2).[13] Sulfur dioxide and nitrogen oxides in the air, partly the result of emissions from electric power plants, gradually react with water vapor and become acids. Precipitation becomes acidic by mixing with these acids. The acidity of the precipitation depends upon the amount of acid in the atmosphere and the amount of water in which it is dissolved. Undissolved acids may also fall to Earth by themselves or in combination with dust particles.

The most severely acidic conditions are found in the eastern United States. EPA believes that acid rain has been the primary cause of the acidification of hundreds of streams in the mid-Atlantic highlands and the New Jersey Pine Barrens and of many lakes in the Adirondack Mountains of New York.[14] The National Acid Precipitation Assessment Program (NAPAP) identified acid rain as one of several possible causes of increased nitrate leaching and acidification of surface waters in several northeastern watersheds. Episodes of acidification are believed to harm populations of fish and invertebrates in small streams and lakes.[15]

Field studies have implicated acid rain in observed damage to high-elevation red spruce forests in the northeastern United States. Nutrient leaching and changes in soil chemistry due to acid deposition have also been detected in forests south of the Great Lakes. In general, NAPAP concluded that acid deposition, among other stressors, threatens the long-term structure, function, and productivity of many sensitive ecosystems.[16]

Some research suggests that emissions of sulfates and other pollutants from the combustion of fossil fuels may be linked to abnormally high mortality rates in

[12]These emission data are specific to particular technologies and locations and provide only rough estimates of emission levels. For example, the coal-fired plants are assumed to be 500-megawatt facilities, each with a capacity factor of 75.0 percent and an efficiency rating of 34.5 percent. Also assumed is the use of electrostatic precipitators to control particulates (99.5 percent effectiveness), scrubbers to control SO_2 emissions (90 percent effectiveness), and low-NO_x burners to control emissions of oxides of nitrogen. The coal used in the East is assumed to have a sulfur content of 2.1 percent by weight, while that used in the West is assumed to contain 0.7 percent sulfur by weight.

[13]*Environmental Science*, p. 324.

[14]U.S. Environmental Protection Agency, *Energy Efficiency and Renewable Energy; Opportunities from Title IV of the Clean Air Act*, EPA 430-R-94-001 (Washington, DC, February 1994), p. 8.

[15]National Acid Precipitation Assessment Program, *1992 Report to Congress* (Washington, DC, June 1993), p. 6.

[16]NAPAP *1992 Report to Congress*, p. 5.

Figure FE2. Electric Power Plants Subject to Emission-Control Requirements of Phase I of the Clean Air Act Amendments of 1990 and Average Acidity of Precipitation in the Continental United States, 1993

Source: **Acid precipitation map:** National Atmospheric Deposition Program/National Trends Network, Natural Resource Ecology Laboratory, Colorado State University. **Power plant map:** Environmental Protection Agency, Office of Air and Radiation.

humans.[17] Clinical studies have shown lung irritation and impaired lung cleansing in human subjects exposed to acidic aerosols.[18]

Urban ozone. Electric power plants contribute heavily to NO_x emissions, which are precursor chemicals that (along with VOCs) react in the atmosphere in the presence of sunlight to form ozone. Strong concentrations of ozone often occur in and downwind of large urban areas.

During cardiovascular exercise, human exposure to ozone at concentrations both above and below the 120-part-per-billion maximum allowed under the NAAQS has been shown to result in transient respiratory problems.[19] Ozone can also seriously irritate the eyes and mucous membranes. The effects of elevated ozone levels are not known for all types of vegetation, but such levels are harmful to many types of trees and crops. High ozone concentrations seem to be more detrimental than low-level extended exposure.[20]

The assessment of the impact of NO_x controls on ozone concentrations is complex and must be studied carefully in developing ozone abatement strategies, according to a 1992 report[21] from a National Research Council committee. The committee found that ambient measurements of VOC/NO_x ratios—which, as they vary, have different effects on ozone formation—were larger than expected from an assessment of emission inventories. The committee also determined that the effectiveness of efforts to control VOC and NO_x emissions depends on ambient VOC/NO_x ratios. Generally, at ratios of 10 or less, VOC control is more effective and NO_x control may be counterproductive. At ratios greater than 20, NO_x control is generally more effective. Hence, if VOC emission inventories have been understated, past ozone control strategies may have been misdirected. Tighter

[17]*Energy Efficiency and Renewable Energy*, p. 10.
[18]NAPAP *1992 Report to Congress*, p. 90.
[19]National Research Council, *Rethinking the Urban Ozone Problem in Urban and Regional Air Pollution* (Washington, DC: National Academy Press, 1992), pp. 31–33.
[20]Ibid., p. 37.
[21]Ibid., pp. 11 and 12.

controls on NO_x may be more effective in controlling ozone under certain circumstances.

The committee also found that combinations of biogenic VOCs and anthropogenic NO_x can significantly affect ozone formation in some urban and rural regions of the United States and concluded, again, that the appropriate strategy may be to monitor and control NO_x emissions.

Global climate change. Greenhouse gases are necessary for life on Earth because they keep ambient temperatures well above what they would otherwise be. Many scientists believe that anthropogenic additions (some from electric power plants) to the Earth's natural complement of greenhouse gases are augmenting this greenhouse effect and thus raising global temperatures.

The principle greenhouse gases are water vapor, CO_2, CH_4, N_2O, and chlorofluorocarbons (CFCs).[22] The levels of CO_2 and N_2O in the atmosphere can be influenced by the amount of electricity generated and the fuel used. Of the fossil fuels, coal has the highest carbon content. Oil and natural gas have approximately 80 percent and 60 percent of the carbon content of coal, respectively, on an energy-equivalency basis.[23]

Although CO_2 is not a regulated pollutant, the reduction of greenhouse gas emissions in general, including those of CO_2, is the focus of several international efforts. The United States signed the Framework Convention on Climate Change during the 1992 United Nations Conference on Environment and Development. President Clinton reaffirmed the U.S. commitment to control greenhouse gases by developing the Climate Change Action Plan. This largely voluntary plan is intended to stabilize greenhouse gases at 1990 levels by 2000. In 1994, electric utility groups signed a memorandum of understanding with DOE to pursue voluntary reductions in emissions of greenhouse gases and DOE completed draft guidelines for utilities to report emissions reductions voluntarily.

Electric Power Environmental Externalities and Their Control

Externalities are defined as "benefits or costs, generated as a byproduct of an economic activity, that do not accrue to the parties involved in the activity. Environmental externalities are benefits or costs that manifest themselves through changes in the physical-biological environment."[24] For example, the pollution emitted by fossil fuel-fired power plants may result in harm to people or the environment. Although those generators of electricity comply with environmental regulations and certainly do not intend to cause that harm, the costs (economic value) of the harm, if any, may not be included in the price of electricity. To the extent that the electricity industry does not pay these environmental costs and consumers do not pay the full cost of electricity they purchase, energy resources may not be allocated efficiently.

The practice of including all costs and benefits in market transactions is known as full-cost pricing. Full-cost pricing of electricity is a complex and controversial matter. Each policy or regulation to ameliorate externalities must account for the existing layer of policies and regulations. Many of these are environmental regulations. Others are regulators' decisions on electricity prices, which may cause prices to exceed the marginal costs of producing electricity. It is also difficult to precisely estimate the magnitude of the externalities. If environmental regulations are not stringent enough, some environmental externalities will remain; if regulations are too stringent, resources will be over-allocated to controls.

Further, the environment can absorb a certain level of pollution without damage. This threshold, below which control is not warranted, may be uniform throughout the country or may vary from region to region, depending on the pollutant and the environmental concern in question. The nature of the pollutant and the environmental problem greatly influence the viability of any abatement approach or strategy, which in turn influences the efficiency of resource allocations.

From the standpoint of developing an efficient control framework, perhaps the most important characteristics of an air pollutant are the sensitivity of its point of emission and whether it causes local, regional, or national air pollution. "Uniformly mixed" pollutants have the same effect on the atmosphere regardless of their geographic point of origin. For example, emissions of CO_2 from anywhere in the country or world have uniform impacts on climate change. The effects of "nonuniformly mixed" pollutants, on the other hand, are very sensitive to conditions around the point of emission. This sensitivity depends upon the state of the

[22] Energy Information Administration, *Emissions of Greenhouse Gases in the United States 1985–1990*, DOE/EIA–0573 (Washington, DC, September 1993), p. 1.

[23] D.J. Wuebbles and J. Edmonds, *Primer on Greenhouse Gases*, (Chelsea, MI: Lewis Publishers, Inc., 1991), p. 33.

[24] National Association of Regulatory Utility Commissioners, *Environmental Externalities and Electric Utility Regulation* (Washington, DC, September 1993), p. 3.

area's environment and whether the prevailing winds might transport the emissions to another area and exacerbate the problems there. The pollutants that cause urban ozone and acid rain are nonuniformly mixed pollutants. The emission of these pollutants in certain areas may not be a problem or result in externalities, and environmental economic theory states that they should be regulated (or not) accordingly.

Historically, three pollution-control techniques have been considered: emission standards, which are an important form of command-and-control measure; emission charges, fees, or taxes; and marketable emission allowances:

- An *emission standard* is simply a legal emissions rate or a limit on the amount of a pollutant an entity can emit. Standards allow pollutant emission levels to be precisely controlled, but they do little or nothing to promote cost minimization and seldom vary with the relative impact of the pollutant.

- *Emission charges or fees* are financial penalties imposed on each unit of emission from a source. In principle, each emission source reduces its emissions to the point where its marginal control costs are equal to the emission charge. This approach thus encourages emission sources to minimize the cost of control even though the regulating body does not know what the control cost is or how it differs from one facility to another. In theory, the emission fee should equal the marginal damage from the emission, i.e., the externality, had it not been internalized by the emission fee. A disadvantage of this approach, as well as the others, is that it does not account for the impact of these fees on the rest of the economy.

  One form of emission fee is expressed in the externality values ("adders") used by some PUCs. Those values are used to monetize the external costs of emissions so that they may be considered in decisions to build new electric power plants.

  The two principal methods of monetization are calculating damage costs and calculating control (mitigation) costs. Damage cost estimations involve analysis and prediction of four factors: (1) emission quantities; (2) emission concentrations in the receiving medium; (3) the effect of those concentrations on the medium; and (4) the economic value of those effects. All four factors are subject to significant uncertainty.

  Because of the difficulty in estimating damage costs, control costs (usually the cost of the most stringent emission control) are sometimes used as a proxy for damage costs. The implicit assumption in control costing is that society controls pollution until the benefits of additional controls would be outweighed by the costs. However, this assumption may not be valid. For instance, criteria air pollutants are controlled to satisfy health-based standards, not some criterion of overall economic efficiency. Furthermore, control costs seldom reflect the variability in damage costs and are thus often poor proxies.

- The use of *marketable emission allowances* permits regulating bodies to precisely control the total level of emissions and also to minimize the costs of control. Under this approach, each source needs an allowance for each unit of emission and the total number of allowances is limited to reflect the desired emission total. Along with technical options, such as changing fuel mixes or retrofitting facilities with pollution control devices, sources can use their marketable allowances to comply with emission regulations. If the operator of a source perceives the value of an allowance to be greater than the costs of retrofitting or switching fuels, the allowance may be saved for future use or sold in the marketplace to the highest bidder. The regulating body has precisely achieved its goal of a certain emission level by issuing the appropriate number of allowances. Because all marginal control costs for the last unit of emission for each source are equal, the total cost of controlling emissions to the desired level has been achieved at minimum cost. A limitation of this approach is the difficulty of agreeing upon the desired emission total. The use of offsets—for example, planting trees to absorb the CO_2 that would be emitted by a new fossil-fueled power plant—is similar to an allowance system and is being tried in several States.

Efficient control programs are much more easily developed for uniformly mixed pollutants than for nonuniformly mixed pollutants because emissions of the former have the same potential for damage regardless of their points of release. The policy objective is simply to control the level of total emissions at the lowest possible cost. The control of a nonuniformly mixed pollutant, on the other hand, is much more complicated. In addition to controlling the total quantity of emissions, regulators must also know the location of the emission sources, relevant wind and rain patterns, and existing environmental conditions within the geographic reach of the pollutant. Because of these factors, a single pollutant emitted from different sources may cause different degrees of damage. Emission charges and marketable allowance systems ideally should account for these differences in order to be as efficient as the systems designed for uniformly mixed pollutants. However, the impracticality of developing such designs could lead to regional dislocations.

Electric Utilities and the Clean Air Act Amendments of 1990

The 1963 Clean Air Act was the first attempt by the Federal Government to establish air quality standards requiring States to control pollution for the protection of human health and the environment. The act has since been amended several times, most recently by passage of the Clean Air Act Amendments of 1990. The CAAA significantly revised U.S. air pollution laws and mandated stringent regulations that were designed to become stricter and more comprehensive over time.[25]

The CAAA's acid rain program controls the emissions of SO_2 and NO_x from electric utilities. A system of marketable allowances is used to limit total emissions and minimize the costs of the SO_2 reduction program. The CAAA also requires EPA periodically to classify communities according to their success in meeting the NAAQS and to set attainment deadlines for those communities that have not yet met the standards. Until recently, more stringent ambient air quality control has not had much impact on the utility industry. However, as discussed above, studies completed after the CAAA became law have revealed that NO_x emissions under certain circumstances contribute to urban air quality problems.[26]

Acid Rain. Title IV of the CAAA authorizes EPA to develop a program to reduce SO_2 and NO_x emissions by 10 million tons annually and 2 million tons annually, respectively, from 1980 emission levels by 2000. The program is divided into two phases. Phase I, effective January 1, 1995, set an SO_2 emission limit of 2.5 pounds per million Btu for 261 generating units at 110 electric utility power plants in 21 States, all of them east of the 100th meridian (Figure FE2). More than 75 percent of the affected generating capacity is located in eight States: Georgia, Illinois, Indiana, Missouri, Ohio, Pennsylvania, Tennessee, and West Virginia.[27] Also effective January 1, 1995, Phase I sets NO_x emission limits for the same 261 generating units if they use dry-bottom wall-fired boilers or tangentially-fired boilers.

Phase II, which begins January 1, 2000, will establish more stringent and far-reaching SO_2 reduction requirements. Virtually all electric utilities with fossil-fueled power plants will be covered. The maximum emission rate for SO_2 at most facilities will be 1.2 pounds per million Btu. Nationwide total SO_2 emissions will be capped at 8.9 million tons annually (14.8 million tons were emitted in 1993[28]). Newly constructed facilities will be able to emit SO_2 only to the extent that they purchase marketable allowances from existing facilities. Phase II also extends the NO_x standards to all remaining electric utility generating units (including wet-bottom boilers; cyclone-fired boilers; dry-bottom, vertically fired boilers; boilers with cell burners; stokers; and fluidized bed combustion boilers) at the 261 Phase I generating units that were not regulated for NO_x emissions during Phase I.

CAAA Title IV allocates SO_2 allowances to affected power plants based on the prescribed emission limits during Phase I or Phase II.[29] The allowances can be used, sold, or saved for future use. In contrast to traditional "command and control" regulations, this market-based approach of selling allowances encourages the limitation of total SO_2 emissions at minimum cost. The Electric Power Research Institute has predicted that the value of the allowances will range from \$190 per ton of SO_2 to \$650 per ton during the period from 1995 through 2007, with the mid-range scenario predicting an increase in allowance prices from \$250 per ton in 1995 to \$480 per ton in 2007.[30]

In the near term, the upper limit on allowance prices can be estimated as the avoided cost of capital equipment for pollution control (\$300 per ton and \$600 per ton in Phase I and Phase II, respectively), or the cost of switching to low-sulfur coal,[31] whichever is lower. However, the March 1994 annual allowance auction

[25]This discussion focuses on electric utilities. Under the provisions of the CAAA, control of emissions from nonutility generators may vary from State to State and according to facility size and startup date.

[26]The sections of the CAAA that address urban air quality and acid rain also have indirect impacts on greenhouse gases. However, those impacts are not discussed in this article.

[27]Energy Information Administration, *Acid Rain Compliance Strategies for the Clean Air Act Amendments of 1990,* DOE/EIA–0582 (Washington, DC, March 1994), Table 2.

[28]Energy Information Administration, *Annual Energy Outlook, with Projections to 2010,* DOE/EIA-0383(95) (Washington, DC, January 1995), p. 30.

[29]Specifically, a unit affected by Phase I requirements is allocated allowances equal to its annual average fuel consumption during the period 1985 through 1987, multiplied by an emissions rate of 2.5 pounds of SO_2 per million Btu. Phase II allowances are computed by using the same fuel consumption number multiplied by an emissions rate of 1.2 pounds of SO_2 per million Btu.

[30]*Energy Efficiency and Renewable Energy,* p. 9.

[31]Low-sulfur coal is defined as coal that, when burned, meets an emission standard of 1.2 pounds or less of SO_2 per million Btu.

produced prices of approximately $150 per ton.[32] This low price partially the result of the mix of strategies chosen by electric utility power plant operators to meet the Phase I SO_2 standards. EIA data reveal that the primary strategy, chosen by 62 percent of operators on grounds of cost-effectiveness, is switching to low-sulfur coal. Approximately 15 percent of operators plan to comply by acquiring SO_2 allowances and 10 percent by installing scrubbers. Most utilities appear able to meet the Phase I standards for both SO_2 and NO_x with minor increases in rates.[33] Given the fixed number of allowances, long-term allowance prices will be driven by growth in both coal-fired generation and its cost.

The marketable allowance approach has been developed for uniform national application. However, acid rain problems vary from region to region. Theoretically, concerns of economic efficiency dictate that regions suffering greater damage from acid rain should allocate more resources to the minimization of SO_2 emissions. However, the CAAA regulations do not impose tighter standards in areas with greater damage, and they prohibit regulating authorities from restricting or controlling the acquisition or transfer of allowances. Although States can develop more stringent standards, it is not clear what steps they can take collectively to address serious region-wide damages. This problem could become more apparent during Phase II, when the western regions might sell excess allowances to the East.[34]

It is not yet clear which compliance strategies will be the most cost-effective for electric utilities. Phase II tightens the standards and extends them to virtually the entire industry, including new electric power plants that must compete for allowances if they are to be constructed. Plants in western States, which were not subject to Phase I requirements, will be covered under Phase II. Because 59 percent of the recoverable coal reserve base in the Western Region is low-sulfur coal (only 11 percent of the coal in the Interior Region and Appalachian Region is low-sulfur),[35,36] it is likely that enough low-sulfur coal will be available for western facilities to meet the standard for some time without turning to other means.

Title IV of the CAAA represents a compromise among the interests of various constituencies. The emphasis of Title IV was significantly to reduce national SO_2 emissions by means of a national cost-sharing and cost-minimization program, rather than to optimize the relationship between compliance costs and damage control. A more ideal program (from an environmental and economic point of view) would have attempted to vary the standards in accordance with the different levels of damage resulting from SO_2 emissions and to allow transfer of marketable allowances only among utilities that contribute to common damages. The current program could result in national compliance but disproportionately high emissions in certain regions of the country, particularly in the East, where damage is believed to be more severe.

Urban Ozone. In 1991, in accordance with the requirements of the CAAA, EPA designated 98 areas of the country as "nonattainment" areas with respect to the NAAQS for ground-level ozone.[37] Since then, EPA has redesignated several of those areas as attainment areas, and in October 1994 EPA released air quality data indicating that many of the remaining nonattainment areas had met the standard and could officially be redesignated as attainment areas upon EPA approval of their State strategies to remain in compliance over the next 10 years. However, almost 100 million people still live in areas with below-standard air quality, primarily in the northeastern States and California (Figure FE3).[38] The northeastern States are attempting to address their regional ozone problems through the Ozone Transport Commission,[39] discussed further below.

Nitrogen oxides are the only pollutant emitted by electric power plants in significant amounts that contributes

[32]A.D. Kissam, "Pollution Control for Cash," *Independent Energy*, Vol. 25, No. 1 (January 1995), pp. 52–54.

[33]*Acid Rain Compliance Strategies*, pp. x–xi.

[34]EIA forecasts that approximately 20 percent (net) of the West's allowances will be transferred to eastern facilities in 2005. See the Supplement to the *Annual Energy Outlook 1995*, DOE/EIA-0554(95)(Washington, DC, February 1995), Detailed Tables 54 through 66.

[35]Energy Information Administration, *U.S. Coal Reserves: An Update by Heat and Sulfur Content,* DOE/EIA–0529(92) (Washington, DC, February 1993), Table 8.

[36]U.S. coal producing regions are defined as follows: The Western Region is Alaska, Arizona, Colorado, Montana, New Mexico, North Dakota, Utah, Washington, and Wyoming. The Interior Region is Arkansas, Illinois, Indiana, Iowa, Kansas, western Kentucky, Louisiana, Missouri, Oklahoma, and Texas. The Appalachian Region is Alabama, eastern Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia.

[37]EPA has set the ozone standard at 0.12 parts per million daily maximum one-hour average concentration, not to be exceeded more than once per year.

[38]U.S. Environmental Protection Agency press release R–255, "EPA report shows continuing progress in cleaning Nation's air," October 19, 1994.

[39]The CAAA established the Ozone Transport Commission (OTC) to coordinate the efforts of States in the Northeast to solve their ozone problems. State-level coordination is necessary because ozone and its precursors, VOC's and NO_x, can be transported over long distances by winds. The OTC includes 12 Northeastern and mid-Atlantic States, the District of Columbia, and the EPA.

Figure FE3. The Ozone Transport Region and Areas with Air Quality Not Meeting National Ambient Air Quality Standards for Ozone as of January 1995

Sources: **Main Map:** Derived by EIA from data supplied by Environmental Protection Agency, Office of Air Quality Planning and Standards. **Inset map:** Memorandum of Understanding Among the States of the Ozone Transport Commission on Development of a Regional Strategy Concerning the Control of Stationary Source Nitrogen Oxide Emissions (September 27, 1994).

to local air pollution. Prior to the passage of the CAAA, NO_x emissions had received little attention. Los Angeles was the only area of the country that violated the NAAQS for nitrogen dioxide. In order to combat ozone formation, the CAAA strengthened NO_x automotive standards, placed controls on NO_x emissions from industrial plants in ozone nonattainment areas, and required coal-fired electric utility plants to meet maximum emission standards that varied with the type of boiler used.

As discussed in the preceding section, recent studies have indicated that, under certain circumstances, more extensive control of NO_x may be more effective at controlling urban ozone than aggressive controls on VOCs. Current NO_x standards under the CAAA may not be tight enough to reduce regional ozone levels in the northern or southeastern United States. Overall control strategies may need to be rethought and cost-effective strategies developed.[40]

Selected State Air Pollution Control Activities

States and EPA share responsibility under the CAAA for ensuring that all areas achieve compliance with air quality regulations. States are responsible for developing State Implementation Plans (SIPs), which define the means whereby States expect to achieve and maintain compliance with the NAAQS.

Some States have been developing emission control programs more stringent than those required by the CAAA. Among the more significant approaches are consideration of externalities in the deliberations of PUCs and State cooperation to address regional problems.

Public Utility Commissions. Some electric utilities have begun to consider externalities in the context of the integrated resource planning (IRP) mandated by a number of PUCs. Specifically, utilities may meet the demand for electric power by means of both supply- and demand-side resources. Supply-side resources include the construction of new capacity and purchases of power from independent power producers. Demand-side resources include demand-side management (DSM) programs, in which projected future demand is addressed in part by reducing energy consumption through the use of more energy-efficient appliances, equipment, and building materials. Integrated resource planning requires utilities to submit plans that consider both supply- and demand-side resources as part of

[40]U.S. Environmental Protection Agency, *Implementing the 1990 Clean Air Act: The First Two Years*, EPA–400–R–92–013 (Washington, DC, November 1992), pp. 66-67.

their overall strategy of providing reliable electric power services at least cost. In some States, utilities must consider externalities, reflecting the desire of those PUCs to ensure that utilities consider the full costs of electricity in their new-resource decisions. Under those regulations, utilities add the externality values as if they were real costs in the utilities' tally of the overall costs of their resource options, and decide on new resources on the basis of the overall costs.

IRP is still a relatively new concept in many States.[41] Several have only recently issued orders requiring IRP plans and the plans are still being filed or are in public hearings and thus are not yet approved. EPACT mandated that all State PUCs and Federal power marketing authorities hold hearings on integrated resource planning for electric utilities so that all States will develop some sort of IRP process.

Although many State PUCs have rejected the use of externalities in IRP, as of July 1995, six PUCs (Table FE2) were quantifying the estimated costs of air pollution for consideration in their decisions to construct new plants.[42] Nevada, for example, arrives at the full cost of electricity by imposing a penalty of over 4 cents per kilowatthour on utility coal-fired plants. These costs vary significantly from State to State (and sometimes within a State), in part because PUCs are just beginning to quantify environmental costs and no consensual approach or methodology yet exists. In general, PUCs

Table FE2. Selected Externality Values Used by State Public Utility Commissions

States	SO_2		NO_x		CO_2		N_2O		PM_{10}	
	$/ton	¢/kWh	$/ton	¢/kWh	$/ton	¢/kWh	$/ton	¢/kWh	$/ton	¢/kWh
California Nonattainment Areas:										
S. Cal. Ed/S.D. G&E	23,490	1.90	31,448	6.92	9.00	0.94	–	–	6,804	0.04
Pacific G&E	4,486	0.36	9,120	2.01	9.00	0.94	–	–	2,624	0.02
California Attainment Areas	1,720	0.14	1,720	0.38	9.00	0.94	–	–	4,608	0.03
Massachusetts[a]	1,700	0.30	7,200	2.09	24.00	2.40	4,400	cu	–	–
Minnesota[b]										
Low	0	0.00	59	0.02	5.99	0.60	–	–	–	–
High	300	0.05	1,640	0.48	13.60	1.36	–	–	–	–
Nevada	1,716	0.14	7,480	1.65	24.00	2.50	4,554	cu	4,598	0.03
New York	1,437	0.25	1,897	0.55	1.00	0.10	–	–	–	–
Oregon[b]										
Low	–	–	2,000	0.44	10.00	1.04	–	–	–	–
High	–	–	5,000	1.10	40.00	4.16	–	–	–	–
Wisconsin	–	–	–	–	15.00	1.50	2,700	cu	–	–

[a]In December 1994, the Massachusetts Supreme Court ruled that the State public utility commission had no authority to require the use of these values and they are no longer in effect.

[b]States use a range of externality values.

SO_2 = sulfur dioxide, NO_x = nitrogen oxides, PM_{10} = particulate matter with diameter less than 10 microns, CO_2 = carbon dioxide, N_2O = nitrous oxide.

S. Cal. Ed./S.D.G.&E = Southern California Edison and San Diego Gas & Electric.

– = Not applicable; externality value not required by public utility commission.

cu: No conversion because emissions data not unavailable.

Note: Conversions of dollars per ton to cents per kilowatthour are estimates by Oak Ridge National Laboratory. The estimates assume that all electric power plants involved burn pulverized coal, that power plants east of the Mississippi River burn bituminous eastern coal, and that power plants west of the Mississippi River burn subbituminous western coal. Cents-per-kilowatthour value for SO_2 in the service area of Southern California Edison and San Diego Gas & Electric is derived by multiplying ($23,490 per ton) x (0.81 tons per gigawatthour) and converting to cents per kilowatthour (1.9).

Source: Oak Ridge National Laboratory, *The Impact of Environmental Externality Requirements on Renewable Energy* unpublished report prepared for the Energy Information Administration (Oak Ridge, Tennessee, July 1994), Table A-1.

[41]Readers interested in more detail on State IRP planning and externality considerations may wish to consult a recent EIA report, *Electricity Generation and Environmental Externalities: Case Studies.* DOE/EIA-0598 (Washington, DC, September 1995). See also the following: a recent unpublished report from Oak Ridge National Laboratory entitled *The Impact of Environmental Externality Requirements on Renewable Energy* (Oak Ridge, TN, July 1994) (contact Mr. Carlin for more information); National Association of Regulatory Utility Commissioners, *Environmental Externalities and Electric Utility Regulation* (Washington, DC, September 1993); and National Renewable Energy Laboratory, *Issues and Methods in Incorporating Environmental Externalities into the Integrated Resource Planning Process,* NREL/TP-461-6684 (Golden, CO, November 1994).

[42]Oak Ridge National Laboratory, *The Impact of Environmental Externality Requirements on Renewable Energy*, unpublished report prepared for the Energy Information Administration (Oak Ridge, Tennessee, July 1994), Table A–1.

employ control-cost values. The recently completed joint DOE-European Commission study,[43] as well as other studies,[44] confirmed the feasibility of calculating damage-cost values, which are theoretically preferred to control-cost estimates. Damage-cost estimates are usually smaller in magnitude than control-cost estimates.

The California Direct Access Proposal. External costs, however, are certainly not the only factors PUCs must address in their deliberations. Customer concerns for lower rates and the prospect of increased competition among all generators of electric power are leading to a deemphasis of externality considerations.

These concerns are, perhaps, most prominent in California. Seeking to lower the cost of electric service in an increasingly competitive economic environment, the California PUC in April 1994 began an investigation and rulemaking on a major restructuring of the State's electric services industry to dismantle the traditional arrangement by which utilities hold regulated monopolies on electric power services in their service areas.

The restructuring revolves around the concept of retail wheeling, also known as direct access. Under a direct access regime, customers would pay their local utilities a retail wheeling charge for transmission and distribution services and could buy electricity generation service from any supplier. The development of competition in the industry could lead to substantially lower consumer prices for electricity and to major gains in the productivity of the economy as a whole.

In its most recent proposal, in April 1995, the California PUC favored the creation of a "pool" that would serve as the operator of the electric grid system, by coordinating dispatch and delivery of electricity, and as a clearinghouse for all electricity transactions. Utilities would purchase power from the pool on behalf of their customers and bid into the pool to sell their generation. All suppliers of electricity (except for existing qualifying facilities and wholesale contracts, and investor-owned nuclear and hydroelectric supplies, which reflect past investment commitments) would compete with one another. They would submit bids to supply power to the pool in specific time increments.[45]

The California proposal retains environmental quality as an important goal but provides little detail on how environmental quality would be preserved under the new regulatory arrangement. The option favored by the PUC is to shift all responsibility for environmental protection to environmental, rather than energy, regulators, although one commissioner favored environmental performance standards for local distribution companies. None of the commissioners favored emissions surcharges that would internalize the damages for environmental externalities.

California is not the only State interested in increased competition and deregulation. The National Conference of State Legislatures (NCSL) has reported a major increase in the number of calls from legislators asking for advice on retail wheeling bills. Among the major opponents of direct access proposals are environmentalists and those supporting energy conservation.

Environmentalists fear that the focus on reducing rates will cause the external costs of fossil fuel-fired generation to be overlooked, thereby rendering renewable energy projects financially infeasible. Opponents also fear the demise of demand-side management programs, because utilities that have made investments in such programs would lose market share if they intended to recover their investments through higher rates. In April 1994, a coalition of almost 60 organizations banded together to oppose such plans, citing environmental and energy conservation concerns.[46] Since then, many fruitful discussions have taken place among the various stakeholders, but there is no consensus yet on an effective means of reducing environmental externalities in a deregulated environment.

If retail wheeling policies are adopted across the country, investor-owned utilities could point to disparities between the requirements they face and those faced by independent generators not under the jurisdiction of State PUCs. PUC-regulated utilities could argue for greater flexibility in selecting the lowest cost resources, unburdened by requirements to consider externalities or non-fossil energy set-asides, both of which increase utilities' costs.

Widespread adoption of retail wheeling would give rise to complex jurisdictional concerns and result in regional markets that transcend State boundaries. It would also introduce a variety of generators into electric power markets; many of those generators would not be under the jurisdiction of State PUCs. Thus, to the extent that damages to human health and the environment are regarded as true economic costs, some public action would be needed if these costs were to be internalized.

[43]McGraw-Hill / Utility Data Institute, *U.S.-EC Fuel Cycle Externality Study, Volumes I-VII* (Washington, DC, 1994-95).

[44]See Office of Technology Assessment, *Studies of the Environmental Costs of Electricity*, OTA–ETI–134 (Washington, DC, September 1994) for discussion.

[45]One commissioner advocated a "purer" model of direct access that omitted the pool.

[46]D. Wagman and J. Simpson, "Retail Wheeling Opponents Join Forces," *Fortnightly*, Vol. 38, No. 8 (April 15, 1994), p. 7.

Such action would require public support and might entail additional Federal involvement. Such a Federal role might reduce the problems associated with piecemeal State-by-State regulation of retail wheeling and might also provide a regulatory framework for addressing environmental externality issues that cross State lines.

Northeast Ozone Transport Commission.

Another major activity involving the States is the creation of the Ozone Transport Commission (OTC) to coordinate control efforts among the States in the Northeast that make up the Ozone Transport Region (OTR). The OTR is divided into the Inner Zone, the Outer Zone, and the Northern Zone (Figure FE3). The OTC's primary mission is to develop strategies for controlling and reducing ozone and its precursors throughout the region. To achieve this objective, a memorandum of understanding among the States of the region to control stationary-source NO_x has been developed. Key sections of the agreement are as follows:

- The States agree to propose regulations and/or legislation for the control of NO_x emissions from fossil-fueled boilers and other indirect heat exchangers with a maximum gross heat input rate of at least 250 million Btu per hour during the period May 1 to September 30 of each year.
- The States agree to propose regulations that require subject sources in the Inner Zone and Outer Zone to reduce their rate of NO_x emissions by 65 percent and 55 percent, respectively, from base year levels by May 1, 1999, or to emit NO_x at a rate no greater than 0.2 pounds per million Btu.
- The States agree to propose regulations that require sources[47] in the Inner Zone and Outer Zone to reduce their rates of NO_x emissions by 75 percent from base year levels by May 1, 2003, or to emit NO_x at a rate no greater than 0.15 pounds per million Btu.[48] The regulations for the Northern Zone are similar, except that NO_x emission levels are to be reduced by 55 percent or to a rate no greater than 0.2 pounds per million Btu.
- The States agree to develop a regionwide trading mechanism in consultation with EPA.[49]

Several utilities in the region have said that complying with the NO_x regulations would cost "tens of millions of dollars."[50] It is likely that utilities in the Northeast will coordinate individual control efforts for NO_x and SO_2 emissions so that a least-cost program that minimizes the combined cost of control is developed.

Summary and Conclusions

Electric power plants emit significant quantities of three pollutants (CO_2, SO_2, and NO_x) that contribute heavily to local, regional, or national environmental problems, or all three. National standards to address problems that vary by region may not optimize the relationship between compliance costs and damage control.

The Phase I provisions of Title IV of the CAAA and the creation of the Ozone Transport Commission reflect a Federal effort to require primarily eastern States to work together in resolving common environmental problems that cross State lines. However, SO_2, a pollutant that leads to different levels of damage in different parts of the country, is being controlled with a national standard. States, particularly those in the Northeast that are believed to be suffering the most severe damages, could develop more stringent standards. They need the cooperation of other States in the region if significant emission reductions are to be achieved. States seeking such cooperation may have to make further adjustments during Phase II, when there could be a net inflow of allowances from the West.

Many States and PUCs have developed utility emission control programs to address the States' particular environmental problems. One such approach is the incorporation of external environmental costs into decisions about how best to meet projected demand for electric power. The possibility that externality considerations could become standard practice in the PUC community is strongly related to the theoretical soundness of the approach chosen, the perception of fairness by all affected parties, and the consistency of treatment from State to State. The more the externality values chosen by PUCs reflect real (even if estimated) damages caused by a particular utility's emissions, the more efficient, fair, and consistent the approach. A key factor

[47]The reductions for 1999 are limited to fossil fuel-fired boilers and other heat exchangers with 250-million-Btu/hour heat inputs and with a potential to emit about 250 tons per year of NO_x at a 50-percent capacity factor and an emission rate of 0.5 pounds of NO_x per million Btu.

[48]The cutoff point for 1999 reductions does not apply (see previous footnote).

[49]Memorandum of Understanding Among the States of the Ozone Transport Commission on Development of a Regional Strategy Concerning the Control of Stationary Source Nitrogen Oxide Emissions (September 27, 1994).

[50]"Eastern Utilities Say OTC NO_x Plan Compliance Would Run Into Millions," *Electric Utility Week* (October 17, 1994), p. 12.

in determining the value of the externality is the sensitivity of the location of the source of a particular emission and any damage to the environment it may cause. Some emissions (such as SO_2) cause measurable damage only if they are emitted or blown into an area of the country that exceeds the threshold for SO_2. On the other hand, any damage to the environment from an emission such as CO_2 is insensitive to the point of emission.

A perfectly efficient and fair policy is elusive. The use of externalities in IRP decision making is complicated by other related regulations, the possible effect of utilities' use of adders on their electricity prices, and the divergence between regulated prices and utilities' marginal costs. Also, the concept of externalities applies not only to different fuels and technologies but also to all electric generating competitors, including utilities in neighboring States, unregulated independent power producers, companies that generate power for their own use, and the nonelectric sectors of the economy.[51] Externalities need to be considered during the debate over increasing electric utility competition. As the debate evolves, PUCs will have to determine whether their concerns for externalities can be addressed equitably and efficiently.

[51]For more information concerning these "piecemeal problems," see National Association of Regulatory Utility Commissioners, *Environmental Externalities and Electric Utility Regulation* (Washington, DC, September 1993) and National Renewable Energy Laboratory, *Issues and Methods in Incorporating Environmental Externalities into the Integrated Resource Planning Process*, NREL / TP-461-6684 (Golden, CO, November 1994).

Feature Article

Renewable Resource Electricity in the Changing Regulatory Environment

by Michael J. Zucchet[1]

Abstract

The United States has been a leader in the development of renewable resource electricity[2] since the early 1980s. During the past 15 years, many renewable technologies have advanced beyond the research stage and into commercial development. But despite its advances, the commercial renewable energy industry makes up a very small share of the electricity market,[3] and the near-term prospects for more renewable energy development remain uncertain. Much of this uncertainty has arisen in a regulatory environment that is changing to make the electric industry increasingly competitive. Heightened competition through the deregulation and restructuring of electricity generation could present several challenges for future renewable energy development. New and proposed regulatory policies may also hurt renewables by reducing the importance of their nonmarket benefits[4] in the resource planning process. This article surveys those recent actions and proposals and summarizes their implications for the renewables industry.

The current form of the renewable energy industry in the United States was spawned during the 1970s, when oil embargoes, rising energy prices, and increased pollution concerns raised questions about the Nation's continued dependence on fossil fuels. As world oil prices increased by 300 percent in 1974, alternative energy sources became a national priority. To spur renewable energy development, the Federal Government provided investment tax credits and research and development funds that topped out at $718.5 million in 1980.[5] Taking advantage of these incentive packages, private industry responded by pioneering new renewable technologies and applications. Consumer interest in alternative energy sources provided the political support for the Federal incentive programs and laid a strong foundation for an industry that grew rapidly.

While these economic and environmental forces lifted renewable energy off the ground, Federal regulation built the industry. The single most important factor in the development of a commercial renewable energy market was the passage of the Public Utility Regulatory Policies Act (PURPA) in 1978. Among other things, PURPA encouraged the development of small-scale electric power plants, especially those fueled by renewable resources. The renewables industry responded to such incentives by growing rapidly, gaining experience, improving technologies and reliability, and lowering costs.

New and proposed regulatory reforms during the 1990s, and especially in 1995, have adversely affected the near-term outlook for renewable electric technologies. Potentially critical regulatory and legislative changes have been proposed in two areas: (1) changes

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[2]For the purposes of this article, "renewable" energy refers to wind, biomass, waste-to-energy, photovoltaic, and solar thermal-electric technologies. Hydropower is considered a mature, conventional energy technology and is not covered in this article.

[3]The Energy Information Administration's *Annual Energy Outlook 1995*, DOE/EIA-0383(95) (Washington, DC, January 1995), estimated 1993 nonhydropower renewable electricity generation at 79 billion kilowatthours, comprising about 2.5 percent of the Nation's electricity supply.

[4]Nonmarket benefits are the desirable byproducts of economic activity that accrue to parties not directly involved in market agreements. These benefits are typically diffuse and are not bought and sold in a market, yet society still values them. In the case of renewable energy production, nonmarket benefits include reduced environmental damages relative to fossil fuel energy production, and reduced supply risk resulting from a more diverse national fuel mix.

[5]M. Silverman and S. Worthman, "The Future of Renewable Energy Industries," *Electricity Journal* (March 1995).

related to PURPA, including the possible repeal of sections of the Act, and (2) changes related to the restructuring and deregulation of electricity generation. While some recent State and regional initiatives continue to provide incentives for renewable energy development, the Federal changes have the potential to severely affect the entire renewable energy industry.

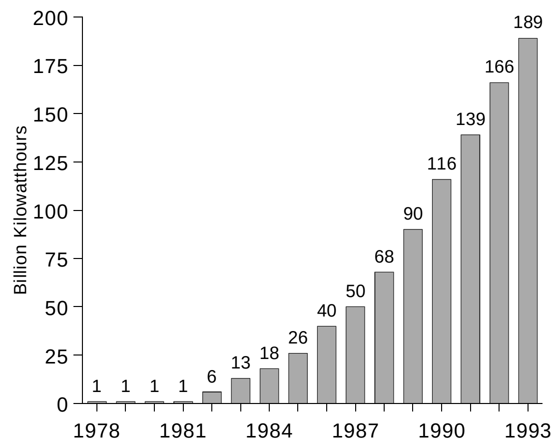
PURPA Power

In enacting PURPA, President Jimmy Carter and the U.S. Congress sought to decrease the Nation's dependence on foreign oil and increase domestic energy conservation and efficiency. To achieve those ends, PURPA encouraged the development of cogenerators[6] and small power producers by eliminating certain barriers that had prevented their entry into a market controlled by public utilities.[7] PURPA defined a class of independent generators as "qualifying facilities" (QFs)[8] and mandated that utilities purchase power from QFs at the utility's full avoided cost. In other words, PURPA required utilities to pay QFs what they would otherwise spend to generate or procure power.[9] The Federal Energy Regulatory Commission (FERC), responsible for the oversight of PURPA implementation, left it to the States and their utility commissions to determine the utilities' avoided costs.

PURPA mandated that utilities interconnect with QFs and buy whatever amount of QF capacity and energy was offered. It also simplified contracts, streamlined the power sales process, increased financial certainty for creditors and equity sponsors, and generally eliminated several procedural and planning problems that had made entry into the electricity market prohibitive for most of the smaller energy producers. These PURPA provisions provided a substantial boost to nonutility power producers (Figure FE1). They also enabled nonutility renewable electricity production to grow into the 1990s, while utility production of renewable electricity declined slightly (Figure FE2).

The renewables industry used its newfound market niche to improve technologies, increase efficiency, and decrease costs. Thanks primarily to PURPA, renewable

Figure FE1. Purchases by Electric Utilities from Nonutility Power Producers, 1978-1993



Source: Energy Information Administration, *Annual Energy Review 1994*, DOE/EIA-0384(94) (Washington, DC, July 1995).

and nonrenewable QFs now comprise large amounts of new and existing generating capacity in certain markets. For example, one-third of the California Edison Company's generating capacity is QF capacity, a substantial fraction of which is renewable energy.[10]

By the mid-1980s, some States (most notably, California) had mandated that QFs receive long-run avoided cost rates that today substantially exceed current market prices. These rates were based on expectations of sharply rising oil and natural gas prices (Figure FE3), as well as the expectation of future increases in the demand for electricity and construction of new generating capacity. From the perspective of the QFs, these above current avoided cost rates (6 cents per kilowatthour or higher) and long terms (often 10 years) were essential to establish the QF power market.

By the late 1980s and early 1990s, however, oil prices had stabilized, natural gas prices had declined, and excess generating capacity in most regions of the country, especially the Southwest and the Northeast,

[6]A cogenerator is a generating facility that produces both electricity and usable thermal energy (such as heat or steam) for industrial, commercial, heating, or cooling purposes.

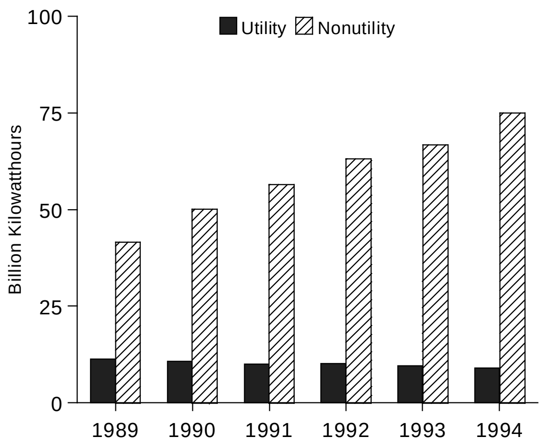
[7]The term "utility" is used generally throughout this article specifically to connote "electric utility."

[8]The rules that implement PURPA stipulate that a small power facility can achieve qualifying status provided that its rated capacity does not exceed 80 megawatts and no more than 50 percent of the plant is owned by a utility. Such a facility is considered to be a renewable QF if 75 percent or more of its fuel is derived from renewable sources. See S. Williams and B.G. Bateman, *Power Plays: Profiles of America's Independent Renewable Electricity Developers*, 1995 Edition (Investor Responsibility Center, June 1995).

[9]Avoided cost is defined in PURPA as the ". . . incremental cost of alternative energy . . . the cost to the electric utility of the electric energy which, but for the purchase from such cogenerator or small power producers, such utility would generate or purchase from another source."

[10]J.R. Bloom and J.M. Karp, "The Folly of PURPA Repeal," *Public Utilities Fortnightly* (July 1, 1995).

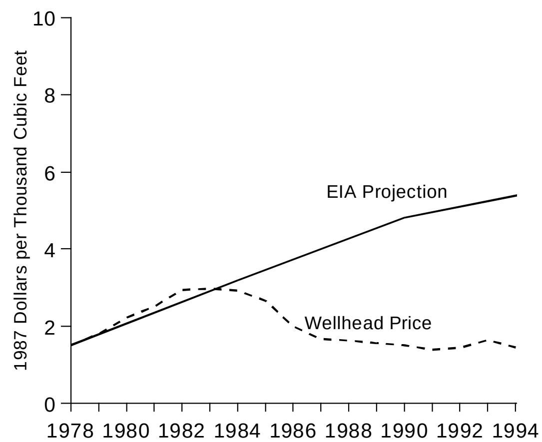
Figure FE2. Net Generation of Renewable Electricity by Utility and Nonutility Power Producers, 1989-1994



Notes: Renewable sources are geothermal, wood, waste, wind, and solar. Nonutility power producers are cogenerators, independent power producers, qualifying facilities, and other small power producers of 1 megawatt capacity or more. Nonutility generation is based on EIA estimates. Utility generation in 1994 is based on preliminary EIA data.

Source: Energy Information Administration, *Annual Energy Review 1994*, DOE/EIA-0384(94) (Washington, DC, July 1995).

Figure FE3. 1979 Projections and Actual Historical Prices for Natural Gas, 1978-1994



Notes: EIA was one of several forecasting organizations that projected substantial increases in natural gas prices throughout the 1980s and into the 1990s. The wellhead price of natural gas is calculated by dividing the total reported value at the wellhead by the total quantity produced, as reported by the appropriate State and Federal agencies. All prices were standardized into 1987 dollars using price deflators from the Bureau of Economic Analysis, U.S. Department of Commerce. The 1994 actual natural gas price is based on EIA estimates.

Sources: **EIA projection:** Energy Information Administration, *Annual Report to Congress 1979*, DOE/EIA-0173(79)/3 (Washington, DC, 1979). **Actual**: Energy Information Administration, *Annual Energy Review 1994*, DOE/EIA-0384(94) (Washington, DC, July 1995).

allowed utilities to buy capacity and energy at much lower prices than had been forecast a decade earlier. The utilities' actual avoided costs dropped lower than in the mid-1980s and were considerably lower than the levels required by the long-term contracts imposed by State commissions. Utilities in California, New York, Maine, and other proactive States were especially affected by long-term QF contracts above current avoided cost.

While some State public utility commissions (California and Wisconsin, for example) still favor long-term contracts and incentive rates, other commissions and almost all affected utilities have complained about above-market energy costs and higher rates. Many utilities contend that PURPA has caused dramatic hikes in retail electric rates, and that new regulatory action must be taken to correct past misjudgments.[11] FERC has recently addressed some of these issues in the form of case decisions that could have a profound impact on the future of renewable energy.

FERC Decisions Involving PURPA

FERC oversees several aspects of the utility industry in the United States. Among its functions are the regulation of wholesale and interstate utility power and transmission transactions and the oversight of PURPA and any rates, terms, or conditions set by State public utility commissions under PURPA. While the States set and mandate the avoided-cost rates paid to QFs, the process used by each State to set these rates is subject to review by FERC.

In response to several cases involving utilities appealing to overturn mandated QF rates, FERC has made rulings that may change the way QF power is purchased and will affect the ability of State commissions to dictate the resource energy mix of their future capacity. In separate cases involving Connecticut Light & Power Company and two California utilities (Southern California Edison Company and San Diego Gas & Electric Company), FERC refused to allow the State to set rates above the current avoided cost of capacity and energy. The most significant of these cases for renewables was the California case, where FERC disapproved the Biennial Resource Plan Update (BRPU) of the California Public

[11] At least nine utilities have formed a coalition to lobby Congress to eliminate the mandatory power purchase provisions of PURPA: Allegheny Power System, Central Maine Power, Consolidated Edison, General Public Utilities, New York State Electric & Gas, Niagara Mohawk, Northwest Utilities, Oklahoma Gas & Electric, and San Diego Gas & Electric.

Utilities Commission (CPUC). BRPU structured a bidding process where only QFs bid against one another for new capacity, and it required renewable "set-asides," forcing utilities to purchase a certain percentage of energy from renewable sources. FERC disallowed the plan, ruling that BRPU forced utilities to pay above avoided costs by excluding some potential generation sources from the bidding for the QF segment of the bid.[12] Citing Section 210(b) of PURPA, FERC ruled that the States must include *all* alternative sources of capacity and energy in their calculations of avoided cost.

While the utilities involved in the cases were satisfied, independent power producers and the CPUC were stunned. CPUC, which has been a leader in the evolution of electric markets, claimed that the FERC order was irreconcilable with California's progressive State energy policy.[13] CPUC further asserted that the FERC rulings limited the ability of States to initiate set-asides or other resource planning activities, which is not a proper role for FERC, according to CPUC. The FERC rulings regarding QF treatment under PURPA are especially critical given the terms of many QF contracts. The majority of QFs in California and, to a much lesser extent, in other States, are now facing an avoided cost "cliff," as 10-year contracts written at rates in the 6-9 cents per kilowatthour range in the mid-1980s expire over the next few years. With current avoided costs in the 3-4 cent range, rolling over the contracts at today's rates would create financial problems for QFs.

Although FERC has since reaffirmed its California decision rejecting QF rates above avoided cost, it has also asserted that States can favor specific energy sources as long as such action does not result in rates above avoided cost. For example, FERC said that States may influence costs incurred by utilities through taxes or tax credits on generation produced by a particular fuel. What FERC explicitly disallowed was the addition of "externality adders" in avoided-cost calculations. Since renewable energy production is environmentally benign relative to most fossil fuel energy technologies, some States have included these adders in their avoided-cost calculations to "level the playing field" between renewables and fossil fuels. FERC ruled, however, that policies that constitute environmental externality adders that result in rates above avoided cost would not be acceptable.

In short, if a State wishes to encourage renewable generation, FERC has indicated that it may do so through the tax code (or some other broad policy measure), but it may not use a rate-setting mechanism that results in a rate that is above avoided cost. CPUC has responded to this directive by considering a proposal mandating that utilities that sell at retail in the State obtain 12 percent of their energy from renewable resources. This approach is designed to support renewables and circumvent the FERC orders rejecting QF rates above avoided cost.

In other cases brought before FERC, the Commission has repeatedly rejected utilities' requests to abrogate existing QF contracts. In unrelated cases involving Niagara Mohawk Power Corporation and New York State Electric and Gas Corporation, FERC reaffirmed its unwillingness to cancel existing QF contracts simply because avoided-cost rates have changed and the deals have gone sour in changing electricity markets. FERC ruled that it will not disturb existing above-avoided-cost QF contracts if they were not challenged at the time they were signed.

In rejecting these petitions, FERC made several key findings. First, it affirmed that PURPA regulations permit QF rates to remain in effect even if avoided cost rates decline over time. Second, it affirmed the policy of relying on States to do the factual determination of avoided cost. And finally, the Commission plainly stated its disposition not to disturb executed contracts.[14]

While the positions of most utilities and QFs are quite evident (and opposite), State public utility commissions and residential and industrial energy consumers are not necessarily decided on the issue of favorable QF treatment. Most State commissions are in favor of the States' ability to control their own energy planning, although not all have endorsed the idea of above-avoided-cost QF contracts as a means to their planning ends. The Nevada Public Service Commission, for example, recently disallowed the rates set for a geothermal development because they were deemed too far above avoided cost to be reasonable, even though the QF and the utility both supported the rates. Many consumers, especially large industrial consumers, do not necessarily favor or oppose renewables but want to ensure both that power purchases are competitive and that utilities cannot exert monopoly power over QFs

[12]Barring a settlement between the CPUC and the California utilities, the FERC decision effectively cancels 1,500 megawatts of new QF capacity, almost 600 megawatts of which was to be provided by renewables. See National Renewable Energy Laboratory, *Public Utility Regulatory Policies Act Briefing Book* (April 10, 1995).

[13]"IPPs Stunned, State Miffed—Just Another Day on the PURPA Front," *Inside F.E.R.C.* (February 27, 1995).

[14]"NYSEG Request for Relief From QF Contracts Blown Out of the Water," *Inside F.E.R.C.* (April 17, 1995).

and independent power producers. On the other hand, some smaller consumers, especially residential consumers, have shown a willingness to pay for environmentally benign electricity.[15]

Proposal to Repeal PURPA

On June 6, 1995, the Energy Production and Regulation Subcommittee of the Senate Energy and Natural Resources Committee, chaired by Senator Don Nickles (R-OK), held a hearing on S. 708, The Electric Utility Ratepayer Act, which would repeal Section 210 of PURPA.[16] Section 210 mandates the purchase of power from QFs at avoided-cost rates.

Proponents of PURPA repeal assert, among other claims, that increased competition in the electricity generation industry makes PURPA unnecessary, and that mandating power purchases from QFs is actually quelling real competition. Many critics of the proposal for repeal argue that while changes are clearly needed in some areas of PURPA, repealing Section 210 would be premature because of continued utility monopoly power over transmission. They add that repeal should not take place until the transmission grid is open to all wholesale buyers and sellers of electricity.

While interests on each side of the debate argue the merits and faults of PURPA, the renewables industry waits in a state of anxious uncertainty. PURPA repeal could seriously hamper renewable energy development, potentially eroding what little market share renewables currently enjoy. One-quarter of all existing QFs are renewables, and without PURPA, much of this renewable capacity likely would not exist. PURPA has provided renewables with the opportunity to compete in an electricity market that was previously dominated by large-scale energy producers. The larger producers were the only ones who could undertake the complicated process of bidding for new capacity, arranging transmission, and securing financing without the guarantees provided by PURPA. PURPA lifted several of those procedural and planning burdens and moved QFs to the head of the energy pack. Repealing PURPA could mean a return to the situation where smaller power producers, including renewables, would have a difficult time penetrating the electricity market.

Restructuring, Deregulation, and Competition

Perhaps the most important regulatory issue affecting the future of renewable energy development is the trend toward utility restructuring and the deregulation of generation.[17] A competitive electricity market may create an opportunity for more customer choice, with some energy consumers willing to pay more for electricity generated from renewable sources (see box on page xxx). But competition will likely force utilities to make resource choices based more heavily on short-run internal costs, meaning that opportunities for valuing the nonmarket benefits of renewables will be diminished. While the overall outlook is uncertain, the renewable energy industry will face serious challenges in a utility environment more focused on short-run cost competition among generating sources.

In recent years, the U.S. electric industry has been under substantial regulatory and economic pressure to become more competitive. These pressures have arisen primarily from three sources. First, a large portion of new capacity additions has been developed by large independent power producers (IPPs), which are nonutility generators that do not qualify as QFs under PURPA. These plants are subject to rate regulation by FERC, but are generally permitted to sell their power at market prices to regulated utilities. Using mostly low-cost, highly efficient gas-fired systems and some advanced coal-fired plants, the IPPs have been able to underprice new and some existing utility generators. In particular, the advancement of combined-cycle gas turbines has made competition more likely by making it possible to build cost-effective power plants that are smaller than conventional fossil steam electric plants. Combined-cycle gas turbines have taken the cost advantages of large-scale electricity production away from utilities, and in so doing have helped to weaken utilities' monopoly position over generation.

Second, large commercial and industrial users have explicitly or implicitly forced limited "retail wheeling" in some States. Retail wheeling refers to the ability of electricity customers to choose their provider and use the local utility for transmission. Large commercial and industrial customers have become increasingly able to

[15]See "Green Pricing" box on page xxx.

[16]L.A. Burkhart, "Lawmakers Target PURPA for Repeal," *Public Utilities Fortnightly* (July 1, 1995).

[17]With some notable exceptions, the electric power industry historically has been composed primarily of investor-owned utilities. These utilities have been predominantly vertically integrated monopolies (combining electricity generation, transmission, and distribution) whose prices have been regulated by State and Federal government agencies. Restructuring the industry entails the introduction of competition into at least the generation phase of electricity production, with a corresponding reduction in regulatory control. Restructuring may also modify or eliminate other traditional aspects of investor-owned utilities, including their exclusive franchise to serve a given geographical area, assured rate of return on their investments, and vertical integration of the production process.

Green Pricing: Encouraging the Development of Renewables in a Deregulated Environment

"Green pricing" programs allow electricity customers to express their willingness to pay for renewable energy development through direct payments on their monthly utility bills. Green pricing represents a market solution to various problems associated with regulatory valuation of the nonmarket benefits of renewables. Under green pricing programs, utilities can encourage the development of renewable energy while simultaneously measuring customer support for renewables under semi-competitive conditions. Customers willing to pay a price premium for renewable energy can do so by adding some incremental amount of money to their regular electricity bills. Such programs are currently available from several utilities, and they are under consideration at many more utilities across the Nation. Examples of some existing programs follow:[a,b]

Public Service Company of Colorado: Participants in the Renewable Energy Alternatives Program (REAP) support the accelerated growth of renewable generating resources through voluntary monthly pledges. Currently more than 6,000 customers participate, at an average monthly pledge of approximately $2.

Traverse City Light and Power: About 200 customers volunteered to pay a 3-year premium of 1.58 cents per kilowatthour to fund construction and operation of a 600-kilowatt wind turbine.

Sacramento Municipal Utility District: Participants in the Photovoltaic Pioneers Program pay a 15-percent premium (about $6 per month) over a 10-year period to have a 4-kilowatt, grid-connected photovoltaic panel attached to their roofs. The full cost of the rooftop system is subsidized through other municipal income. Current participation is about 300 customers.

Portland General Electric: The "Penny Jar" program enables customers to "round up" their monthly utility bills, at an average of 50 cents a month. This amount supports future renewable energy generation programs.

Detroit Edison: Participants in the "Solar Currents" program pay a monthly premium to help fund the development of a planned 28.4-kilowatt photovoltaic facility. The utility will use $113,600 in Federal funds to pay a portion of the construction costs for the facility.

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[a]K. Baugh et al., "Green Pricing: Removing the Guesswork," *Public Utilities Fortnightly* (August 1995).
[b]"Detroit Edison to Offer PV Program as Michigan PSC Okays 'Green Pricing'," *Electric Utility Week* (August 7, 1995).

wield their market power over utilities, forcing them to either allow service from outside providers or match the rates available from those providers by threatening to cogenerate, move, or expand in a different service territory. As the large customers have been successful in pressuring utilities, some smaller nonresidential customers have demanded equal treatment. The trend toward retail wheeling, where any customer can receive service from any interconnected utility, has the effect of forcing utilities to compete more aggressively on price. In addition, some States, including Massachusetts, New Hampshire, and California, have formal proposals before their public utility commissions to explicitly permit some form of retail wheeling.

Finally, electric utilities are facing additional competitive pressures from end-use conservation programs. Demand-side management and other end-use conservation initiatives have reduced capacity demand in some areas,[18] forcing utilities to compete for a share of a diminishing overall market.

These competitive pressures could affect the future of renewables in several ways. First, as utilities are forced to compete more heavily on price in the short term, the flexibility to experiment with new or unproven technologies, including renewables, is diminished. The premium for short-term certainty and short-term cost minimization increases substantially, squeezing out

[18]According to the Energy Information Administration's *Annual Energy Outlook 1995*, DOE/EIA-0383(95) (Washington, DC, January 1995), demand-side management programs are expected to reduce the demand for electricity by 73 billion kilowatthours in 1997, relative to the level that would have been reached in their absence.

technologies that are not as cost-effective in the short run. Utilities that might otherwise invest in projects that might be cost-effective in the long run but carry high short-run costs (or high capital costs) would be less likely to do so in a price-competitive market. As the ability of the utility to compete on price in the short term becomes paramount, long-run investments may become less appealing. And if customers are permitted to shop the power market for low-price electricity, utilities with expensive power plants (or expensive QF contract obligations) may strand investments,[19,20] which could be financially damaging in a competitive market that does not allow utilities to recover those costs. Where a utility could previously roll expensive generation together with less costly generation, it must today consider each power source separately and determine whether each source is competitive. Under these conditions, the economic viability of renewable energy may be severely compromised. Renewable technologies, with their relatively high capital costs and low operating and maintenance costs, may be cost-effective in the long run, but they are less attractive to an industry facing severe near-term competitive pressure.

Another implication of competition and utility restructuring is the reduction in ratepayer-funded research, development, and demonstration (RD&D). With increasing competition, utilities no longer have as much flexibility or as many incentives to spend money on the development of new technologies that offer common benefit to all generators. To a large extent, this has already happened at both the State and national levels. In California, for instance, RD&D in advanced generation technologies plummeted by 88 percent in 1995 from 1993 levels. Contributions from California utilities to the Electric Power Research Institute, a utility-funded research and development organization, were also reduced by 50 percent in 1995 from 1994 levels.[21]

Increased price competition will also have the effect of limiting the importance of the beneficial (but mostly external) attributes of renewables. Renewable energy technologies are environmentally benign relative to conventional energy technologies, and they reduce the risks associated with fuel prices and availability by offering a more diverse fuel mix and by decreasing the Nation's dependence on foreign energy supplies. However, because these benefits accrue to the public in general, they are not usually explicitly counted in cost decisions and are not captured in electricity market prices. Even if these benefits were to be included in resource planning decisions, as some States have tried to do, they can be extremely difficult to measure. The acknowledgment and treatment of these benefits in the Nation's future energy policies may dictate the path to commercialization for renewable energy in the United States.

Although these electric industry trends will likely have a negative effect on renewable energy development, direct government incentives or mandates could still provide the necessary foundation to make renewables more cost-competitive at some point in the future. On the national level, for example, wind and biomass energy producers receive tax credits under the Energy Policy Act of 1992. State policies and incentives will also continue to play a major role in the development of renewables.

State and Regional Renewables Incentives

California is the leader in providing incentives for environmentally friendly technologies, especially renewable energy technologies. The California Public Utilities Commission has consistently developed State energy plans that favor the use of renewables, although, as discussed above, the most recent resource plan was struck down by FERC. The CPUC has responded by proposing that utilities keep and promote their current use of renewable energy through quantity mandates rather than price mandates. The success of this proposal could encourage and persuade other States interested in renewable energy development to enact similar policies.

Wisconsin is another State that provides an incentive for renewables development. Wisconsin's Advance Plan 6, passed in 1992, made it the only State to offer renewable energy incentives through direct payments on generation. Investor-owned Wisconsin utilities with qualifying wind, solar thermal, or photovoltaic generation receive a payment of 0.75 cents per kilowatthour, while all other qualifying renewable generation receives a payment of 0.25 cents per kilowatthour. The incentive payment applies to facilities that receive construction authority by December 31, 1998.

Like the CPUC, the Wisconsin Public Service Commission recognized that utility ratepayers would ultimately bear the costs of these incentives, but accepted the tradeoff in the interest of promoting renewables and obtaining such nonmarket benefits as fuel diversity and

[19]Stranded investment refers to financial impairment—not necessarily plant closure in the physical sense—when the price of plant output falls to a level at which the owner can no longer earn a sufficient return on investment.

[20]"Stranded What, Exactly?" *Public Utilities Fortnightly* (December 1, 1994).

[21]"CEC Hearings to Explore Restructuring's Effect on Utility RD&D Spending Levels," *The Solar Letter* (January 20, 1995).

emissions reductions. Given the regulatory climate on the national level, State initiatives take on increased importance in guiding the future of renewable energy development.

The Uncertain Future of Renewable Energy

The FERC rulings limiting the use of above-avoided-cost renewable set-asides may severely affect the commercial renewable electricity industry. The industry is also facing increasing competition among generating plants and the possible repeal of PURPA. The extent to which the renewables industry will be able to continue to grow under these conditions is uncertain.

The immediate future of renewables is largely dependent on three factors. First, most renewables depend on the willingness of the public (expressed in the form of direct State and Federal government incentives or green pricing programs) to support renewable energy development. The programs and initiatives of State and local governments are especially important, and the States' continued involvement in the promotion of renewables will have a large impact on the future of renewables. Second, continued improvement in the technical and cost merits of renewable technologies will increase the probability of their commercialization. Simply put, if performance and cost measures continue to improve relative to alternative energy sources, more renewable technologies will become cost-competitive with conventional technologies. Finally, the prices of fossil fuels, especially natural gas, will establish the baseline for determining renewable energy's cost competitiveness. As prices change over time, so too does the economic viability of renewables. As the technologies develop, and especially if fossil fuel prices rise, renewables have the potential to compete with conventional fuels in all areas, including cost.

Introduction

This report presents the following information on the history, status, and prospects of renewable energy in the United States: historical renewable energy data; estimates of renewable resources; characterizations of renewable energy technologies; descriptions of industry infrastructures for individual technologies; evaluations of current market status; and assessments of near-term prospects for market growth. (Longer term quantitative outlooks for renewable energy are provided in EIA's *Annual Energy Outlook 1995*.[1]) An international section is included, as well as two feature articles that discuss issues of importance for renewable energy as a whole. The report also contains a number of technical appendices and a glossary. The renewable energy sources included in the report are biomass (wood), municipal solid waste, biomass-derived liquid fuels, geothermal, wind, and solar and photovoltaic.

Even though renewable energy currently contributes only a small portion of the Nation's energy supply, its importance is expected to increase in the future. It is therefore appropriate to focus attention on the current use of renewable energy and the issues facing the renewable energy industry.

The report is divided into six major parts. It begins with two feature articles that discuss cross-cutting issues affecting the use of renewable energy sources. Section I then provides a summary of renewable energy consumption data for the years 1990 through 1994. The data come from EIA surveys, where possible. For fuel areas not covered by EIA surveys, the report presents data collected by other organizations. Section II contains analytical material on renewable energy. General background material on the resources and technologies is given, including a milestone table of significant historical events for each energy source, as well as analyses and assessments of factors likely to affect each renewable source in the near term. Section III presents the current status of renewable projects worldwide and the prospects for their continuing development. The appendices generally contain either detailed tabular information requiring no additional discussion or detailed technical material that supports major points in the body of the report. The final segment of the report contains a glossary of renewable energy terms.

The U.S. Department of Energy (DOE) supports renewable energy development through a number of programs, including the Photovoltaic Systems Program, Biomass Power Program, Geothermal Technology Development Program, Wind Energy Program, Integrated Resource Planning Program, Climate Challenge Program, and Hydrogen Research Program. In addition, the National Renewable Energy Laboratory (NREL) in Golden, Colorado, supports DOE with wide-ranging research assessments and development activities for a variety of renewable energy sources. The major program emphasis at NREL is solar energy and photovoltaics, owing to its beginnings as the Solar Energy Research Institute. In developing information in this report, EIA has conducted extensive analyses of materials from DOE's Office of Energy Efficiency and Renewable Energy and from NREL, other DOE laboratories, and private sources.

[1]Energy Information Administration, *Annual Energy Outlook 1995*, DOE/EIA-0383(95) (Washington, DC, January 1995).

Highlights

Data Summary

- In 1994, consumption of renewable energy totaled 6.4 quadrillion Btu, 7 percent of total energy consumption (88.5 quadrillion Btu) (Table H1).
- Biomass energy consumption provided 2.9 quadrillion Btu in 1994, with wood energy consumption contributing 2.3 quadrillion Btu and waste energy consumption 0.5 quadrillion Btu. Consumption of biomass-derived alcohol fuels (ethanol) increased at an annualized rate of 4.6 percent to 0.098 quadrillion Btu in 1994.
- Total geothermal energy consumption provided nearly 0.4 quadrillion Btu of energy in 1994, representing a 2.2-percent annualized growth rate since 1990.
- Wind energy consumption increased faster than any other renewable fuel—by 50 percent from 1990 to 1994, from 0.024 to 0.036 quadrillion Btu.
- Solar energy provided 0.07 quadrillion Btu in 1994, with the residential sector contributing 0.06 quadrillion Btu and the industrial sector contributing 0.01 quadrillion Btu.
- Shipments of solar thermal collectors increased by 9 percent in 1994 to 7.6 million square feet. While the price of solar thermal collectors decreased, the value of shipments rose by 3 percent to $28.4 million.
- Shipments of low-temperature solar thermal collectors increased by 13 percent from 1993 to 1994, while medium-temperature collector shipments decreased by 14 percent. This represents a reversal of trends experienced between 1992 and 1993.
- Photovoltaic cell and module shipments increased by 24 percent during 1994 to 26 peak megawatts, capping a decade-long string of increases. The annualized rate of increase over the previous 10 years was 16 percent. Overall unit peak watt prices fell substantially in 1994, resulting in a 4-percent decrease in the value of shipments to $106 million.
- Exports of photovoltaic cells and modules reached a record 18 peak megawatts, 20 percent higher than in 1993. Since 1985, export shipments have increased at an average annual rate of 27 percent.

Table H1. U.S. Renewable Energy Consumption by Source, 1990-1994
(Quadrillion Btu)

Energy Source	1990	1991	1992	1993	1994
Renewable Energy					
Conventional Hydroelectric Power[a]	3.113	3.196	2.871	3.156	3.037
Geothermal Energy	0.327	0.331	0.349	0.362	0.357
Biomass[b]	2.632	2.642	2.788	2.784	2.852
Solar Energy[c]	0.067	0.068	0.068	0.069	0.069
Wind Energy	0.024	0.027	0.030	0.031	0.036
Total Renewable Energy	**6.163**	**6.265**	**6.106**	**6.403**	**6.350**

[a]Hydroelectricity generated by pumped storage is not included in renewable energy.

[b]Includes wood, wood waste, peat, wood sludge, municipal solid waste, agricultural waste, straw, tires, landfill gases, fish oils, and/or other waste.

[c]Includes solar thermal and photovoltaic.

Notes: Annual totals reflect revised renewable energy estimates, and some data differ from data published in EIA's *Annual Energy Review 1994* (DOE/EIA-0384(94) (Washington, DC, July 1995). See data characteristics and caveats section in Chapter 1 for a detailed explanation. Totals may not equal sum of components due to independent rounding.

Sources: Energy Information Administration, Form EIA-759, "Monthly Power Plant Report"; *Solar Collector Manufacturing Activity 1993*, DOE/EIA-0174(93) (Washington, DC, August 1994), Appendix F; and estimates from the Office of Coal, Nuclear, Electric and Alternate Fuels. Natural Resources Canada, *Electric Power in Canada 1993*, National Energy Board of Canada, Electricity Exports and Imports (Ottawa, Canada, 1994). Fossil Energy, Form FE-781R, "Annual Report of International Electricity Export/Import Data."

Summary of Findings

Wood/Biomass

- The Nation's wood resource is large, contains a vast amount of energy, renews itself, and has several environmental advantages relative to fossil fuels.
- In 1991, approximately 17.9 billion cubic feet or 2 percent of roundwood resources were harvested from U.S. timberland, by far the largest contributor of wood energy. About 18 percent of this total, or 3.2 billion cubic feet (an equivalent energy value of 871 trillion Btu), was used as fuelwood. About 5 billion cubic feet, or 28 percent of the roundwood harvest, was used as pulpwood; about 30 percent of the pulpwood volume is recoverable for energy in the form of black liquor.
- Approximately 1,000 power plants currently operating in the United States use wood. A third of these power plants offer electricity for sale; the remainder provide in-house steam, heat, and electrical power, mostly in the pulp and paper industry.
- Most of the wood-fired power plants are owned by independent power producers, are cogeneration systems, and have a capacity in the range of 10 to 25 megawatts. Several wood-fired power plants operating today are in the 40- to 50-megawatt range. While future power plants could be larger to take advantage of technical and economic benefits associated with larger facilities, their ultimate size may be limited by wood transportation costs.
- The niche for the use of wood in the future could be the environmental advantages associated with its relatively low emissions of sulfur dioxide, carbon dioxide, and, under certain conditions, nitrogen oxides.

Biomass-Derived Liquid Fuels

- On June 30, 1994, the EPA issued a final regulation that would have required that 15 percent of the oxygenates added to reformulated gasoline in 1995 be derived from renewable sources. The regulations would have increased this percentage to 30 percent after January 1, 1996. The U.S. Department of Agriculture estimated that full implementation of this regulation would result in a net increase in ethanol demand of 500 million gallons annually and require an increase in corn production of 200 million bushels. However, the U.S. Court of Appeals, District of Columbia, rendered a stay of implementation of this regulation in response to a suit filed by the American Petroleum Institute and the National Petroleum Refiners Association.

Municipal Solid Waste

- The waste-to-energy (WTE) industry, a component of the municipal solid waste (MSW) industry, grew rapidly during the late 1980s and early 1990s, as privately owned facilities accelerated their activities in order to qualify for favorable pre-1986 tax reform laws. The recent slowdown is at least partially due to an inability to sustain the accelerated activities of the late 1980s. Another major factor causing the slowdown is recent U.S. Supreme Court rulings that State and municipal activities controlling the flow of waste violate the Commerce Clause of the Constitution.
- As a result of recent legislative and judicial decisions, waste is more likely to be disposed of in cheaper, less capital-intensive landfills than at WTE facilities. Congress is currently contemplating legislation that would authorize States and municipalities to control waste flows. If such legislation is not passed, there will be a net decrease in the number of WTE facilities, because many existing facilities are economically dependent on waste flow control laws and will be unable to survive in the competitive marketplace. On the other hand, if legislation is passed that in part allowed States to restrict imports of waste, and if the cost of landfilling increased as a result of new environmental standards, the competitive position of WTE facilities would be enhanced.

Geothermal

- Geothermal electricity generating plants in the United States operate on 19 fields in the States of California, Nevada, Utah, and Hawaii. Domestic geothermal development, however, has declined in recent years. In 1995, worldwide geothermal generating capacity totaled 6,000 megawatts in 20 countries.

Wind Energy

- Wind-based electricity generation capacity has increased markedly in the United States since 1970, although it remains a small fraction of total electricity capacity. Technological improvements in wind turbines have helped reduce capital and operating costs and some new turbines are reported to generate electricity for as little as 5 cents per kilowatthour. Although there are several constraints on wind energy's contribution to the U.S. energy supply, significant wind energy resources, some of which are currently economical, are located near existing high-voltage transmission lines, and wind energy generation potential is large.

Solar and Photovoltaic

- Photovoltaics provide a cost-effective source of electricity in remote, off-grid locations. The price of electricity from solar thermal trough technologies has fallen from more than 25 cents per kilowatthour in 1980 to less than 8 cents today. Costs must continue to fall, however, to make solar technologies more competitive with conventional energy technologies.
- The newest operating baseload solar thermal plant is Solar Two, which began testing subsystems in 1995. Once the technical checkout is complete, a consortium plans to operate the plant for 3 years.
- Thirty-nine electric utilities are testing grid-connected photovoltaic systems in the United States. The photovoltaic industry and 85 utilities have teamed together to form cost-shared partnerships totaling more than $385 million of startup capital over a 5-year period. Another photovoltaic partnership program (PV for Utility Scale Applications, or PVUSA) was formed in 1989 to test hardware for utility applications.
- The next phase of growth for large-scale, grid-connected solar electric technologies could be the federally sponsored Solar Enterprise Zone (SEZ) in southern Nevada. SEZ has proposals for 1,016 megawatts, including 175 megawatts of photovoltaics and 841 megawatts of solar thermal electric systems. Construction is scheduled to begin in 1996, and the full target capacity could be on line by 2003.

International Renewable Energy

- Many countries are pursuing renewables as part of their sustainable energy supply programs. International organizations, such as the World Bank and the United Nations, are providing loans supporting renewable energy projects in developing countries, many of which provide export markets for renewable energy technologies supplied by U.S. companies.

Section I

Renewable Energy Data

1. Renewable Data Overview

Renewable energy contributed an estimated 6.4 quadrillion Btu, 7 percent, of the Nation's total energy consumption of 88.5 quadrillion Btu in 1994 (Table 1 and Figure 1).[2] Hydroelectric power accounted for nearly one-half of renewable energy consumption, while biomass contributed 45 percent. Geothermal energy consumption amounted to just under 6 percent of total renewable energy consumption in 1994.

The electric utility sector accounted for nearly 50 percent of total renewable energy consumption in 1994 (Table 2). The industrial / nonutility sector accounted for 40 percent, followed by the residential and commercial sector with 10 percent. Consumption in each sector is dominated heavily by a single renewable energy source.

Other than hydroelectric power and electricity generation from wood and wood wastes, no renewable energy resource provided a significant portion of U.S. electric power before the 1970s. In 1970, U.S. renewable electricity generation capacity totaled about 63,000 megawatts, almost 18 percent of U.S. total generation

Table 1. U.S. Energy Consumption by Energy Source, 1990-1994
(Quadrillion Btu)

Energy Source	1990	1991	1992	1993	1994
Fossil Fuels					
Coal	19.101	18.770	18.868	19.430	19.541
Coking Coal (Net Imports)	0.005	0.009	0.027	0.017	0.024
Natural Gas[a]	19.296	19.606	20.131	20.841	21.156
Petroleum[b]	33.553	32.845	33.527	33.841	34.653
Total Fossil Fuels	**71.955**	**71.231**	**72.553**	**74.129**	**75.373**
Nuclear Electric Power	6.161	6.579	6.607	6.519	6.830
Hydroelectric Pumped Storage[c]	-0.036	-0.047	-0.043	-0.041	-0.035
Renewable Energy					
Conventional Hydroelectric Power[d]	3.113	3.196	2.871	3.156	3.037
Geothermal Energy	0.327	0.331	0.349	0.362	0.357
Biomass[e]	2.632	2.642	2.788	2.784	2.852
Solar Energy[f]	0.067	0.068	0.068	0.069	0.069
Wind Energy	0.024	0.027	0.030	0.031	0.036
Total Renewable Energy	**6.163**	**6.265**	**6.106**	**6.403**	**6.350**
Total Energy Consumption	**84.243**	**84.027**	**85.223**	**87.010**	**88.518**

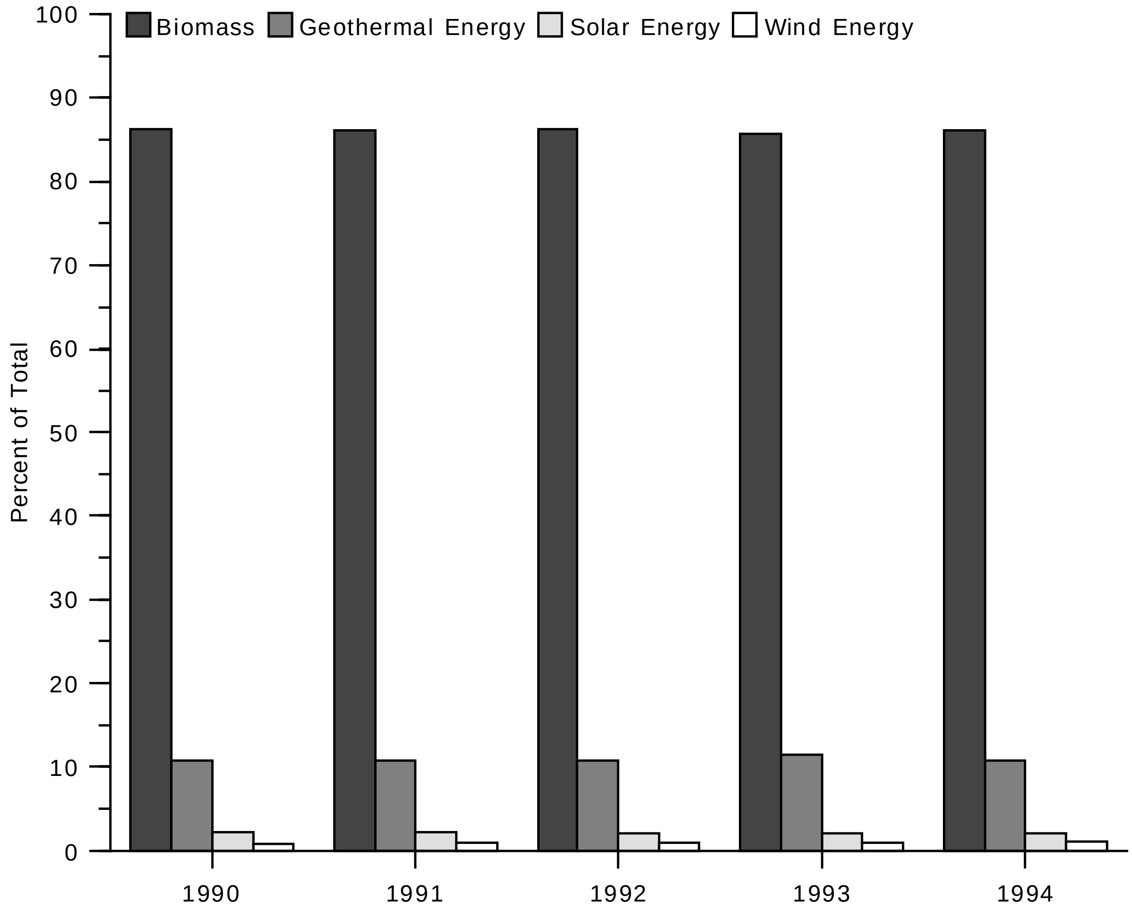
[a]Includes supplemental gaseous fuels.
[b]Petroleum products supplied, including natural gas plant liquids and crude oil burned as fuel.
[c]Represents total pumped-storage facility production minus energy used for pumping.
[d]Includes estimates of net imports of electricity known to be from renewable resources (geothermal and hydroelectric).
[e]Includes wood, wood waste, peat, wood sludge, municipal solid waste, agricultural waste, straw, tires, landfill gases, fish oils, and/or other waste.
[f]Includes solar thermal and photovoltaic.

Notes: Annual totals reflect revised renewable energy estimates, and some data differ from data published in EIA's *Annual Energy Review 1994* (DOE/EIA-0384(94) (Washington, DC, July 1995). See data characteristics and caveats section for a detailed explanation. Totals may not equal sum of components due to independent rounding.

Sources: Energy Information Administration, Form EIA-759, "Monthly Power Plant Report"; *Solar Collector Manufacturing Activity 1993*, DOE/EIA-0174(93) (Washington, DC, August 1994), Appendix F; and estimates from the Office of Coal, Nuclear, Electric and Alternate Fuels. Natural Resources Canada, *Electric Power in Canada 1993*, National Energy Board of Canada, Electricity Exports and Imports (Ottawa, Canada, 1994). Fossil Energy, Form FE-781R, "Annual Report of International Electricity Export/Import Data."

[2]See Appendix A for a detailed description of EIA's renewable energy data sources.

Figure 1. Renewable Energy Consumption Shares by Energy Source, 1990-1994



Note: Excludes hydroelectric power.

Sources: Energy Information Administration, Form EIA-759, "Monthly Power Plant Report"; *Solar Collector Manufacturing Activity 1993*, DOE/EIA-0174(93) (Washington, DC, August 1994), Appendix F; and estimates from the Office of Coal, Nuclear, Electric and Alternate Fuels. Natural Resources Canada, *Electric Power in Canada 1993* (Ottawa, Canada, 1994). Federal Energy Regulatory Commission, Form FE-781R, "Annual Report of International Electricity Export/Import Data."

capacity.[3] Of that total, however, more than 61,000 megawatts were accounted for by conventional hydroelectric power. Roughly another 1,000 megawatts were accounted for by wood and wood waste facilities. The remainder is distributed among the other renewable energy resources.

Since 1990, renewable energy consumption has grown at an annualized rate of 0.8 percent, compared with 1.2-percent annual growth in total energy consumption (Figure 2). All sources of renewable energy consumption have grown, except for hydroelectric power, which is highly dependent on precipitation levels, so its lack of growth should not be viewed as part of any long-term trend.

The largest source of renewable energy is hydroelectric power (Table 1), which is used almost exclusively (about 95 percent) in the electric utility sector (Table 2). The remainder is consumed by industrial facilities that operate their own hydroelectric generators (usually "run-of-the-river" units). It is important to note that the term "industrial/nonutility" is used in this publication to reflect the inclusion of independent power producers as well as cogeneration operations of grid-connected and non-grid-connected facilities.

[3]For electric utilities, net summer capability is used. For nonutilities, nameplate capacity is used. See Energy Information Administration, *Renewable Resources in the U.S. Electricity Supply*, DOE/EIA-0561 (Washington, DC, February 1993), p. 4.

Table 2. Renewable Energy Consumption by Sector and Energy Source, 1990-1994
(Quadrillion Btu)

Sector and Source	1990	1991	1992	1993	1994
Residential and Commercial					
Biomass	0.581	0.613	0.645	0.592	0.582
Solar Energy	0.060	0.060	0.060	0.060	0.060
Total	**0.641**	**0.673**	**0.705**	**0.652**	**0.642**
Industrial and Nonutility[a]					
Biomass	1.948	1.943	2.042	2.084	2.152
Geothermal Energy	0.146	0.162	0.179	0.204	0.212
Conventional Hydroelectric Power[b]	0.082	0.083	0.097	0.118	0.136
Solar Energy	0.007	0.008	0.008	0.009	0.008
Wind Energy	0.024	0.027	0.030	0.031	0.036
Total	**2.206**	**2.223**	**2.357**	**2.446**	**2.543**
Transportation					
Biomass[c]	0.082	0.065	0.079	0.088	0.098
Electric Utility					
Biomass	0.021	0.021	0.022	0.020	0.020
Geothermal Energy	0.181	0.170	0.169	0.158	0.145
Conventional Hydroelectric Power[b]	2.929	2.899	2.511	2.766	2.540
Solar and Wind Energy	*	*	*	*	*
Net Renewable Energy Imports[d]	0.102	0.214	0.243	0.271	0.361
Total	**3.234**	**3.304**	**2.965**	**3.217**	**3.066**
Total Renewable Energy Consumption	**6.163**	**6.265**	**6.106**	**6.403**	**6.350**

[a]Includes generation of electricity by cogenerators, independent power producers, and small power producers. Renewable consumption at other industrial sites not connected to the grid is also included.

[b]Hydroelectricity generated by pumped storage is not included in renewable energy.

[c]Ethanol blended into gasoline.

[d]Includes estimates of net imports of electricity known to be from renewable resources (geothermal and hydroelectric).

*Less than 0.5 trillion Btu.

Note: Totals may not equal sum of components due to independent rounding.

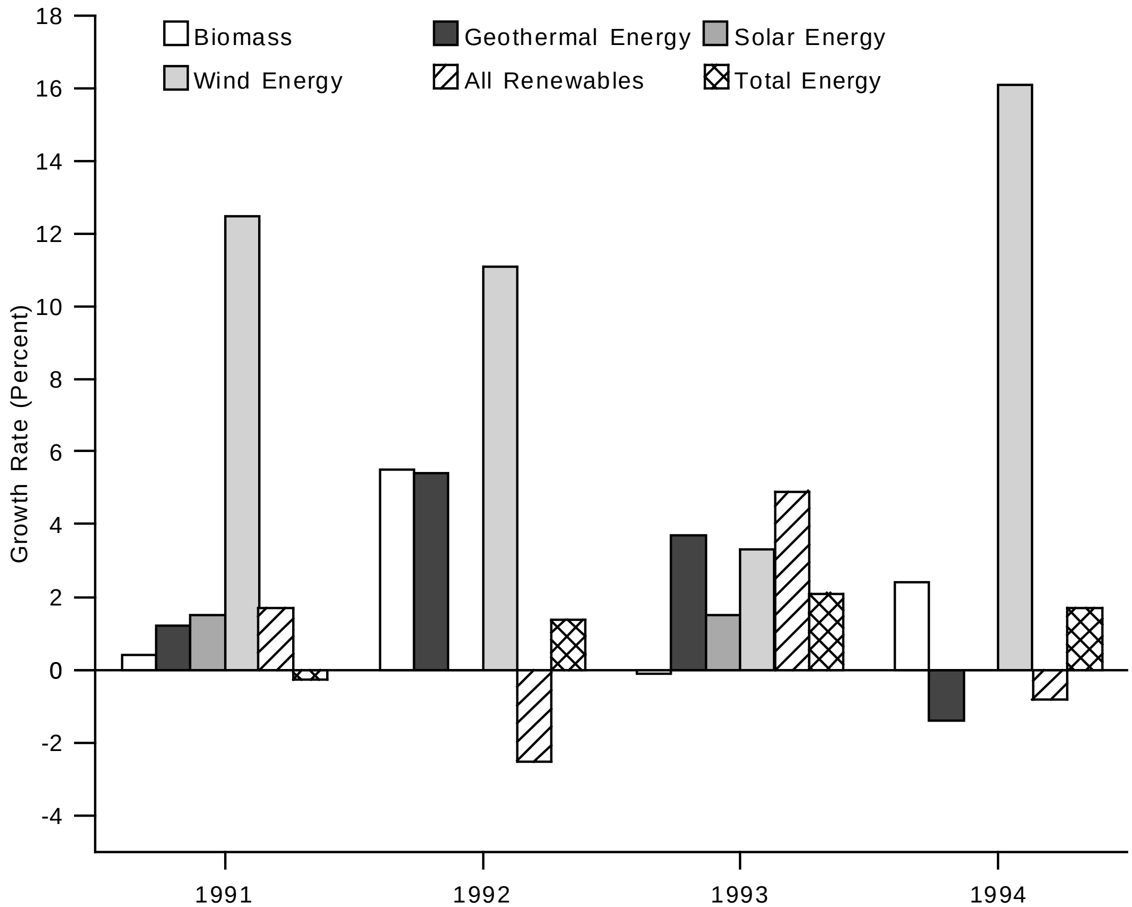
Sources: Energy Information Administration, Form EIA-759, “Monthly Power Plant Report” and Form EIA-867, “Annual Nonutility Power Producers Report”; *Solar Collector Manufacturing Activity 1993*, DOE/EIA-0174(93) (Washington, DC, August 1994), Appendix F; and estimates from the Office of Coal, Nuclear, Electric and Alternate Fuels. Natural Resources Canada, *Electric Power in Canada 1993*, National Energy Board of Canada, Electricity Exports and Imports (Ottawa, Canada, 1994). Fossil Energy, Form FE-781R, “Annual Report of International Electricity Export/Import Data.”

In contrast, biomass is used largely to produce heat for use in the residential, industrial, and nonutility sectors. The industrial and nonutility sectors accounted for more than 75 percent of total biomass energy consumption in 1994. About 75 percent of the biomass used for energy by industries was for “process heat” used to make products such as bricks and paper. The major source of industrial and nonutility biomass energy was black liquor (a pulpwood by-product waste fuel), roundwood fuelwood, and residues from primary and secondary wood mills. Wood-burning in the residential sector accounted for about 20 percent of total biomass energy consumption in 1994; a small amount of energy (0.04 quadrillion Btu) was derived from wood-burning in the commercial sector. Biomass in the form of alcohol fuels is the only renewable energy used in any measurable amount in the transportation sector.

Geothermal energy has three applications: electricity production or generation, low-temperature process heat (e.g., for crop drying), and heating and cooling applications for buildings. The data shown in this report, however, represent only geothermal energy used to generate electricity. EIA does not collect consumption information on geothermal energy used for low-temperature process heat or geothermal (groundwater) heat pumps. Of the geothermal energy devoted to electricity production, nearly 60 percent is used by the industrial sector (Table 2).

Virtually all wind energy consumption and all growth in solar energy consumption since 1990 has been for power production in the industrial and nonutility sectors. Small-scale solar energy devices in the residential and commercial sectors have remained flat at

Figure 2. Renewable Energy Consumption Annual Growth Rates by Energy Source, 1991-1994



Note: Excludes hydroelectric power.

Sources: Energy Information Administration, Form EIA-759, "Monthly Power Plant Report"; *Solar Collector Manufacturing Activity 1993*, DOE/EIA-0174(93) (Washington, DC, August 1994), Appendix F; and estimates from the Office of Coal, Nuclear, Electric and Alternate Fuels. Natural Resources Canada, *Electric Power in Canada 1993* (Ottawa, Canada, 1994). Federal Energy Regulatory Commission, Form FE-781R, "Annual Report of International Electricity Export/Import Data."

0.06 quadrillion Btu since 1990, while industrial solar energy consumption has increased slightly, from 7 trillion Btu in 1990 to 8 trillion Btu in 1994. Wind energy consumption has grown steadily at a 10.7-percent annualized rate since 1990, reflecting the after-tax economic viability of wind energy in appropriate locations.

Electricity generation consumed an estimated 4 quadrillion Btu of renewable energy in 1994 (Table 3), 63 percent of which came from conventional hydroelectric generation in the electric utility sector. Generation from biomass in all sectors accounted for another 15 percent, net imports of electricity from renewable energy accounted for 9 percent, and domestic generation from geothermal energy contributed another 9 percent.

While renewable energy consumption for electricity generation in the utility sector has declined at a 3.5-percent annual rate over the past 4 years, industrial sector generation has increased steadily. Since 1990, industrial and nonutility consumption of geothermal-based electricity has increased by 10 percent per year, with their use of electricity from biomass increasing by 7 percent per year.

Renewable energy contributed 375 billion kilowatt-hours, or 11 percent, of the Nation's estimated 3,286

Table 3. Renewable Energy Consumption for Electricity Generation by Energy Source, 1990-1994
(Quadrillion Btu)

Source	1990	1991	1992	1993	1994
Industrial Sector[a]					
Biomass	0.447	0.506	0.552	0.573	0.590
Geothermal Energy	0.146	0.162	0.179	0.204	0.212
Hydroelectric Power	0.082	0.083	0.097	0.118	0.136
Solar Energy	0.007	0.008	0.008	0.009	0.008
Wind Energy	0.024	0.027	0.030	0.031	0.036
Total	**0.706**	**0.786**	**0.867**	**0.936**	**0.982**
Electric Utility Sector[b]					
Biomass	0.021	0.021	0.022	0.020	0.020
Geothermal Energy	0.181	0.170	0.169	0.158	0.145
Conventional Hydroelectric Power	2.929	2.899	2.511	2.766	2.540
Solar and Wind Energy	*	*	*	*	*
Total	**3.132**	**3.090**	**2.702**	**2.945**	**2.706**
Imports and Exports[c]					
Geothermal Energy (Imports)	0.011	0.015	0.019	0.018	0.022
Conventional Hydroelectric Power (Imports)	0.168	0.231	0.278	0.294	0.359
Conventional Hydroelectric Power (Exports)	0.078	0.032	0.034	0.040	0.020
Total Net Renewable Energy Imports	**0.102**	**0.214**	**0.263**	**0.271**	**0.361**
Total Renewable Energy Consumption for Electricity	**3.940**	**4.090**	**3.831**	**4.152**	**4.048**

[a]Includes generation of electricity by cogenerators, independent power producers, and small power producers. Renewable consumption at other industrial sites not connected to the grid is also included.
[b]Excludes net imports.
[c]EIA estimates.
*Less than 0.5 trillion Btu.
Note: Totals may not equal sum of components due to independent rounding.
Sources: Energy Information Administration, Form EIA-759, “Monthly Power Plant Report,” and Form EIA-867, “Annual Nonutility Power Producer Report.” Natural Resources Canada, *Electric Power in Canada 1993*, National Energy Board of Canada, Electricity Exports and Imports (Ottawa, Canada, 1994). Fossil Energy, Form FE-781R, “Annual Report of International Electricity Export/Import Data.”

billion kilowatthours[4] of net electricity generation in 1994 (Table 4).[5] The electric utility sector provided 68 percent of renewable-based electricity and the non-utility sector 23 percent. Net imports accounted for the remaining 9 percent.

U.S. renewable generating capacity totaled 95 thousand megawatts in 1994 (Table 5). Of this, 83 percent was hydroelectric, followed by biomass (12 percent) and geothermal (3 percent).

Note that the capacity and generation totals for wind and solar do not always increase or decrease proportionately from year to year. Two factors may contribute to this phenomenon:

- Increased utilization rates (capacity factors) resulting from technological improvements would increase electricity generation per unit of capacity.
- The availability of intermittent resources, such as solar and wind, may vary from year to year. This variability affects the amount of electricity generated from a given amount of capacity.

Note also that hydroelectric generation depends heavily on precipitation patterns. Finally, care should be taken when interpreting changes between 1991 and 1992. Different sources were used for data before and after 1991, and these sources have differing definitions regarding the size of generating units included.

[4]Based on a previous estimate of 375 billion kilowatthours of nonutility generation (from Form EIA-867) and 2,911 billion kilowatthours of utility generation (from Table 11 of the *Electric Power Annual*, Volume I).
[5]See Appendix B for additional information on electricity production from renewables.

Table 4. Electricity Generation From Renewable Energy by Energy Source, 1990-1994
(Thousand Kilowatthours)

Source	1990	1991	1992	1993	1994
Nonutility Sector (Gross Generation)[a]					
Biomass	43,297,000	48,897,000	53,607,000	55,746,000	57,392,000
Geothermal Energy	6,916,000	7,695,000	8,578,000	9,749,000	10,122,000
Hydroelectric Power	7,960,000	8,007,000	9,446,000	11,511,000	13,227,000
Solar/Photovoltaic Energy	663,000	779,000	746,000	897,000	824,000
Wind Energy	2,295,000	2,650,000	2,916,000	3,052,000	3,482,000
Total	**61,131,000**	**68,028,000**	**75,293,000**	**80,955,000**	**85,047,000**
Electric Utility Sector (Net Generation)[b]					
Biomass	2,067,270	2,046,499	2,092,945	1,990,407	1,988,257
Geothermal Energy	8,581,228	8,087,055	8,103,809	7,570,999	6,940,637
Conventional Hydroelectric Power	283,433,659	280,060,624	243,736,029	269,098,329	247,070,938
Solar/Photovoltaic Energy	2,448	3,338	3,169	3,802	3,472
Wind Energy	398	285	308	243	309
Total	**294,085,003**	**290,197,801**	**253,936,260**	**278,663,780**	**256,003,613**
Imports and Exports					
Geothermal Energy (Imports)	538,313	736,980	889,864	877,058	1,072,061
Conventional Hydroelectric Energy (Imports)	16,302,116	22,318,503	26,948,408	28,558,134	34,907,685
Conventional Hydroelectric Energy (Exports)	7,543,487	3,138,562	3,254,289	3,938,973	1,993,004
Total Net Imports	**9,296,942**	**19,916,921**	**24,583,983**	**25,496,219**	**33,986,742**
Total Renewable Electricity Consumption	**364,512,945**	**378,142,722**	**353,813,243**	**385,114,999**	**375,037,355**

[a]Includes generation of electricity by cogenerators, independent power producers, and small power producers. Nonutility generation is rounded to the nearest thousand kilowatthours due to changed sample size. 1990 and 1991 were estimated based on data collected from Form EIA-867, "Annual Nonutility Power Producer Report."

[b]Excludes imports.

Note: Totals may not equal sum of components due to independent rounding.

Sources: Energy Information Administration, Form EIA-759, "Monthly Power Plant Report" and Form EIA-867, "Annual Nonutility Power Producer Report." Natural Resources Canada, *Electric Power in Canada 1993*, National Energy Board of Canada, Electricity Exports and Imports (Ottawa, Canada, 1994). Fossil Energy, Form FE-781R, "Annual Report of International Electricity Export/Import Data."

Data Characteristics and Caveats

The data included in these chapters is characterized by certain limitations. Appendix B details these limitations and provides information about the quality of renewable energy consumption data. In additions, some data may be different than that published in the *Annual Energy Review 1994*.[6] These differences generally fall into four categories:

1. *Wood.* Biomass data for 1993 and 1994 wood energy consumption shown in this report have been revised to include estimates for the commercial sector.

2. *Geothermal.* Geothermal energy consumption shown in this report is considerably higher than that shown in the *Annual Energy Review 1994*. This report revises the heat rate for geothermal energy in electricity applications from that used for fossil fuels (10,280 Btu per kilowatthour in 1994) to a heat rate appropriate for the average geothermal electricity-producing plant (20,914 Btu per kilowatthour). This change implies that about twice as much geothermal energy is used to generate electricity as previously reported.

3. *Electricity imports.* In the *Annual Energy Review 1994*, hydroelectric consumption data included all net imported electricity. This report revises hydroelectric consumption to reflect only imported and exported electricity estimated to be from renewable sources (geothermal and hydroelectric). Precise data on exported renewable electricity are not available, but the plants that export electricity are known, and the EIA has used supplementary data to estimate exported kilowatthours.

[6]Energy Information Administration, *Annual Energy Review 1994*, DOE/EIA-0384(94) (Washington, DC, July 1995).

Table 5. U.S. Electric Generating Capacity, 1990-1994
(Megawatts)[a]

Source	1990	1991	1992	1993	1994
Hydroelectric[b]	72,693	73,228	77,029	77,504	78,560
Geothermal	2,720	2,663	2,993	3,065	3,082
Biomass	9,114	9,827	10,276	10,636	11,081
Solar/PV	404	392	362	365	358
Wind	2,267	2,156	1,822	1,814	1,745
Total Renewables	**87,198**	**88,266**	**92,484**	**93,384**	**94,826**
Nonrenewables[c]	692,980	701,743	654,079	667,365	669,617
Total	**780,178**	**790,009**	**746,563**	**760,749**	**764,443**

[a]For 1990 and 1991, nameplate capacity is used. For 1992-1994, net summer capability is used.

[b]Excludes pumped storage, which is included in “Nonrenewables.”

[c]Includes hydrogen, sulfur, batteries, chemicals, spent sulfite liquor, and hydroelectric pumped storage. For 1990 and 1991, EIA utility hydroelectric pumped storage values were subtracted from renewable “hydroelectric” category estimates from the source used for renewable data for these years. These pumped storage estimates were then added to the “nonrenewables” category. This was done to improve definitional consistency of the data shown, since EIA does not classify pumped storage as renewable energy.

Note: Totals may not equal sum of components due to independent rounding.

Sources: 1990-1991: **Pumped storage**: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels. **Other Utility**: Energy Information Administration, *Inventory of Power Plants in the United States*, DOE/EIA-0095 (Washington, DC, 1990 and 1991). **Nonutility**: Edison Electric Institute, *1993 Capacity and Generation of Non-Utility Sources of Energy* (Washington, DC, November 1994), p. 52; 1992: Energy Information Administration, *Electric Power Annual 1993*, DOE/EIA-0348(93) (Washington, DC), pp. 17-18; 1993-1994: Energy Information Administration, *Electric Power Annual 1994, Volume 2*, DOE/EIA-0348(94/2) (Washington, DC), pp. 15-16.

4. *Revised calculations*. Data shown in this report reflect information taken from a newly developed renewable energy database. The database ensures that all calculations are made to the same level of precision and that exact conversion factors are used in a consistent manner. As a result, some minor revisions have been made to data reported in the *Annual Energy Review 1994.*

2. Biomass

Biomass provided 2.852 quadrillion Btu of energy, or 45 percent of total renewable energy consumption, in 1994 (Table 6).[7] Of the renewable energy sources, only hydroelectric power provided more energy than biomass. Biomass energy consumption has grown at an annualized rate of 2 percent per year since 1990, compared with a growth rate of 0.8 percent per year for total renewable energy consumption. Biomass energy is derived from three distinct energy sources: wood, waste, and alcohol fuels.

In 1994, wood energy consumption amounted to 2.266 quadrillion Btu, or nearly 80 percent of total biomass energy consumption. Wood energy is derived both from direct use of harvested wood as a fuel and from wood waste streams. In fact, the largest source of energy from wood is pulping liquor, or "black liquor," a waste product from processes of the pulp, paper, and paperboard industry. Pulping liquor represents between 60 and 70 percent of total U.S. wood and wood-derived energy consumption.

Waste energy is the second-largest source of biomass energy. The main contributors to waste energy are municipal solid waste (MSW), manufacturing waste, and landfill gas. Of these three, MSW accounts for about two-thirds of the total energy derived from waste. Energy from waste sources has grown at the relatively rapid rate of 5.4 percent per year since 1990, reaching 0.488 quadrillion Btu in 1994.

Biomass alcohol fuel, or ethanol, is derived almost exclusively from corn.[8] Its principal use is as an oxygenate in gasoline.[9] The passage of the Clean Air Act Amendments of 1990 (CAAA90) provided a boost to ethanol consumption, which has grown by 4.6 percent per year since 1990, to 0.098 quadrillion Btu in 1994.

Biomass Energy Consumption by Region

Both wood and ethanol use are dependent on proximity to the ultimate sources of supply: forests and cornfields. Thus, more than 60 percent of wood energy consumption occurred in the South in 1994, compared with around 15 percent in the West (mostly the Northwest) (Table 7). Similarly, ethanol consumption occurs almost entirely in the Midwest and South, with nearly 70 percent occurring in the Midwest during 1994. However, ethanol consumption has picked up in recent years in the West, primarily as a result of air pollution abatement mandates in southern California.

Waste energy consumption is fairly uniform among the four census regions and is highly related to population. However, a number of local legal and environmental issues are beginning to affect regional trends of energy production from waste (see Chapter 8). While energy from waste has grown substantially overall, consumption in the Midwest has remained flat since 1990. In other regions consumption has increased by 4 to 10 percent per year.

Wood Energy Consumption by Sector

Wood is used as an energy source primarily in the industrial sector, which consumed nearly three-fourths of the wood energy total in 1994. Between 1990 and 1994, the average annual growth rate for the industrial sector was 1.7 percent. However, wood energy use as a whole grew at an average annual rate of only 1.3 percent per year, reflecting a decline in residential sector consumption.

The U.S. pulp, paper, and paperboard industry, where mills consume large quantities of electricity, is the largest consumer of wood and wood waste for energy. The American Forest and Paper Association reported that 55 percent of the energy consumed by the industry in 1993 was self-generated, compared with 40 percent in 1972.[10] In addition to generation from spent pulping liquor, the industry also derives some of its energy from hydroelectric power.

In other forest product industries, wood, wood residues, and scrappage from wood product manufacturing

[7]For a description of the procedures used to develop the biomass data in this chapter, see Appendix D.

[8]Methanol, another alcohol fuel that is also used in significant quantities, is derived principally from natural gas and is not included in this report.

[9]The original impetus for fuel ethanol use was the Energy Tax Act of 1978, which was designed to encourage the use of ethanol as a fuel extender to promote self-sufficiency in the U.S. transportation fleet.

[10]American Forest and Paper Association, *U.S. Pulp and Paper Industry's Energy Use: Calendar Year 1993* (November 1994).

Table 6. Biomass Energy Consumption by Energy Source, Sector, and Census Region, 1990-1994
(Trillion Btu)

Energy Source	1990	1991	1992	1993	1994
Wood	**2,155**	**2,151**	**2,249**	**2,228**	**2,266**
Sector					
Residential	581	613	645	548	537
Commercial[a]	--	--	--	44	45
Industrial*	1,562	1,528	1,593	1,625	1,673
Electric Utility	12	10	11	11	11
Census Region					
Northeast	256	224	264	R277	R278
Midwest	330	290	286	R222	R223
South	1,064	1,167	1,234	R1,405	R1,437
West	505	R469	466	R324	R328
Waste[b]	**395**	**426**	**460**	**468**	**488**
Census Region					
Northeast	119	134	148	151	157
Midwest	89	99	84	85	88
South	114	109	128	130	134
West	73	87	100	102	107
Alcohol Fuels (Ethanol)	**82**	**65**	**79**	**88**	**R98**
Census Region					
Northeast	*	*	*	*	*
Midwest	55	45	55	61	68
South	17	11	13	15	16
West	10	9	10	11	12
Total Biomass Energy Consumption	**2,632**	**2,642**	**2,788**	**2,784**	**2,852**

[a]Commercial wood energy use for 1990-1992 is not included because there are no accurate data sources to provide reliable estimates. However, from the "1986 Nonresidential Energy Consumption Survey," conducted by the Energy Information Administration (EIA), it is estimated that commercial sector use is about 20 to 40 trillion Btu.

[b]Municipal solid waste, manufacturing waste, refuse-derived fuel, and methane recovered from landfills.

-- = Not available.

R = data revised from Energy Information Administration, *Estimates of U.S. Biomass Energy Consumption 1992*, DOE/EIA-0548(92) (Washington, DC, May 1994).

*Less than 0.5 trillion Btu.

Note: Totals may not equal sum of components due to independent rounding.

Sources: **1990 Wood Energy, Industrial Sector:** American Paper Institute, *Fact Sheet on 1990 Energy Use in the U.S. Pulp and Paper Industry* (July 1991). **1990 Wood Energy, Residential Sector:** Energy Information Administration (EIA), 1990 Residential Energy Consumption Survey. **1990 Waste Energy:** EIA, *Estimates of the U.S. Biofuels Consumption 1990 (October 1991)*, Table ES1. **1990 Alcohol Fuels:** U.S. Department of Transportation, *Monthly Motor Fuel Reported by States,* FHWA-PL-92-011 (September 1991); U.S. Department of Treasury, Bureau of Alcohol, Tobacco, and Firearms, *Monthly Distilled Spirits Report*, Report Symbol 76 (June 1991); *Alcohol Fuels Report*, internal quarterly report (September 1991). **1991 and 1992:** EIA, *Estimates of U.S. Biomass Energy Consumption 1992* (May 1994). **1993 and 1994 Wood Energy, Residential Sector:** EIA, Form EIA-457, "1993 Residential Energy Consumption Survey," and extrapolations from "1993 Residential Energy Consumption Survey," for 1994 estimates. **1993 and 1994 Wood Energy, Commercial and Industrial Sectors:** EIA, Office of Coal, Nuclear, Electric and Alternate Fuels (CNEAF), estimates derived from information from other government agencies, trade journals, and industry association reports; Form EIA-846, "1991 Manufacturing Energy Consumption Survey." **1993 and 1994 Wood Energy, Electric Utility Sector:** EIA, Form EIA-759, "Monthly Power Plant report." **1993 and 1994 Waste Energy:** Government Advisory Associates, *Resource Recovery Yearbook* and *Methane Recovery Yearbook*; EIA, CNEAF estimates. **1993 and 1994 Alcohol Fuels:** EIA, Form EIA-819M, "Monthly Oxygenate Telephone Report."

Table 7. Wood Energy Consumption by Sector and Census Region, 1993 and 1994
(Trillion Btu)

Census Region	Industrial		Residential		Commercial		Electric Utility		Total	
	1993	1994	1993	1994	1993	1994	1993	1994	1993	1994
Northeast	122	125	141	139	11	11	3	3	**277**	**278**
Midwest	97	100	111	109	11	11	3	3	**222**	**223**
South	1,216	1,252	175	170	11	12	3	3	**1,405**	**1,437**
West	190	196	121	119	11	11	2	2	**324**	**328**
Total Wood Energy Consumption	**1,625**	**1,673**	**548**	**537**	**44**	**45**	**11**	**11**	**2,228**	**2,266**

Sources: **Totals:** Energy Information Administration (EIA), Form EIA-457, "1993 Residential Energy Consumption Survey"; Office of Coal, Nuclear, Electric and Alternate Fuels (CNEAF) estimates derived from information from other government agencies, trade journals, and industry association reports; Form EIA-846, "1991 Manufacturing Energy Consumption Survey"; and Form EIA-759, "Monthly Power Plant report." **Regions:** EIA, CNEAF estimates.

are also used for energy. The resulting thermal energy is used to produce shaft power, space heat, and electricity, as well as process heat for drying at facilities such as kilns and plywood factories. Comparatively small amounts of wood and wood waste are consumed for energy by the ceramics and metallurgy industries.

Consumption of wood in the residential sector is influenced by variables such as average temperature and the cost of competing fuels (heating oil and natural gas). Residential sector wood use displayed a marked increase during the energy crises of the 1970s but declined with the return of lower oil prices.

Wood consumption for energy in the electric utility and commercial sectors has remained flat since 1990. (Estimates for commercial wood energy consumption are available only for 1993 and 1994.) There are currently about 10 dedicated, wood-fired electric utility plants in the country. The majority of power generation from wood is by independent power producers, the largest subgroup being pulp and paper mills. Because co-firing wood and coal as boiler fuel reduces certain emissions compared to straight coal firing, it is possible that wood consumption in the electric utility sector could increase.

Commercial consumption of wood for energy is difficult to estimate but in any event is extremely small in comparison with industrial and residential consumption. Other wood used for energy includes urban tree trimmings (known as "urban silviculture"), recycled wood pallets, and wood pellets used as a fuel for residential woodstoves (see Chapter 7).

Electricity from Biomass

Electricity generation from biomass grew by 7 percent per year between 1990 and 1994, reaching 59,380 gigawatthours in 1994 (Table 4). Most of the growth occurred in the industrial sector, where electricity generation from biomass increased from 43,297 gigawatthours in 1990 to 57,392 gigawatthours in 1994. In contrast, electric utility use of biomass has remained flat since 1990 at around 2,000 gigawatthours. Major sources for biomass-fired electricity in the industrial sector include the pulp, paper, and paperboard industry and mills in the forest products industry. Mill use of self-generated electricity from run-of-the-river hydroelectric facilities may become increasingly rare due to the relatively stringent environmental requirements these facilities now face as they come up for relicensing.

3. Geothermal

Geothermal energy consumption[11] in the United States totaled less than 0.4 quadrillion Btu in 1994, providing just over 17,000 gigawatthours of electricity generation (Table 8). EIA does not collect data on other applications of geothermal energy, but available sources indicate that in 1992, when geothermal energy use for electricity generation totaled 349 trillion Btu, other uses (direct heating and heat pumps) totaled over 4,000 gigawatthours.[12] On average, geothermal energy consumption for electricity generation has grown by 2.2 percent per year since 1990. However, consumption in the industrial/nonutility sector has grown by 9.8 percent per year, while utility sector consumption has declined by 5.4 percent per year.

A large percentage of utility sector geothermal energy consumption stems from The Geysers facility in California. Electricity generation from The Geysers is at least 10 times that from the next-largest utility-owned geothermal facility and 4 times that from the largest nonutility facility. As discussed in Chapter 10, production problems have caused a sharp drop in electricity generation from The Geysers since 1990. Nevertheless, almost 90 percent of geothermal electricity generation (utility and nonutility) came from California in 1994, and 10 percent came from Nevada (Table 8).

Table 8. Geothermal Energy Consumption and Electricity Generation, 1990-1994

Estimate	1990	1991	1992	1993	1994
Geothermal Energy Consumption[a] (Quadrillion Btu)					
Electric Utility	0.181	0.170	0.169	0.158	0.145
Nonutility	0.146	0.162	0.179	0.204	0.212
Total	**0.327**	**0.331**	**0.349**	**0.362**	**0.357**
Electricity Generation (Thousand Kilowatthours)					
Electric Utility					
California	8,429,403	7,900,814	7,917,440	7,422,851	6,745,833
Other States	151,825	186,241	186,369	148,148	194,804
Total	**8,581,228**	**8,087,055**	**8,103,809**	**7,570,999**	**6,940,637**
Nonutility					
California	6,027,290	6,583,321	7,361,287	8,003,990	8,294,586
Nevada	844,459	990,782	1,214,404	1,587,686	1,636,592
Other States	44,251	120,897	2,309	157,324	190,822
Total	**6,916,000**	**7,695,000**	**8,578,000**	**9,749,000**	**10,122,000**
Total Geothermal Electricity Generation	**15,497,228**	**15,782,055**	**16,681,809**	**17,319,999**	**17,062,637**

[a]As measured at the plant turbine.

Note: Totals may not equal sum of components due to independent rounding.

Sources: Energy Information Administration, Form EIA-759, "Monthly Power Plant Report," and Form EIA-867, "Annual Nonutility Power Producer Report."

[11]As measured at the plant turbine.

[12]P.J. Lienau, J.W. Lund, K. Rafferty and G. Culver, *Reference Book on Geothermal Direct Use* (August 1994), p. 4.

4. Wind

Wind energy consumption is smaller than any of the other renewable energy sources measured by EIA. In 1994, wind energy consumption amounted to less than 0.04 quadrillion Btu, providing less than 3,500 gigawatthours of electricity generation (Table 9). However, consumption of wind energy has increased more rapidly than that of the other renewable fuels: by 50 percent from 1990 to 1994, or by 11 percent annually. More than 98 percent of U.S. electricity generation from wind energy in 1994 occurred in California, where Federal and State tax credits spurred the development of large wind energy farms in the early 1980s (see Chapter 11). Nearly all of the electricity from wind energy is produced by nonutilities (Table 9). Wind energy is also consumed directly, most notably, for pumping water. EIA does not measure such dispersed usage, however, and no reliable primary source of consumption data is known to exist.

Table 9. Wind Energy Consumption and Electricity Generation, 1990-1994

Estimate	1990	1991	1992	1993	1994
Wind Energy Consumption (Quadrillion Btu)					
Electric Utility	*	*	*	*	*
Nonutility	0.024	0.027	0.030	0.031	0.036
Total	**0.024**	**0.027**	**0.030**	**0.031**	**0.036**
Electricity Generation (Thousand Kilowatthours)					
Electric Utility					
California	43	0	0	0	0
Other States	355	285	308	243	309
Total	**398**	**285**	**308**	**243**	**309**
Nonutility					
California	2,284,000	2,617,000	2,893,000	3,030,000	3,422,000
Other States	11,000	33,000	23,000	22,000	60,000
Total	**2,295,000**	**2,650,000**	**2,916,000**	**3,052,000**	**3,482,000**
Total Wind-Powered Electricity Generation	**2,295,398**	**2,650,285**	**2,916,308**	**3,052,243**	**3,482,309**

*Less than 0.5 trillion Btu.

Note: Totals may not equal sum of components due to independent rounding.

Sources: Energy Information Administration, Form EIA-759, “Monthly Power Plant Report,” and Form EIA-867, “Annual Nonutility Power Producer Report.”

5. Solar and Photovoltaic

Solar Energy Data

Solar energy consumption in 1994 totaled 0.069 quadrillion Btu: 0.060 quadrillion Btu in the residential/commercial sector and 0.008 quadrillion Btu in the industrial nonutility sector (Table 10). Data on electricity generation from solar energy are collected on Form EIA-759, "Monthly Power Plant Report," and Form EIA-867, "Annual Nonutility Power Producer Report." In addition, EIA collects solar energy industry data on Forms CE-63A, "Annual Solar Thermal Collector Manufacturers Survey," and CE-63B, "Annual Photovoltaic Module/Cell Manufacturers Survey."

Solar Thermal Collectors

Since 1974, approximately 226 million square feet of solar thermal collectors have been shipped for eventual installation in the United States (Table 11). Solar thermal collectors are grouped into three categories: low-temperature, medium-temperature, and high-temperature. Presuming an overall efficiency of 50 percent for all three categories and an average of 1,500 Btu per square foot of daily insolation (solar energy received at the Earth's surface), the potential thermal energy production from the 226 million square feet of solar thermal collectors shipped since 1974 can be estimated at 0.060 quadrillion Btu in 1994. Assuming an efficiency of 50 percent for solar thermal collectors and exposure to 1,500 Btu insolation per square foot per day is a simplified approach to this energy calculation. A mildly cloudy day produces about 1,500 Btu of insolation onto an area 1 foot square, but the amount of energy received varies with changing weather conditions. Moreover, the efficiencies of low-temperature and high-temperature collectors have been rated at more than 50 percent, and medium-temperature collectors are generally less than 50 percent efficient.

In 1994, 41 active solar collector manufacturing companies shipped 7,627 thousand square feet of collectors. Imports of solar thermal collectors totaled 1,815 thousand square feet in 1994, and exports totaled 405 thousand square feet (Table 12). Total shipments increased by 9 percent from 1993 to 1994. Of the 1994 shipments, 89 percent were low-temperature and 11 percent medium-temperature collectors; only 2,000 square feet of high-temperature specialty collectors were shipped (Table 13 and Figure 3). The total value of solar thermal collector shipments increased by 3 percent, from $27.6 million in 1993 to $28.4 million in 1994 (Table 14). The average price per square foot for all shipments in 1994 was 6 percent lower than in 1993, and the 1994 average for liquid and air low-temperature collectors was 9 percent lower. The average price for low-temperature collectors decreased from $2.79 per square foot in 1993 to $2.53 per square foot in 1994. In contrast, the average for medium-temperature collector average price increased from $11.73 to $13.53 per square foot (Table 14 and Figure 4). High-temperature collectors are designed for limited, specialized applications. As a result, their prices are much higher and subject to wide fluctuations.

Photovoltaic Cells and Modules

Since 1982, approximately 78 peak megawatts of photovoltaic cells and modules have been shipped for

Table 10. Solar Energy Consumption by Sector, 1990-1994
(Quadrillion Btu)

Sector	1990	1991	1992	1993	1994
Residential/Commercial	0.060	0.060	0.060	0.060	0.060
Industrial	0.007	0.008	0.008	0.009	0.008
Total	**0.067**	**0.068**	**0.068**	**0.069**	**0.069**

Note: Totals may not equal sum of components due to independent rounding.

Sources: **Residential/Commercial:** Energy Information Administration, Form CE-93A, "Annual Solar Thermal Collector Manufacturers Survey." **Industrial:** Energy Information Administration, Form EIA-759, "Monthly Power Plant Report," and Form EIA-867, "Annual Nonutility Power Producer Report."

Table 11. Annual Photovoltaic and Solar Thermal Shipments, 1974-1994

Year	Domestic Shipments[a]	
	Photovoltaic Cells and Modules (Peak Kilowatts)	Solar Thermal Collectors (Thousand Square Feet)
1974	--	1,274
1975	--	3,743
1976	--	5,801
1977	--	10,312
1978	--	10,020
1979	--	13,396
1980	--	18,283
1981	--	19,362
1982	6,897	18,166
1983	10,717	16,669
1984	7,759	16,843
1985	4,099	[b]19,166
1986	3,224	9,136
1987	3,029	7,087
1988	4,318	8,016
1989	5,462	11,021
1990	6,293	11,164
1991	6,035	6,242
1992	5,760	6,770
1993	6,137	6,557
1994	8,363	7,222
Total	**78,093**	**226,250**

[a]Total shipments minus export shipments.
[b]Estimated data.
-- = Not available.
Sources: **1974-1977:** Federal Energy Administration telephone survey. **1978-1984:** Energy Information Administration, Form EIA-63, "Annual Solar Thermal Collector and Photovoltaic Module Manufacturers Survey." **1985-1994**: Energy Information Administration, Form CE-63A, "Annual Solar Thermal Collector Manufacturers Survey," and Form CE-63B, "Annual Photovoltaic Module/Cell Manufacturers Survey."

Table 12. Annual Shipments of Solar Thermal Collectors, 1986-1994

Year	Number of Companies	Collector Shipments (Thousand Square Feet)[a]		
		Total	Imports	Exports
1986	98	9,360	473	224
1987	59	7,269	691	182
1988	51	8,174	814	158
1989	44	11,482	1,233	461
1990	51	11,409	1,562	245
1991	48	6,574	1,543	332
1992	45	7,086	1,650	316
1993	41	6,968	2,039	411
1994	41	7,627	1,815	405

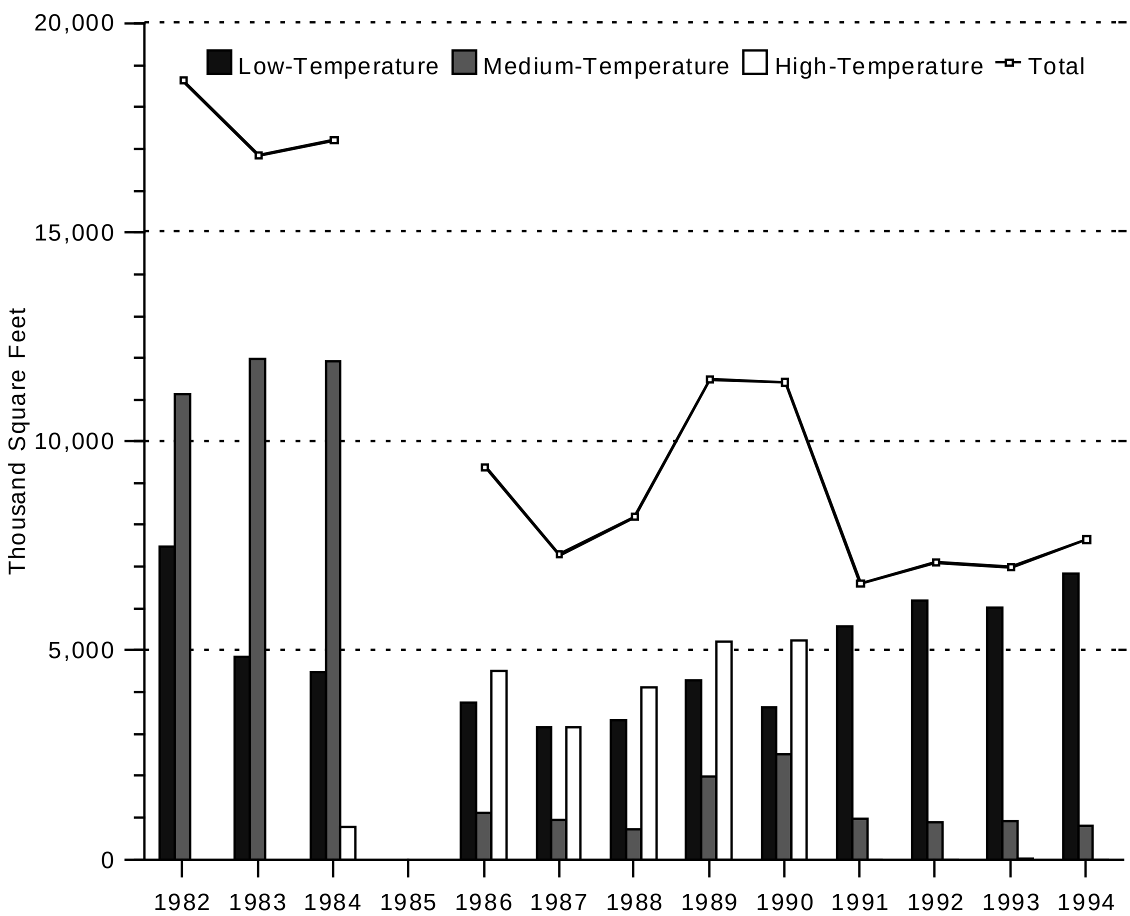
[a]Includes imputation of shipment data to account for nonrespondents.
Note: Total shipments as reported by respondents include all domestic and export shipments and may include imported collectors that subsequently were shipped to domestic or foreign customers.
Source: Energy Information Administration, Form CE-63A, "Annual Solar Thermal Collector Manufacturers Survey."

Table 13. Annual Shipments of Solar Thermal Collectors by Type, 1986-1994
(Thousand Square Feet)

Year	Low-Temperature		Medium-Temperature		High-Temperature Total Shipments[a,b]
	Total Shipments[a]	Average per Manufacturer	Total Shipments[a]	Average per Manufacturer	
1986	3,751	171	1,111	13	4,498
1987	3,157	263	957	19	3,155
1988	3,326	416	732	16	4,116
1989	4,283	428	1,989	55	5,209
1990	3,645	304	2,527	62	5,237
1991	5,585	349	989	24	1
1992	6,187	387	897	26	2
1993	6,025	464	931	28	12
1994	6,823	426	803	26	2

[a]Includes imputation of shipment data to account for nonrespondents.
[b]For high-temperature collectors, average annual shipments per manufacturer are not disclosed.
Source: Energy Information Administration, Form CE-63A, "Annual Solar Thermal Collector Manufacturers Survey."

Figure 3. Solar Thermal Collector Shipments by Collector Type, 1982-1994



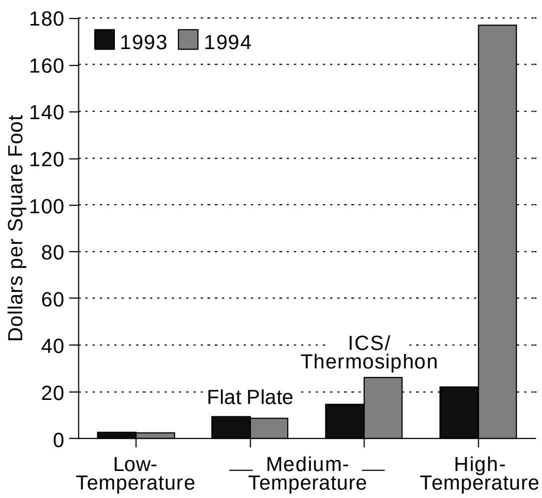
Note: Data for 1985 are incomplete and are not shown.
Sources: **1981-1984:** Energy Information Administration, Form EIA-63, "Annual Solar Thermal Collector and Photovoltaic Module Manufacturers Survey." **1986-1994:** Energy Information Administration, Form CE-63A, "Annual Solar Thermal Collector Manufacturers Survey."

Table 14. Solar Thermal Collector Shipments by Type, Quantity, Value, and Average Price, 1993 and 1994

Type	1993			1994		
	Quantity (Thousand Square Feet)	Value (Thousand Dollars)	Average Price (Dollars per Square Foot)	Quantity (Thousand Square Feet)	Value (Thousand Dollars)	Average Price (Dollars per Square Foot)
Low-Temperature						
Liquid and Air	6,025	16,819	2.79	6,823	17,241	2.53
Medium-Temperature						
Air	1	7	10.19	3	34	13.63
Liquid						
ICS/Thermosiphon	304	4,446	14.62	215	5,615	26.10
Flat Plate	623	5,887	9.44	583	5,123	8.79
Evacuated Tube	2	174	82.19	2	112	52.91
Concentrator	1	9	14.40	1	1	67.38
All Medium-Temperature	931	10,523	11.73	803	10,985	13.53
High-Temperature						
Parabolic Dish and Trough	12	260	22.11	2	28	176.99
Total	**6,968**	**27,602**	**3.96**	**7,627**	**28,411**	**3.73**

Notes: ICS = integral collector storage. Totals may not equal sum of components due to independent rounding.
Source: Energy Information Administration, Form CE-63A, “Annual Solar Thermal Collector Manufacturers Survey.”

Figure 4. Average Price of Solar Thermal Collector Shipments, 1993 and 1994



Note: See Table 13 for data values.
Source: Energy Information Administration, Form CE-63A, “Annual Solar Thermal Collector Manufacturers Survey.”

eventual installation in the United States (Table 11). Assuming a 27.5-percent capacity factor,[13] the potential energy production in 1994 from the 78 peak megawatts was 188,000 megawatthours of electricity, which is equivalent to 0.002 quadrillion Btu of thermal energy, using a thermal conversion rate of 10,302 Btu per kilowatthour of electricity generation.[14]

Photovoltaic cell and module shipments totaled 26,077 peak kilowatts in 1994, an increase of nearly 25 percent from 1993 (Table 15 and Figure 5). Exports of 17,714 peak kilowatts—an increase of nearly 20 percent from 1993—represented 68 percent of total shipments in 1994. Shipments of photovoltaic cells and modules were reported by 22 companies, or 3 more than in 1993. Imports in 1994 totaled 1,960 peak kilowatts (Table 15).

Photovoltaic shipments are divided into three categories by product type: (1) crystalline silicon cells and modules (including single-crystal, cast silicon, and ribbon silicon); (2) thin-film silicon cells and modules (made from a number of layers of photosensitive materials, such as amorphous silicon); and (3) concentrator silicon cells and modules (in which a lens is used to gather and converge sunlight onto the cell or module surface). Crystalline silicon cells and modules continued to dominate the photovoltaic industry in 1994, accounting for 95 percent of total shipments (Table 16). In particular, single-crystal silicon shipments totaled 16,520 peak kilowatts, an increase of 22 percent from 1993. Together, cast and ribbon silicon shipments totaled 8,264 peak kilowatts in 1994, 25 percent higher than in 1993 (Figure 6). Shipments of thin-film cells and modules

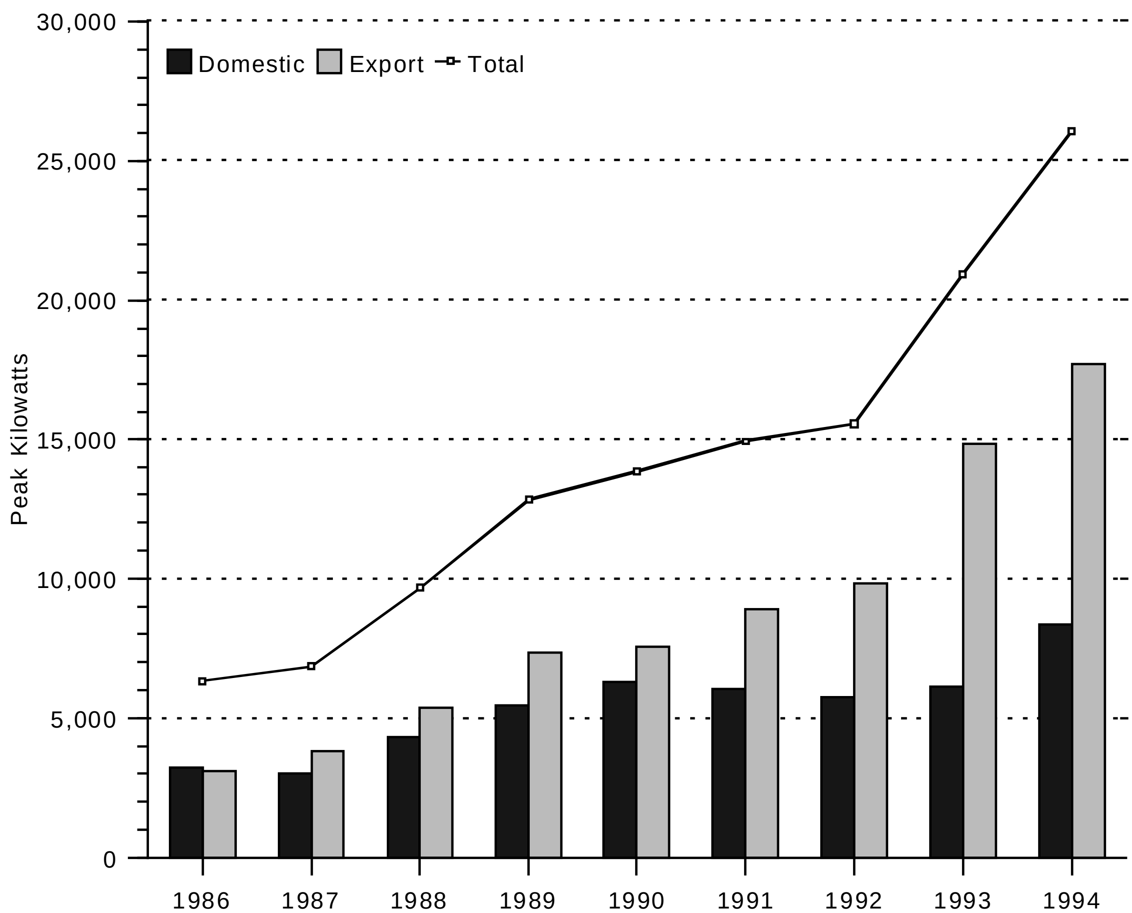
[13]U.S. Department of Energy, “The Potential of Renewable Energy: An Interlaboratory White Paper” (Washington, DC, March 1990), p. G-5.
[14]Energy Information Administration, *Annual Energy Review 1994*, DOE/EIA-0384(94) (Washington, DC, June 1994), Table A7.

Table 15. Annual Shipments of Photovoltaic Cells and Modules, 1985-1994

Year	Number of Companies	Photovoltaic Cell and Module Shipments (peak kilowatts)[a]		
		Total	Imports	Exports
1985	15	5,769	285	1,670
1986	17	6,333	678	3,109
1987	17	6,850	921	3,821
1988	14	9,676	1,453	5,358
1989	17	12,825	826	7,363
1990	[b]19	[b]13,837	1,398	7,544
1991	23	14,939	2,059	8,905
1992	21	15,583	1,602	9,823
1993	19	20,951	1,767	14,814
1994	22	26,077	1,960	17,714

[a]Does not include shipments of cells and modules for space/satellite applications.
[b]Includes imputed data for one nonrespondent, which exited the industry during 1990.
Note: Total shipments as reported by respondents include all domestic and export shipments and may include imported collectors that subsequently were shipped to domestic or foreign customers.
Source: Energy Information Administration, Form CE-63B, “Annual Photovoltaic Module/Cell Manufacturers Survey.”

Figure 5. Photovoltaic Cell and Module Shipments, 1986-1994



Note: Domestic shipments equal total shipments minus exports.
Source: Energy Information Administration, Form CE-63B, “Annual Photovoltaic Module/Cell Manufacturers Survey.”

Table 16. Photovoltaic Cell and Module Shipments by Type, 1992-1994

Type	Shipments (peak kilowatts)			Percent of Total		
	1992	1993	1994	1992	1993	1994
Crystalline Silicon						
Single-Crystal	9,078	13,560	16,520	58	65	63
Cast and Ribbon	5,379	6,587	8,264	35	31	32
Subtotal	14,457	20,146	24,785	93	96	95
Thin-Film Silicon	1,075	782	1,061	7	4	4
Concentrator Silicon	40	21	231	*	0	1
Other[a]	11	2	0	*	0	0
Total	**15,583**	**20,951**	**26,077**	**100**	**100**	**100**

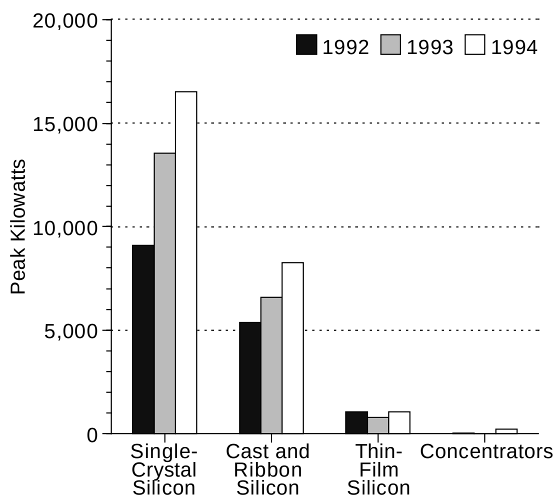
[a]Includes categories not identified by reporting companies.

*Less than 0.5 percent,

Notes: Data do not include shipments of cells and modules for space/satellite applications. Totals may not equal sum of components due to independent rounding.

Source: Energy Information Administration, Form CE-63A, "Annual Photovoltaic Module/Cell Manufacturers Survey."

Figure 6. Photovoltaic Cell and Module Shipments by Type, 1992-1994



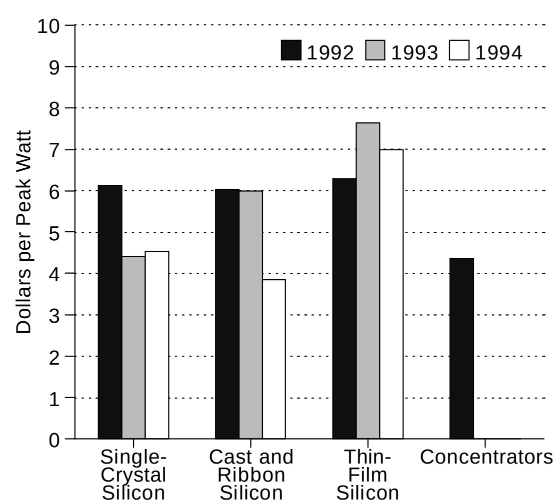
Note: See Table 15 for data values.

Source: Energy Information Administration, CE-63B, "Annual Photovoltaic Module/Cell Manufacturers Survey."

increased by 36 percent from 1993 to 1994, but represented only 4 percent of total shipments in both years (Table 16).

The total value of photovoltaic cell and module shipments decreased 4 percent to $106 million in 1994, despite almost a 25 percent increase in total shipments (Table 17). This was due to price decreases resulting from technological improvements and lower manufacturing costs. The total value of crystalline silicon (single-crystal, cast, and ribbon) shipments was $95.6 million in 1994, 7 percent less than in 1993. The value of thin-film silicon shipments in 1994 was $7.4 million, 23 percent higher than in 1993. The average price of crystalline silicon modules in 1994 was $4.22 per peak watt, a decrease of 17 percent from 1993. The average price of thin-film modules in 1994 was $7.00 per peak watt, 8 percent lower than the 1993 price (Figure 7). The total average price (dollars per peak watt) for all categories of photovoltaic modules in 1994 was $4.46, a 15-percent decrease from 1993, whereas the average price of photovoltaic cells was 44 percent lower in 1994 than in 1993.

Figure 7. Average Price of Photovoltaic Cell and Module Shipments by Type, 1992-1994



Note: Data for concentrator shipments in 1993 and 1994 have been withheld to prevent disclosure of individual company data.

Source: Energy Information Administration, Form CE-63B, "Annual Photovoltaic Module/Cell Manufacturers Survey."

Solar Electric Capacity and Generation

U.S. nonutility power producers reported installed capacity of 358 megawatts in 1994, with gross electricity generation of 824 million kilowatthours (equivalent to 0.8 trillion Btu of thermal energy) from solar thermal collectors.[15] Nine operating Solar Electric Generating System (SEGS) plants in southern California—SEGS I through IX—accounted for 98 percent (354 megawatts) of the total nonutility solar generating capacity. A tenth SEGS plant, planned in 1991, was never constructed.

U.S. electric utilities reported 3,472 thousand kilowatthours of net electricity generation from photovoltaic modules in 1994 (Table 18).[16] Of this total, 91 percent was generated in California (63 percent from a single plant).

Table 17. Value and Average Price of Photovoltaic Cell and Module Shipments by Type, 1993 and 1994

Type	1993			1994		
	Value (thousand dollars)	Average Price (dollars per peak watt)		Value (thousand dollars)	Average Price (dollars per peak watt)	
		Modules	Cells		Modules	Cells
Crystalline Silicon						
Single-Crystal	63,277	4.41	5.02	64,718	4.53	3.00
Cast and Ribbon	39,216	6.00	5.15	30,925	3.84	1.47
Subtotal	102,493	5.11	5.03	95,643	4.22	2.92
Thin-Film Silicon	6,001	7.64	10.13	7,411	7.00	6.60
Concentrator Silicon	W	W	2.38	W	W	W
Other[a]	1,215	W	489.99	W	W	W
Total	**109,797**	**5.24**	**5.23**	**105,858**	**4.46**	**2.94**

[a]Includes categories not identified by reporting companies.

W = Withheld to avoid disclosure of individual company data.

Notes: Data do not include shipments of cells and modules for space/satellite applications. Totals may not equal sum of components due to independent rounding.

Source: Energy Information Administration, Form CE-63B, "Annual Photovoltaic Module/Cell Manufacturers Survey."

Table 18. U.S. Utility Capacity and Net Electricity Generation From Photovoltaic Modules, 1994

Utility	Plant	Nameplate Capacity (megawatts)	1994 Net Generation (megawatthours)
Sacramento Municipal Utility District (California)	Solar	2.00	2,195
Austin Electric (Texas)	Decker Creek	0.30	293
Pacific Gas & Electric (California)	PVUSA 1	1.00	973
	PVUSA 2	0.50	0
	PVUSA 3	0.50	0
Virginia Electric Power (Virginia)	North Anna	0.06	11
Total		**4.36**	**3,472**

Source: Energy Information Administration, Form EIA-759, "Monthly Power Plant Report."

[15]Energy Information Administration, Form EIA-867, "Annual Nonutility Power Producers Report."

[16]Net generation is gross generation minus plant use.

Section II

Renewable Energy Status and Analysis

6. Biomass: Wood

Background

Wood is a substantial renewable resource that can be used as a fuel to generate electric power and other forms of energy products. Wood for use as fuel comes from a wide variety of sources. The Nation's forestland (or timberland) is the primary, and in most cases original, resource base for fuelwood. Wood for fuel use is also derived from private land clearing and silviculture and from urban tree and landscape residues. A third major wood resource is waste wood, which includes manufacturing and wood processing wastes, as well as construction and demolition debris.

Worldwide, one-half of the annual timber harvest is used for fuelwood, representing economic value of at least $75 billion on a replacement fuel cost basis. Half the world's population uses wood for heating and cooking. In developing countries, fuelwood accounts for 90 percent of the timber harvested.[17] In the United States, however, fuelwood and timber residues used for fuel amount to only about 25 percent of the timber harvest.

Other than hydroelectric power, wood and other biomass resources provide the largest source of renewable electricity and thermal energy produced today in the United States. U.S. biomass power plants account for about 6,500 megawatts of installed electric generating capacity and provide a significant amount of energy in the form of heat and steam from cogeneration. The amount of electric power produced from wood in 1992 was about 42,000 gigawatthours, using approximately 50 million tons of biomass fuel. The contribution to the U.S. energy supply was equivalent to nearly 200,000 barrels of oil per day.[18]

Wood Resources

Timberland Harvests

Before its colonization, the land now occupied by the United States included more than 1 billion acres of forests. By 1907, U.S. forests had been reduced to 759 million acres. In the 1920s and 1930s, forested land area began to stabilize, and it has remained relatively constant since then, totaling 737 million acres in 1992. In the case of fuelwood, no statistical linkage can be made between available resources (supply) and actual consumption. Very little information is available on fuelwood supply. Nevertheless, this chapter provides a qualitative profile and rough measure of fuelwood resources, with the caveat that the resulting data are only approximate. Consumption data (see Chapter 3) are more reliable, and some survey-supported numbers are available.

Analysis readily reveals the underlying difficulty of quantifying fuelwood supplies. The forest products industry is made up of thousands of suppliers and thousands of consumers—sometimes even within a given State. While some operators are large, many are very small, scattered, and autonomous. Most of the statistical resource data used here are either provided by or derived from forest resource assessment data published by the U.S. Forest Service. The most recent assessment by the Forest Service was for statistical year 1991.[19]

U.S. forest acreage currently represents 7 percent of the world's forests.[20] U.S. timberland contains the equivalent of about 858 billion cubic feet of roundwood,[21] which is timber stock that typically consists of 92

[17]D.J. Brooks, *U.S. Forests in a Global Context*, U.S. Forest Service, General Technical Report No. RM-228 (Washington, DC, July 1993), p. 9.

[18]See Appendix D for detailed information on the procedures used by EIA to estimate biomass consumption levels.

[19]See Appendix E for additional information on wood resources.

[20]U.S. Department of Agriculture, Forest Service, *RPA Assessment of the Forest and Rangeland Situation in the United States: 1993 Update*, Forest Resource Report No. 27 (Washington, DC, June 1994). Unless otherwise noted this publication is the source of the data in this section. The forest and wood-related terminology used in this report conforms to Forest Service definitions.

[21]Roundwood consists of logs, bolts, and other commercially viable sections of growing stock or salvable dead trees, generally more than five inches in diameter at breast height.

percent live, sound trees (called "growing stock") and 8 percent rotten, cull, or "salvable" dead trees (Table 19). While a percentage of rotten, cull, or salvable dead timber may be suitable for lumber or veneer logs (which are used mainly in plywood manufacturing), most is used for pulp, fuel, and products that require only low-quality wood.

According to the last comprehensive Forest Service estimate, for statistical year 1991, roundwood harvested from U.S. timberland totaled 17.9 billion cubic feet. This set of Forest Service statistics specifically reports only fuelwood of roundwood class that was commercially harvested for use by primary wood-using mills[22] or for fuel. About 18 percent of this quantity—about 62 million tons or 3.2 billion cubic feet—was used as fuelwood (Table 20), with an equivalent energy value of 871 trillion Btu (Table 21). Almost three times more nongrowing roundwood stock than growing roundwood stock was used for fuel, because, under prevailing market conditions, higher quality logs are used for value-added products. Some 28 percent of the roundwood harvest, or about 5 billion cubic feet, was used as pulpwood. Pulpwood is an important resource category of industrial wood energy, because about 30 percent of the volume of pulpwood consumed in the kraft pulp and paper manufacturing process is recoverable for energy in the form of black liquor. A rough approximation of the energy recovered from roundwood pulpwood in 1991 is about 370 trillion Btu. Roundwood is only one source of pulpwood and this estimate does not include energy recovered from both forest and nonforest residues that are used for pulpwood.

Other important wood resource categories reported by the Forest Service are the salvable wood from (1) living and dead stock cut or knocked down and left at the harvest site, (2) cull trees, (3) growing stock tops consisting of wood less than 4 inches in diameter, (4) growing stock trees less than 5 inches in diameter, and (5) growing stock removed from forestland by cultural operations or timberland clearing.[23] The Forest Service reports these categories as *logging residues* and *other removals*. Table 22 indicates that total wood supply available from these sources in 1991 was about 5 billion cubic feet. While there are few hard statistics that shed any light on the disposition of these resources, anecdotal evidence indicates that most of them are used for industrial boiler fuel, pulpwood, residential fuelwood,

Table 19. Net Volume of Timber by Region, Species Group, and Timber Class in the United States, 1992
(Million Cubic Feet)

Region	All Timber			Growing Stock			Live Cull			Sound Dead		
	Total	Softwood	Hardwood	Total	Softwood	Hardwood	Total	Softwood	Hardwood	Total	Softwood	Hardwood
Northeast	132,717	36,690	96,027	121,800	33,580	88,220	9,122	2,305	6,817	1,796	805	990
North Central	100,343	18,617	81,726	85,319	17,397	67,923	13,690	969	12,721	1,334	251	1,083
Southeast	130,760	52,636	78,124	120,872	51,931	68,941	9,518	481	9,036	371	224	147
South Central	144,143	52,610	91,533	129,722	50,996	78,726	13,578	1,211	12,367	844	403	440
Great Plains	4,313	2,048	2,265	3,656	1,935	1,722	570	39	531	87	74	13
Intermountain	120,010	110,399	9,611	106,582	99,552	7,030	5,667	4,402	1,265	7,761	6,445	1,316
Pacific NW and Alaska	165,721	149,114	16,607	160,024	144,371	15,653	2,138	1,201	937	3,560	3,542	18
Pacific SW and Hawaii	59,556	51,101	8,455	57,643	50,134	7,509	1,396	507	888	518	459	59
U.S. Total	**857,565**	**473,215**	**384,349**	**785,617**	**449,895**	**335,722**	**55,678**	**11,116**	**44,562**	**16,270**	**12,205**	**4,066**

Source: U.S. Department of Agriculture, Forest Service, *Forest Resources of the United States, 1992*, General Technical Report RM-234 (Revised) (Fort Collins, CO, June 1994), Table 11, pp. 46-47.

[22]Sawmills, veneer mills, and pulp and paper mills are examples of primary mills.
[23]D.S. Powell et al., *Forest Resources of the United States, 1992,* U.S. Forest Service, Technical Report RM-234 (Washington, DC, September 1993), pp. 114-116.

Table 20. Volume of Roundwood Products Harvested in the United States for Pulpwood and Fuelwood, by Region, Species Group and Timber Class, 1991
(Thousand Cubic Feet)

Region	Total of All Sources			Growing Stock			Other Sources		
	Total	Softwood	Hardwood	Total	Softwood	Hardwood	Total	Softwood	Hardwood
Northeast									
Pulpwood	521,903	246,167	275,736	410,925	191,952	218,973	110,978	54,215	56,763
Fuelwood	939,654	84,473	855,181	121,417	11,245	110,172	818,237	73,228	745,009
North Central									
Pulpwood	631,787	142,859	488,928	547,984	126,640	421,344	83,803	16,219	67,584
Fuelwood	745,157	33,993	711,164	105,253	6,559	98,694	639,904	27,434	612,470
Southeast									
Pulpwood	1,586,159	1,162,982	423,177	1,386,013	1,041,529	344,484	200,146	121,453	78,693
Fuelwood	444,066	53,436	390,630	259,853	28,900	230,953	184,213	24,536	159,677
South Central									
Pulpwood	1,810,075	1,076,094	733,981	1,651,639	1,009,962	641,677	158,436	66,132	92,304
Fuelwood	408,223	16,152	392,071	108,770	5,227	103,543	299,453	10,925	288,528
Great Plains									
Pulpwood	303	303	0	303	303	0	0	0	0
Fuelwood	58,560	2,635	55,925	3,718	361	3,357	54,842	2,274	52,568
Intermountain									
Pulpwood	29,668	29,518	150	28,160	28,010	150	1,508	1,508	0
Fuelwood	95,764	79,494	16,270	6,832	5,219	1,613	88,932	74,275	14,657
Pacific Northwest and Alaska									
Pulpwood	455,847	402,269	53,578	81,696	73,499	8,197	374,151	328,770	45,381
Fuelwood	256,494	174,077	82,417	152,725	95,507	57,218	103,769	78,570	25,199
Pacific Southwest and Hawaii									
Pulpwood	13,535	7,174	6,361	3,214	1,704	1,510	10,321	5,470	4,851
Fuelwood	238,750	161,575	77,175	89,362	76,667	12,695	149,388	84,908	64,480
U.S. Total Pulpwood	**5,049,277**	**3,067,366**	**1,981,911**	**4,109,934**	**2,473,599**	**1,636,335**	**939,343**	**593,767**	**345,576**
U.S. Total Fuelwood	**3,186,668**	**605,835**	**2,580,833**	**847,930**	**229,685**	**618,245**	**2,338,738**	**376,150**	**1,962,588**
U.S. Total Roundwood	**17,889,347**	**11,180,887**	**6,708,460**	**14,041,025**	**9,848,125**	**4,192,900**	**3,848,322**	**1,332,762**	**2,515,560**

Note: Pulpwood data is included in this table for separate analysis under another title.
Source: U.S. Department of Agriculture, Forest Service, *Forest Resources of the United States, 1992*, General Technical Report RM-234 (Revised) (Fort Collins, CO, June 1994), Table 36, pp. 110-111.

compost, mulch, and animal bedding. If wood chips used for pulpwood and the resulting black liquor byproduct are also considered, an energy value of at least 600 trillion Btu is represented by logging residues and other removals. Stumpage prices vary regionally and may fluctuate by as much as 40 percent over the short term, even though demand remains flat over the long term.[24] Fuelwood normally has a lower value than saw timber, veneer wood, or pulpwood, and its price varies according to available wood supply and demand for such higher valued commodities.

[24]R.G. Haight, *Technology Change and the Economics of Silvicultural Investment*, U.S. Forest Service, General Technical Report RM-232 (Washington, DC, August 1993), p. 3.

Table 21. Approximate Weight and Energy Yield of Roundwood Fuelwood for Roundwood Harvested in the United States for Fuelwood, by Region, Species Group, and Timber Class, 1991
(Million Tons)

Region	Total of All Sources			Growing Stock			Other Sources[a]		
	Total	Softwoods	Hardwoods	Total	Softwoods	Hardwoods	Total	Softwoods	Hardwoods
Northeast	18.58	1.48	17.10	2.40	0.20	2.20	16.18	1.21	14.90
North Central	14.82	0.60	14.22	2.09	0.11	1.97	12.73	0.40	12.25
Southeast	8.75	0.94	7.81	5.13	0.51	4.62	3.62	0.43	3.19
South Central	8.12	0.28	7.84	2.16	0.09	2.07	5.96	0.19	5.77
Great Plains	1.16	0.46	1.12	0.07	0.01	0.06	1.09	0.04	1.05
Intermountain	1.72	1.39	0.33	0.12	0.09	0.03	1.59	1.30	0.29
Pacific Northwest and Alaska	4.70	3.05	1.65	2.82	1.67	1.14	1.91	1.38	0.54
Pacific Southwest and Hawaii	4.37	2.83	1.54	1.60	1.34	0.25	2.78	1.49	1.29
U.S. Total Fuelwood	**62.22**	**10.60**	**51.62**	**16.38**	**4.02**	**12.37**	**45.87**	**6.85**	**39.29**
Approximate Total Energy Yield[b] (trillion Btu)	**870.80**	**148.40**	**722.60**	**229.40**	**56.30**	**173.10**	**642.20**	**95.90**	**550.10**

[a]Weight is derived from Forest Service volume data, reported according to *wet basis* air dry moisture content of 12 percent to 13 percent, multiplying by Forest Service conversion standards of 35 pounds per cubic foot for softwoods and 40 pounds per cubic foot for hardwoods.
[b]Based on an EIA-estimated energy yield of approximately 14 million Btu per ton.
Note: Totals may not equal sum of components due to independent rounding.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.

Nonforest Residues

Private Clearing and Silviculture

Wood is salvaged for fuel by private owners from woodlots, farm fence rows, cropland clearing, orchards, and various operations of private urban silviculture. Comprehensive information on the disposition of wood from these sources is not available, while anecdotal evidence indicates that this wood represents an important component of residential fuelwood supply and is also commonly chipped for boiler fuel or pulpwood.[25] A Forest Service study of residential fuelwood use in Michigan revealed that rural woodlands in heavily forested areas supplied more than 94 percent of the residential firewood for those areas. In addition, 84 percent of the firewood supply of a more heavily populated region of the State was cut locally within that region. While general conclusions cannot be drawn from evidence of this type, it does appear that cutting from private land and various types of urban clearing are probably more important sources of residential firewood than cutting by commercial harvesters on forestland. The Michigan study indicated that production of firewood by households was 20 times greater than production by commercial harvesters.[26]

Urban Tree and Landscape Residues

Urban tree and landscape residues consist of tree limbs, tops, brush, leaves, stumps, and grass clippings. They are generated by commercial tree care firms, municipal tree trimming operations, electric utility power line maintenance departments, municipal park and recreation departments, orchards, and landscapers. These residues, unrecovered, make up about 18 percent of the municipal solid waste stream and represent a serious disposal problem for landfills.[27] Alternative uses include processing for mulch, compost, wood products such as animal litter and bedding, and fuel. It has been

[25]U.S. Forest Service, *RPA Assessment of the Forest and Rangeland Situation in the United States: 1993 Update*, Forest Resource Report No. 27 (Washington, DC, June 1994), p. 34.
[26]B. Smith and A. Weatherspoon, *Production and Sources of Residential Fuelwood in Michigan*, U.S. Forest Service, Resource Bulletin NC-122 (Washington, DC, October 1990), pp. 3-4.
[27]However, wood improves the energy content of the municipal solid waste stream. See Chapter 8 for a detailed discussion of this issue.

Table 22. Wood Supply from Logging Residues and Other Removals from Noncommercial Growing Stock and Other Sources, 1991
(Thousand Cubic Feet)

Region	Total	Logging Residues		Other Removals	
		Growing Stock[a]	Other Sources[b]	Growing Stock[c]	Other Sources[d]
Northeast					
Softwood	236,305	23,757	176,180	19,886	16,482
Hardwood	392,139	73,584	200,176	61,442	56,937
North Central					
Softwood	55,043	8,360	9,836	24,990	11,857
Hardwood	486,647	106,819	77,722	165,954	136,152
Southeast					
Softwood	469,279	148,057	62,528	227,202	31,492
Hardwood	773,809	171,107	199,422	237,915	165,365
South Central					
Softwood	492,101	169,198	241,437	60,977	20,489
Hardwood	997,142	205,628	535,703	117,500	138,311
Great Plains				138	
Softwood	2,655	2,443	12	3,554	62
Hardwood	7,784	1,305	757		2,168
Intermountain					
Softwood	71,501	71,501	0	0	0
Hardwood	943	943	0	0	0
Pacific Northwest & Alaska	786,024	284,247			
Softwood	18,598	5,344	488,555	0	11,673
Hardwood			10,483	0	2,122
Pacific Southwest & Hawaii					
Softwood	164,887	65,035	98,682	1,549	1,059
Hardwood	18,185	7,422	10,763	649	0
U.S. Total	**4,973,042**	**1,344,750**	**2,112,256**	**921,867**	**594,169**

[a]Growing stock volume cut or knocked down during harvesting operations and left at harvest site.
[b]Wood volume other than growing stock cut or knocked down during harvesting operations but left on the ground. This volume is net of wet rot and advanced dry rot, and excludes old punky logs; essentially, it consists of material sound enough to chip. It includes dead and cull tees, tops above the 4-inch growing-stock top, and trees smaller than 5 inches in diameter at breast height and excludes stumps and limbs.
[c]Growing stock removed by cultural operations or timberland clearing not counted under harvesting of commercial growing stock.
[d]Wood volume other than growing stock removed by cultural operations and timber clearing; provisions of footnote (b) apply.
Source: U.S. Department of Agriculture, Forest Service, *Forest Resources of the United States, 1992*, General Technical Report RM-234 (Revised) (Fort Collins, CO, June 1994), Table 38, pp. 114-115.

estimated that about 200 million cubic yards a year are produced by all the sources generating this category. Firewood and boiler fuel (as products) and wood burned for energy by the producer of the residue are recovered from this resource. Total recovered energy from urban tree and landscape residues amounts to about 45 trillion Btu, or the equivalent of about 7 million barrels of oil per year.[28] Additionally, recovery of these residues for fuel and other products avoids the economic and environmental costs to society of land-filling.

Waste Wood

Waste from Primary and Secondary Wood Mills

Primary mills include sawmills, veneer mills, and pulp mills. Secondary mills include manufacturers of dimension lumber, trusses and building components, flooring, windows and doors, cabinets, pallets, poles and fencing, barrels, boats, highway transport trailers, manufactured homes, musical instruments, etc. Waste products include chips, slabs, edges, sawdust, and

[28]J. Whittier et al., *Urban Tree Residues: Results of the First National Inventory* (NEOS Corporation, 1994).

planer shavings. Because many of the mill waste residues are clean—in contrast with such wastes as construction and demolition debris or treated lumber—they are often a source of the wood chips used by pulp and paper mills.[29]

Mill waste residues are used primarily as fuel, with the next most important application being use as pulp and fiber for making paper products. The paper production process yields a byproduct known as "black liquor," which is also a source of energy. Pulp and paper mills use large quantities of wood bark, edgings, and residues from their own log-stripping operations for fuel, and also buy them from facilities such as sawmills. Total annual estimated energy production from primary mill wood residues used for fuel is 744 trillion Btu (Table 23).

A comprehensive survey by the Tennessee Valley Authority (TVA) of mill residues in the Tennessee Valley region provides a good profile of residue uses (Table 24). Sawmills are the largest generator of mill wood waste, and finding uses for excess sawdust is a problem for sawmills. Some entrepreneurs have taken advantage of this resource as a raw material in the manufacture of densified wood fuel products, such as briquettes and pellets, which are used in both residential stoves and industrial boilers.

Construction and Demolition Debris

Construction and demolition debris, which makes up 10 to 15 percent of the municipal solid waste stream, includes wood, ferrous and nonferrous metals, corrugated cardboard, plastics such as wire and cable sheathing, brick, rock, and concrete. Combustible construction and demolition debris includes materials such as dimension lumber, plywood, appliance packing cartons, cardboard, wire and cable sheathing, old railroad ties, and demolished wooden bridges. Wood typically makes up about 40 percent of total construction and demolition wastes, and its uses include serving as boiler fuel and providing raw material for wood pellets.[30] Of the 31 million tons of construction and demolition debris generated each year, 8 million tons is wood, representing an energy potential of about 150 trillion Btu. The amount of wood contained in construction and demolition debris is expected to reach 9.5 million tons by the year 2000.[31] However, environmental regulations restrict the recovery of fuelwood from such debris to processing sites that can separate clean wood from treated wood.

Wood from Pallets and Containers

Pallets represent a large percentage of the wood used in shipping. Point sources for pallet wastes are harbor

Table 23. Weight of Bark and Residue from Primary Wood-Using Mills Used for Fuel by Region, Species Type, and Material Used for Fuel, 1991
(Thousand Dry Tons)

Region	Total Residue			Bark Residue			Coarse Material			Fine Materials		
	Total	Softwood	Hardwood	Total	Softwood	Hardwood	Total	Softwood	Hardwood	Total	Softwood	Hardwood
Northeast	5,055	1,544	3,511	886	229	657	1,905	840	1,065	2,264	475	1,789
North Central	3,544	420	3,124	1,421	258	1,163	1,073	88	985	1,050	74	976
Southeast	9,722	7,027	2,695	4,650	3,339	1,311	572	280	292	4,500	3,408	1,092
South Central	13,736	8,260	5,476	8,238	5,379	2,859	758	183	575	4,740	2,698	2,042
Great Plains	108	66	42	56	44	12	35	10	25	17	12	5
Intermountain	1,888	1,886	22	885	881	4	229	218	11	774	767	7
Pacific Northwest and Alaska	7,136	6,919	217	2,966	2,889	77	1,875	1,800	75	2,295	2,230	65
Pacific Southwest and Hawaii	3,610	3,580	30	1,143	1,133	10	1,157	1,147	10	1,310	1,300	10
U.S. Total	**44,799**	**29,682**	**15,117**	**20,245**	**14,152**	**6,093**	**7,604**	**4,566**	**3,038**	**16,950**	**10,964**	**5,986**
Total Estimated Energy Content	**743.7 Trillion Btu**											

Source: United States Forest Service, *Forest Resource of the United States* (GTR-RM-234, 1992).

[29]Southeast Regional Biomass Energy Program, *A Sourcebook on Wood Waste Recovery and Recycling in the Southeast* (June 1994), p. IV-5.
[30]L. Perez, "Amazing Recyclability of Construction & Demolition Wastes," *Solid Waste Technologies,* Vol. VII, No. 1 (January/February 1994), pp. 12-18.
[31]"Growing Demand for Wood Fiber," *Wood Recycler* (June 1994), p. 6.

Table 24. Production and Disposition of Wood Residues in the Tennessee Valley by Primary and Secondary Mills in 1979

Production of Residues	Percent of Total Produced	Percent of Total Unused
Sawmills	56.6	74.3
Pulp, Paper & Paperboard	20.2	7.3
Dimension Lumber, Flooring	4.6	5.1
Furniture	5.6	3.9
Planing Mills	3.9	2.5
Miscellaneous Wood Products	3.9	2.2
Pallets & Containers	2.9	3.5
Special Product Sawmills	1.1	0.5
Prefabricated Buildings & Mobile Homes	0.6	0.5
Plywood & Veneer	0.3	0.1
Boats, Sporting Goods, & Games	0.2	0.1
Total	**100.0**	**100.0**
Disposition of Residues	**Percent of Total**	
Used for Pulp & Fiber	24.0	
Metallurgical Use	1.4	
Used for Industrial Fuel	33.5	
Used for Domestic Fuel	7.6	
Miscellaneous Use	10.6	
Unused	22.9	
Total	**100.0**	

Source: Tennessee Valley Authority, Division of Land and Forest Resources, *Production and Use of Industrial Wood and Bark Residues in the Tennessee Valley, 1979,* Technical Note B45, April 1991, pp. 3-4. While this information is somewhat dated, a literature search revealed a scarcity of similar detailed information, and it is useful for providing a profile of one regional forest product infrastructure.

and port authorities, redistribution centers, furniture movers, common carriers, computer manufacturers, major department and retail stores, and warehouses. Because of their construction, pallets and containers recovered for fuel are most likely to be hammermilled to remove metal fasteners and then chipped for boiler fuel. (The same applies to wood from construction and demolition debris.)

In 1990, according to the Forest Service, one-third to one-half of all hardwood lumber consumption was by the pallet industry. The National Wooden Pallet and Container Association (NWPCA) estimates that 540.7 million wooden pallets were manufactured in 1991, 565.6 million in 1992, and 599.0 million in 1993.[32] About 60 percent of the pallets made in the United States in 1990 were of heavy-duty construction and were intended to be used for as long as possible; about 40 percent were of lighter construction and were intended to be "one-way."[33] More recently, according to the NWPCA, environmental considerations are leading to an ongoing decrease in the production of one-way or single-use pallets, and the reuse of heavy-duty pallets and the establishment of user pools are growing. The NWPCA believes that one-way pallets probably will disappear by the year 2000.

A recent survey of the pallet manufacturing industry by the Virginia Polytechnic Institute indicated that 44 percent of the respondents conducted recycling operations, and that heavy-duty or "multi-use" pallets constituted 90 percent of their activity in 1992.[34] The survey data indicated that more than 3 million wooden pallets, equivalent to 48.5 million board feet of lumber,

[32]Telephone conversation with William Sardo of the NWPCA (August 31, 1994).
[33]U.S. Forest Service, *An Analysis of the Timber Situation in the United States 1989-2040*, General Technical Report RM-199 (Washington, DC, December 1990), p. 226.
[34]E. Hansen et al., *Recycling in the U.S. Pallet Industry: 1992* (Blacksburg, VA: Virginia Polytechnic Institute, Center for Forest Products Marketing, October 1993).

were ground or chipped by pallet manufacturers in 1992 for use as fuel.

Wood Pellets[35]

Wood pellets, manufactured from finely ground wood fiber, represent a growing biomass fuel market. Wood pellets are typically 1/4-inch to 5/16-inch in diameter by about 3/4-inch in length and weigh more than 40 pounds per cubic foot. They are generally bagged and wholesaled to feed and seed stores and residential fuel distributors to be resold for use in pellet stoves.

Sales of pellet stoves and wood pellets have increased rapidly in the past 10 years. Currently, there are 67 pellet manufacturers. Fifty-nine of these plants reported their sales, which are reflected in Table 25. The average price for pellets was $100/ton, representing wholesale revenues of about $50 million to manufacturers. About 70,000 pellet stoves were sold in 1993 and 88,000 were purchased in 1994. Total U.S. inventory of pellet stoves was estimated to be 330,000 by the end of 1994. Total heat energy produces by pellet stoves in 1994 can be roughly estimated to have been 8 trillion Btu, replacing the equivalent of over one million barrels of imported crude oil. Sales of pellet stoves continue to be very good and this industry is expected to grow in the near term. Pellet stoves benefit from extremely good combustion efficiency and emissions characteristics.

The Biomass Power Industry

The biomass power industry is a decentralized, loosely knit coalition of firms, such as independent power producers, electric utilities, engineering and construction firms that use or develop biomass products, and fuel suppliers. Unlike many large utilities, biomass power producers typically are not vertically integrated (where one firm owns supply, generation, and distribution facilities) but, rather, are horizontally integrated in some areas, such as construction and engineering firms that specialize in biomass projects or provide turbines and other specialized components. Most biomass power companies today are independent power producers or are in the forest industry.

The Energy Policy Act of 1992 offers a production tax credit of 1.5 cents per kilowatthour to biomass power producers that purchase biomass fuels from “closed-loop systems.” A closed-loop system has been interpreted to mean an energy crop farm. Today, there are no such facilities in existence to allow capture of the tax credit, although several have been proposed recently.

Table 25. Regional Distribution of Pellet Fuel Sales, 1992-1993
(Tons)

Region	1993-1994	1992-1993	Percent Change	1993-1994 U.S. Market Share (percent)
Northeast	62,000	35,000	77	12
Southeast	21,000	16,000	31	5
Great Lakes	26,000	11,000	136	5
Central	18,000	21,000	-14	4
Mountain	130,000	145,000	-10	26
Pacific	239,000	198,000	21	48
U.S. Total	496,000	426,000	16	100
Energy Yield (17 MM Btu per Ton)	8.4×10^9	7.2×10^9	17	--

Sources: Great Lakes Regional Biomass Energy Program, *Wood Pelletization Sourcebook: A Sample Business Plan for the Potential Pellet Manufacturer*, March 1995, p. 9.

[35]Great Lakes Regional Biomass Energy Program, *Wood Pelletization Sourcebook: A Sample Business Plan for the Potential Pellet Manufacturer*, March 1995.

Prospects for Wood Energy

The Federal Government began to encourage the development and use of renewable power, including biomass-generated electricity, after the energy crises of the 1970s. Accordingly, the wood energy industry grew along with many other alternative energy industries throughout the 1980s and early 1990s. Biomass power grew to approximately 6,500 megawatts of generating capacity in 1989 from less than 200 megawatts in 1979.[36] About 1,000 wood-fired power plants are currently operating in the United States; however, only a third of these offer electricity for sale.[37] The remainder are owned and operated by major industrial firms, mostly in the pulp and paper industry, which operate plants to provide in-house steam, heat, and electrical power. Most biomass installations are independent power producers and cogeneration systems with 10 to 25 megawatts capacity.[38] Several larger power plants (40 to 50 megawatts) are operating today, and future power plants promise to be larger. Significant technical and economic benefits are associated with larger plants.

In the past several years, however, a variety of factors have combined to limit the viability of biomass power. Electric utilities have gone from a condition of undercapacity to adequate capacity. Coal prices are relatively low (about $1.00 to $1.50 per million Btu) and the utility avoided cost for coal-fired electricity can be as low as 2 to 3 cents per kilowatthour, whereas the breakeven range for biomass power may be in the range of 4 to 7 cents per kilowatthour. Many utilities are not renewing expired purchase contracts with small producers. Section 29 of the Internal Revenue Service code (which provides for a 1.5-cent-per-kilowatthour tax credit for biomass-based electricity generation) is due to expire December 31, 1995, and extension is currently being debated in Congress. In addition to these factors, the problems of small power producers in the Western United States have been compounded by a limited supply of waste wood for fuel use, due to forest management constraints on logging.

On the other hand, the pulp and paper industry, which is by far the largest consumer of biomass among independent power producers, may not be as strongly affected by the above developments as are other power producers. Pulp and paper facilities are large rather than small in operating scale, and the wood and wood byproducts they burn for power and steam are largely waste materials that would otherwise represent a disposal problem. Also, much of the power generated by pulp and paper mills is consumed by the mills themselves.

Three-year-old hybrid poplars, planted for paper pulp and energy, at James River Corporation's Lower Columbia River Fiber Farm.

Biomass Technologies and Resources Today

Although today's biomass power generation systems use direct combustion Rankine cycle technology, which is the same technology used in thermal-steam systems for coal-fired plants, technology improvements over the past 20 years in the paper and forest products industry have led to improvements in energy efficiency. Through significant investments in new biomass and recovery boilers, fossil fuel use has been reduced by almost 45

[36]U.S. Department of Energy, *Electricity from Biomass: National Biomass Power Program Five-Year Plan (FY 1994-FY 1998)* (Washington, DC, April 1993), p. 15.
[37]National Wood Energy Association, *Biomass Database* (March 1994).
[38]Utility Data, Inc., *COGEN 0994 File* (September 1994).

percent and biomass use increased to now supply over 56 percent of the industry's energy needs. The industry is one of the two leading industry cogenerators, providing over half of its electricity requirements from over 9,000 megawatts of installed capacity. The paper industry was among the first to install circulating fluidized-bed boilers and combined cycle cogeneration, and is now involved in the research and development of biomass gasification.

Biomass fuels, primarily wood, fired in these systems are supplied by the forest and agricultural sector. A significant portion of the biomass power industry is comprised of cogenerators in the pulp and paper industry. These cogenerators use black liquor, bark and wood residues as fuel. Most wood fuels from the forestry and agricultural sectors have a high moisture content (up to 50 percent) and low heating value (4,000 to 5,000 Btu per pound). Urban wood wastes are generally drier (between 5 and 15 percent moisture content) and have a higher heating value (6,000 to 8,000 Btu per pound), with the exception of fresh wood trimmings, which are similar to forest residues.

Most biomass power plants operating today are characterized by low boiler efficiencies (65 to 75 percent) and low net plant efficiencies (20 to 25 percent). Beyond the fuel characteristics, the small size of most facilities contributes to the low efficiencies. Resource limitations and capacity caps promulgated under the Public Utility Regulatory Policies Act of 1978 (PURPA) limited biomass-fired plants to 50 megawatts; thus, the designs have not harnessed economies of scale, such as reheat steam loops and multistage feedwater heating. Some gasification technologies, which gasify biomass and burn the gases, have been used successfully in small-scale commercial applications, but they have not yet been integrated into large power plant designs. The Vermont Gasification Project at the McNeil Power Plant in Burlington may be the first large-scale utility demonstration of the new, higher efficiency, gasification technology.

Coal-fired power plants have also co-fired biomass with coal for many years. Recent data from controlled test burns promise significant reductions in sulfur dioxide emissions, and perhaps nitrogen oxide emissions, although the latter results are still experimental. The benefits of sulfur dioxide reductions, coupled with carbon dioxide recycling, have increased the interest in co-firing within the utility industry. Co-firing biomass with fossil fuels, however, may require boiler modifications,[39] electrostatic precipitator improvements, and changes in fuel handling systems. Nonetheless, this option may be an attractive and cost-effective emission reduction strategy, particularly because of the reduced sulfur dioxide emissions. In the future, even natural gas could be co-fired with gasified biomass, enhancing fuel substitution strategies.

One issue that continues to create technical difficulties for direct-fired systems is alkali fouling. Alkaline compounds, such as potassium and sodium, contained in the biomass melt at low temperatures (for boilers). When the molten or partially molten ash particles come in contact with the boiler walls or the heat exchanger tubes, they cool and form glass-like coatings that reduce the boiler efficiency over time. Wood fuels generally minimize this phenomenon, but other biomass fuels, such as straw and agricultural products, still present a technological challenge to the industry.

Future Biomass Power Technologies

Future biomass power technologies include co-firing,[40] fast pyrolysis systems,[41] and gasification systems[42] for use in fueling combustion turbines and fuel cells.[43] Cofiring, especially in coal-fired plants, provides a promising avenue for increased biomass use by electric utilities, because it reduces sulfur dioxide and carbon monoxide emissions. Currently, independent power producers account for the majority of biomass use for electricity generation, but their role is threatened by the possible wholesale expiration of their PURPA contracts with utilities. The potential benefits of wood co-firing may be offset for utilities by the increasing pressure they are expected to experience as a result of deregulation and increased competition from some independent power producers (primarily, combined-cycle natural-gas-fired plants).

Gasification involves the transformation of solid biomass into a gaseous state, followed by burning in advanced gas turbines, such as combined-cycle turbines,

[39]Cyclone boilers are more tolerant of fuel differences than are pulverized coal boilers.

[40]D. Tillman et al., "Cofiring Wood Waste and Coal in Cyclone Boilers: Test Results and Prospects," in *Proceedings of Second Biomass Conference of the America* (Portland, OR, August 1995), pp. 382-389.

[41]T. Bridgewater and C. Peacocke, "Biomass Fast Pyrolysis," in *Proceedings of Second Biomass Conference of the America* (Portland, OR, August 1995), pp. 1037-1046.

[42]C.T. Donovan and J.E. Fehrs, "Recent Utility Efforts To Develop Advanced Gasification Biomass Power Generation Facilities," in *Proceedings of Second Biomass Conference of the America* (Portland, OR, August 1995), pp. 702-710.

[43]D. Patel, G. Steinfeld, and B. Baker, "Direct Fuel Cell: A High-Efficiency Power Generator for Biofuels," in *Proceedings of Bioenergy '94* (Reno, NV, October 1994), pp. 495-501.

which have overall efficiencies of 40 percent or higher. Specific areas of research and development include improving hot gas cleanup to remove alkaline compounds, identifying the source of turbine blade deposits, and identifying methods to remove particulates through temperature control using mechanical systems and feedstock additives. Demonstration units have been tested, and the first commercial-scale gasifier is planned for 1996 in Burlington, Vermont. These systems have the potential to reduce biomass power costs to levels competitive with natural gas.

Fast pyrolysis produces "biocrude," a liquid similar to crude oil, by subjecting the biomass to extreme pressure and temperatures. Research agendas include determining the combustion characteristics of various types of biocrude made from different biomass resources, understanding the interactions between fast pyrolysis conditions and the resulting characteristics of the oils, validating combustion tests, removing ash, and developing acid-resistant components.

Several types of fuel cells are under development (phosphoric acid, molten carbonate, and solid oxide fuel cells), and several are in commercial use, fueled by natural gas, methanol, or ethanol feedstocks.[44,45] Fuel cells produce electricity through chemical reactions, as opposed to combustion, and can approach efficiencies of 60 percent, making them very attractive options. Gas or fuel quality is a particular concern for fuel cell manufacturers and operators, since small amounts of contaminants create significant problems. Much of the research in hot gas cleanup for gasification will be applicable to fuel cells. Also, programs to produce ethanol or methanol from biomass will significantly affect the economics of fuel cell operations. Expanded availability and lower cost of feedstocks will expand fuel cell opportunities.

Obstacles to Continued Growth

The key barriers to growth of biomass power today are high delivered fuel costs compared with fossil fuels, lack of public awareness of biomass power technologies, fuel supply reliability issues, and a lack of understanding the environmental impacts of the technologies and fuel supply systems. The complexity of biomass power infrastructure systems is also a challenge for utilities that are more familiar with well-established coal and natural gas fuel markets.

The technology can be improved significantly as well. Today's low efficiencies and smaller power plants could be replaced by larger facilities and technological advances currently being investigated by industry and by Department of Energy research and development activities.

Economic Benefits of Biomass Power

Although use of biomass for power generation probably has only a modest effect on energy imports, it diversifies domestic fuel resources, offering new industry development potential in rural areas or areas outside of conventional fuel supplies (coal, oil, and natural gas). States with significant biomass resources (such as California, Maine, Georgia, Minnesota, Oregon, Washington, and Michigan) benefit from using local resources rather than exporting dollars outside the State to coal- or oil-producing regions. The direct jobs generated in a wide variety of sectors can diversify local job opportunities. New industry sectors, such as information technology, engineering design and construction, equipment manufacturing, systems controls, electronic design, and others can be developed, based on local resources. The indirect impact on jobs and economic growth can be significant. According to a recent study of the direct and indirect economic benefits of biomass power in the United States, 6,500 megawatts of biomass power production capacity resulted in a net impact of more than $1.8 billion in personal income and corporate income in 1992.[46] Today, more than 66,000 jobs are supported by this industry. Other benefits, such as Federal, State, and local taxes are also generated.

Environmental Aspects of Wood

Biomass is important in connection with possible global warming. Through photosynthesis, biomass removes carbon from the atmosphere, thus reducing the amount of atmospheric carbon dioxide, a major contributor to the possibility of global warming. When biomass is burned to produce energy, the stored carbon is released, but the next growing cycle absorbs carbon from the atmosphere once again. This "carbon cycle" offers a unique potential for mitigating any global warming.

U.S. forest ecosystems contain nearly 58 billion tons of carbon and represent an important environmental resource for reducing atmospheric carbon dioxide.[47] In

[44]Morgantown Energy Technology Center, *Fuel Cells: Addressing America's Future Power Needs* (Morgantown, WV, not dated).

[45]Morgantown Energy Technology Center, *Fuel Cells: A Handbook*, Revision 3, DOE/METC-94/1006 (Morgantown, WV, January 1994).

[46]U.S. Department of Energy, *Electricity from Biomass: National Biomass Power Program Five-Year Plan (FY 1994-FY 1998)* (Washington, DC, April 1993), p. 2.

[47]U.S. Department of Agriculture, Forest Service, *Carbon Storage and Accumulation in United States Forest Ecosystems*, General Technical Report WO-59 (Washington, DC, August 1992), p. 3.

the United States, live trees are currently accumulating carbon from the atmosphere at an average rate of 1,252 pounds per acre per year, representing a 2.7-percent yearly increase in sequestered carbon. Society realizes an annual "bonus" of 117 million tons of carbon sequestered additionally—the estimated net annual increase stored by forest systems. This is the amount of carbon left stored after the total quantity accumulated by live and dead trees (508 million tons) minus the carbon removed by timber harvest, land clearing, and fuelwood production. However, 117 million tons of carbon is equivalent to only 9 percent of total annual U.S. atmospheric carbon emissions.[48]

Biomass combustion does produce ash, but it results in less ash than coal combustion does, reducing ash disposal costs and landfill space requirements. The biomass ash can also be used as a soil additive on farmland.

[48]U.S. Department of Agriculture, Forest Service, *Carbon Storage and Accumulation in United States Forest Ecosystems*, General Technical Report WO-59 (Washington, DC, August 1992), pp. 3-6.

Biomass Milestones

1890	Wood as a primary fuel supply	Wood was the primary fuel for residential, commercial, and transportation uses.
1930	Wood displaced by new fuels	Kerosene and fuel oil began displacing wood for some commercial, transportation, and residential uses.
1950	More new fuels displacing wood	Electricity and natural gas displaced wood heat in homes and commercial buildings.
1973	Wood use at all-time low	Higher oil and gas prices and oil embargoes hit the country at the time that wood consumption for energy was at an all-time low of roughly 50 million tons per year.
1974	Rise in woodstove sales, switching by some industries from coal to waste wood	The oil crises of 1973-74 prompted significant increases in woodstove sales for residential use. The paper and pulp industry also began to install wood and black liquor boilers for steam and power displacing fuel oil and coal.
1978	Public Utility Regulatory Policies Act (PURPA) passed	PURPA guaranteed nonutility generators a market to sell power by mandating that utilities pay "avoided cost" rates for any power supplied by a qualifying facility.
1984	Startup of Burlington Electric plant	Burlington Electric (Burlington, Vermont) built a 50-megawatt wood-fired plant with electricity production as the primary purpose. This plant was the first of several built since 1984.
1985	Standard Offer #4 contracts begin	The Californian biomass power industry began to grow, eventually adding 850 megawatts of power due to fuel cost escalation clauses in the Standard Offer #4 contracts which were based on predicted oil costs of $100 a barrel. These 10-year contracts guaranteed power purchase rates.
1989-90	First trials of direct wood-fired gas turbines conducted	Pilot direct wood-fired gas turbine plants were tried for the first time by Canadian Solifuels, Inc. (in Canada) and Aerospace Research Corporation (in the United States).
1990	Biomass generating capacity at 6,000 megawatts	Electricity generating capacity from biomass (not including municipal solid waste) reached 6 gigawatts. Of 190 biomass-fired electricity generating facilities, 184 were nonutility generators, mostly wood and paper plants.
1992	Rise in biomass prices to $55 per dry ton in California	The industry overbuilt capacity, with little regard for supply limitations, resulting in escalating feedstock prices as the last of the Standard Offer #4 contract power plants came on line. New sources of biomass eventually reduced costs to an average of $35 per dry ton.

1994	Hot gas cleanup identified as key to gasification success.	Successful operation of several biomass gasification tests identified hot gas cleanup as key to widespread adoption of the technology. Promising high efficiencies were achieved.
1995	Half of the California biomass power industry shut down	As of the end of August 1995, 15 biomass power plants (500 megawatts) had been closed through sales or buyout of their Standard Offer #4 agreements, primarily as a cost reduction strategy by the local utilities required to buy the power, which had sometimes risen to more than 10 cents per kilowatthour, depending on the contract.

7. Biomass: Municipal Solid Waste

Introduction

The municipal solid waste (MSW) industry is diverse and complex. The industry has four components: recycling, composting, landfilling, and waste-to-energy via incineration (Figure 8).[49] MSW is total waste excluding industrial waste, agricultural waste, and sewage sludge. As defined by the U.S. Environmental Protection Agency, it includes durable goods, nondurable goods, containers and packaging, food wastes, yard wastes, and miscellaneous inorganic wastes from residential, commercial, institutional, and industrial sources. Examples from these categories include appliances, newspapers, clothing, food scraps, boxes, disposable tableware, office and classroom paper, wood pallets, rubber tires, and cafeteria wastes. MSW does not include wastes from other sources, such as municipal sludge, combustion ash, and industrial nonhazardous process wastes that might also be disposed of in municipal waste landfills or incinerators. MSW also excludes all categories of hazardous wastes, including batteries and medical wastes.

Although many different products are included in MSW and the mix of products varies from city to city and by time of year (the proportion of lawn clippings, for example), some general proportions of MSW components can be estimated (Figure 9). In 1993, the quantity of MSW generated in the United States totaled 206.9 million tons. Paper or paperboard products accounted for 38 percent of the weight of materials in MSW; yard wastes 16 percent; plastics 9 percent; metals 8 percent; food wastes, glass, and wood 7 percent each; and other materials, such as rubber, leather, and textiles the remaining 9 percent.

Waste-to-Energy

The waste-to-energy (WTE) industry has been producing heat and power in the United States for a century. Early facilities were incinerators, used primarily for volume reduction. Many also produced steam heat and power. With the adoption of the Public Utility Regulatory Policies Act of 1978 (PURPA), the market for electricity production became more widespread, offering an additional stream of revenue to keep waste processing fees as low as possible. The disposal of solid waste has been the primary driver of MSW combustion, with electricity generation being an ancillary product. The goal of most MSW combustion is to reduce the volume of waste that must be landfilled. Energy production, including steam and electricity sales, provides added revenues to improve a project's financial picture. Currently, 116 WTE facilities in the United States market energy.

Resource Assessment

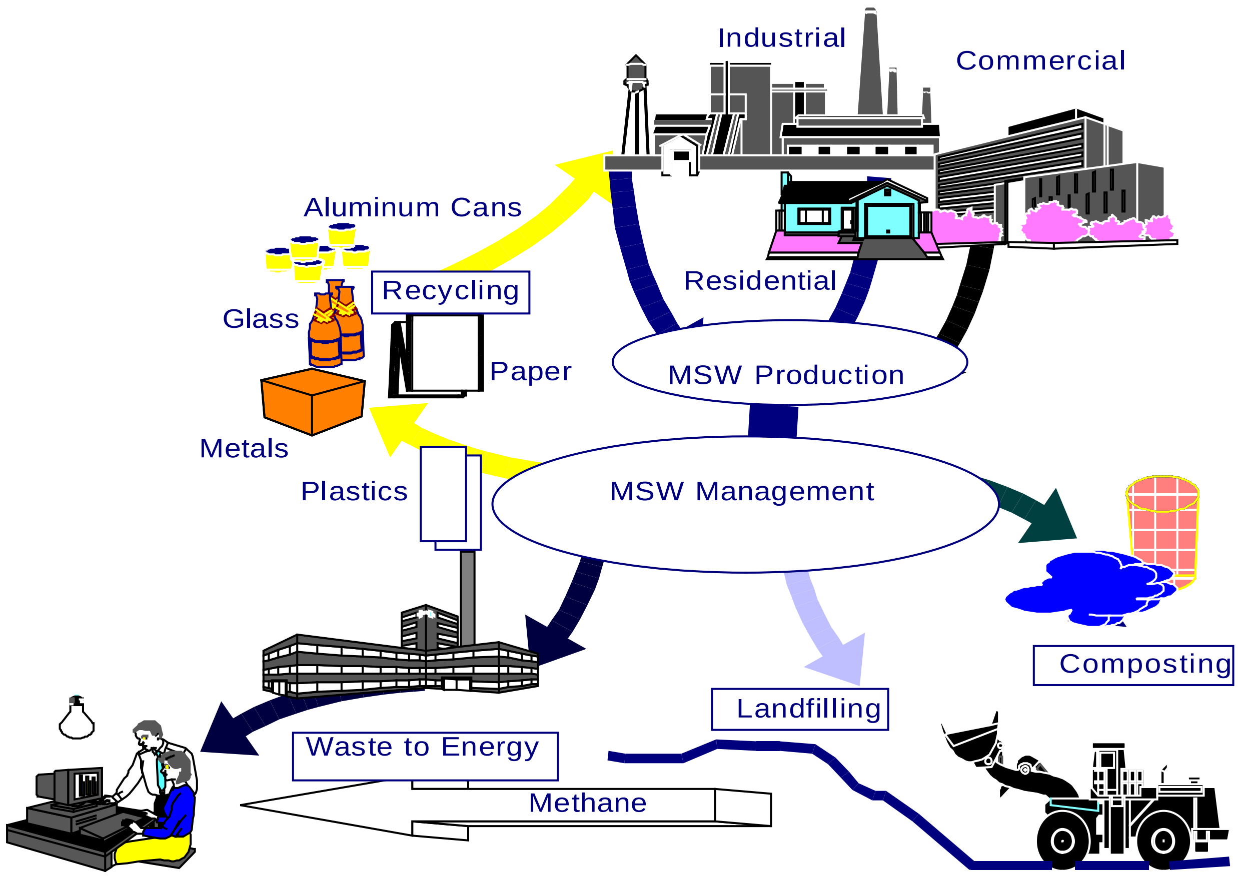
The U.S. Environmental Protection Agency (EPA) tracks the flow of MSW. Total MSW generation grew from 88 million tons in 1960 to 206.9 million tons in 1993, a growth rate of 2.6 percent per year. Although much of the increase is the result of population growth, waste generation per person has also grown, from 2.7 pounds in 1960 to 4.4 pounds in 1993; thus, the national increase in MSW generated annually can be attributed almost equally to population growth and to behavior patterns that produce more waste. On the other hand, changing behavior patterns in recent decades appear to be resulting in less waste per person. During the 1960s, MSW volumes grew at a rate of 3.5 percent per year while population grew by 1.2 percent per year; during the 1980s, the growth rates were 2.8 percent and 1.0 percent, respectively.[50]

In 1960, 63 percent of MSW was landfilled, and 31 percent was combusted without energy recovery (Table 26). Between 1960 and 1993, the disposal of MSW via combustion without energy recovery declined dramatically, both in absolute terms and as a percentage of total MSW generation. Landfilling in absolute terms and as a percentage of total MSW disposal peaked in the mid-1980s and began declining as landfill siting became more difficult. Over the past 30 years, the most dramatic changes in MSW management have been

[49]Data on waste-to-energy facilities used in this chapter were obtained from E.B. Berenyi and R.N. Gould, *Resource Recovery Yearbook,* (New York, NY: Government Advisory Associates, Inc., 1993). Updated data for 1994 and 1995 were obtained from Eileen B. Berenyi in September 1995. The yearbook is published biennially.

[50]U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, *Characterization of Municipal Solid Waste in the United States: 1994 Update*, EPA/530-R-94-042 (Washington, DC, November 1994).

Figure 8. Major Components of Municipal Solid Waste Management



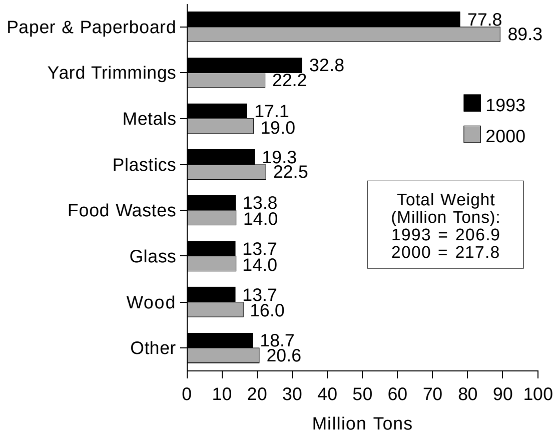
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.

rapid increases in combustion for energy recovery, composting, and recycling. In addition to the shortage of suitable landfills, the enactment of PURPA, which required utilities to purchase electricity from independent power producers—including WTE facilities—and additional recycling laws greatly influenced municipalities' waste disposal choices.

In any given year, the amount of MSW available for combustion is a function of the heat value of the waste, the amount produced, and landfilling, recycling, and composting rates. The heat value of a typical pound of MSW is widely estimated to be between 4,500 and 6,000 Btu. The future value of MSW will be influenced by the changing composition of the waste stream. The Office of Technology Assessment (OTA) states that, "The organic fraction of MSW was estimated to be about 81 percent in 1986. It appears to be growing slowly, primarily because the portions of paper and plastics in MSW also are growing . . . . Removing particular materials from MSW prior to incineration can affect combustibility. For example, removing yard wastes and inorganic recyclables such as glass and metals can reduce moisture and increase average HHV (higher heating value). In contrast, removing paper and plastics lowers HHV and increases moisture content. The net effect will depend on what is removed."[51] Data from the EPA and the OTA indicate that the heat value of MSW increased from 3,774 Btu per pound in 1960 to 4,457 Btu per pound in 1980, and an increase to 5,569 Btu per pound is expected by 2000. The expected increase in MSW heat value can be attributed largely to an increased share of paper and paperboard and a reduced share of yard trimmings in the waste stream. Since many paper products are recycled, however, it does not necessarily follow that the heat value of the waste stream available for combustion into energy will increase.

[51]U.S. Congress, Office of Technology Assessment, *Facing America's Trash: What Next in Municipal Solid Waste?*, OTA-0-424 (Washington, DC, October 1989), p. 85.

Figure 9. Municipal Solid Waste Generation by Weight, 1993 and 2000



[a]"Other" includes, for example, rubber, leather, and textiles.

Source: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, *Characterization of Municipal Solid Waste in the United States: 1994*, EPA/530-R-94-042 (Washington, DC, November 1994).

Almost 220 million tons of MSW, with a heat value of approximately 2.4 quadrillion Btu, is projected by the EPA to be produced in 2000 (Figure 9). An EIA sensitivity analysis of different possible scenarios for recycling (including composting) and landfilling provides a range of estimates for the amount of energy that could be derived from WTE resources in the year 2000 (Table 27). Currently, 16 percent, or approximately 328 trillion Btu, of MSW is combusted into energy each year, and 19 percent is recycled. If the EPA's recycling goal of 25 percent by 2000 is met and the current landfill rate of 62 percent remains the same, the energy value of the MSW available for combustion will decline slightly. If the landfill rate declines to 60 percent, the available energy from MSW will increase from 328 trillion Btu to 360 trillion Btu. If the recycling market becomes saturated and the recycling rate drops to 20 percent while the landfill rate drops to 50 percent for one reason or another, energy production from MSW will increase to 730 trillion Btu in 2000.

Technology

WTE facilities are designed to burn 24 hours a day, 7 days a week, at high temperatures and a utilization rate or capacity factor around 85 percent.[52] On average, a ton of garbage produces 500 to 600 kilowatthours of electricity, or 4,000 to 6,000 pounds of steam. WTE facilities generally fall into four categories: mass burn, refuse-derived fuel, modular controlled air, and pyrolysis.

WTE combustion is similar to conventional combustion of solid fuels such as coal. The MSW fuel is either burned in its original form with little preprocessing (mass burn) or, after the extraction of recyclable materials, converted to refuse-derived fuel (RDF) for more efficient combustion. The fuel handling equipment, boiler, ash disposal, emissions control, and power plant controls are similar to those for coal-fired power plants. The most important differences between the two

Table 26. Historical and Projected Means of Disposal for Municipal Solid Waste, Selected Years, 1960, 1970, 1980, 1990-1993, and 2000
(Million Tons)

Means of Disposal	1960	1970	1980	1990	1991	1992	1993	2000
Combustion[a]	27.0	25.1	13.7	31.9	33.3	32.7	32.9	34.0
Recovery for Recycling	5.9	8.6	14.5	28.7	32.3	35.5	38.5	54.2
Recovery for Composting	0.0	0.0	0.0	4.2	5.0	6.0	6.5	11.2
Discards to Landfill	55.0	88.2	123.3	133.2	126.2	128.8	129.0	118.3
Total Production	87.8	121.9	151.5	198.0	196.8	203.0	206.9	217.8

[a]Includes combustion of MSW in mass burn or refuse-derived form, incineration without energy recovery, and combustion with energy recovery of source separated materials in MSW.

Note: Totals may not equal sum of components due to independent rounding.

Source: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, *Characterization of Municipal Solid Waste in the United States: 1994 Update*, EPA/530-R-94-042 (Washington, DC, November 1994).

[52]Information in this discussion is taken from Electric Power Research Institute, *Technical Assessment Guide*, Revision 7—1993, Volume 1, "Electricity Supply," EPRI TR-1022765 (Palo Alto, CA, June 1993).

Table 27. Sensitivity Analysis of Availability of Waste-to-Energy Resources for Combustion to Energy, 2000
(Quadrillion Btu)

Recycling Rates (percent)	Landfill Rates (percent)			
	50	55	60	65
20	0.73	0.61	0.49	0.36
25	0.61	0.49	0.36	0.24
30	0.49	0.36	0.24	0.12

Note: Recycling rate includes composting.
Assumptions: Approximately 2.4×10^{15} Btu available in 2000 (calculated by multiplying 5,569 Btu per pound $\times$ 2,000 pounds per ton $\times$ 217.8 million tons).
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.

arise from the much greater variability of the MSW and its much higher proportion of compounds that adversely affect boiler and emissions control operations. The net effect of the fuel variability is that operating and maintenance costs tend to be high and performance tends to be uneven. The use of RDF instead of unprocessed MSW improves boiler performance, but at a significant fuel preparation cost. Additionally, the low heat content of MSW (roughly one-half that of coal), the high proportion of noncombustible materials, and potentially harmful compounds mean that twice the mass of material must be handled, combusted, and environmentally controlled than with coal. This further increases costs.

The major components of a typical mass burn power plant are shown in Figure 10. In a typical 40-megawatt power plant, the charging chutes of each of the two mass burn boilers receive mixed waste via an overhead crane and bucket. A hydraulic ram pushes the waste onto the sloping grate of the furnace, where it is passed through three zones: drying, combustion, and burnout. Air is injected above and below the grate. The heat transfer surface is located in the waterwalls and convective pass, where superheated steam (900 psi and 830ºF) is generated. The steam from the two incinerators is used to drive a 40-megawatt steam turbine generator (the gross capacity is 45.5 megawatts, with 5.5 megawatts used for auxiliary power). Assuming a 24.8-percent moisture content and 4,900 Btu per pound, a 40-megawatt mass burn power plant can consume 1,606 tons of waste per day. The average facility has a thermal efficiency of 20.8 percent and a net heat rate of 16,377 Btu per kilowatthour.

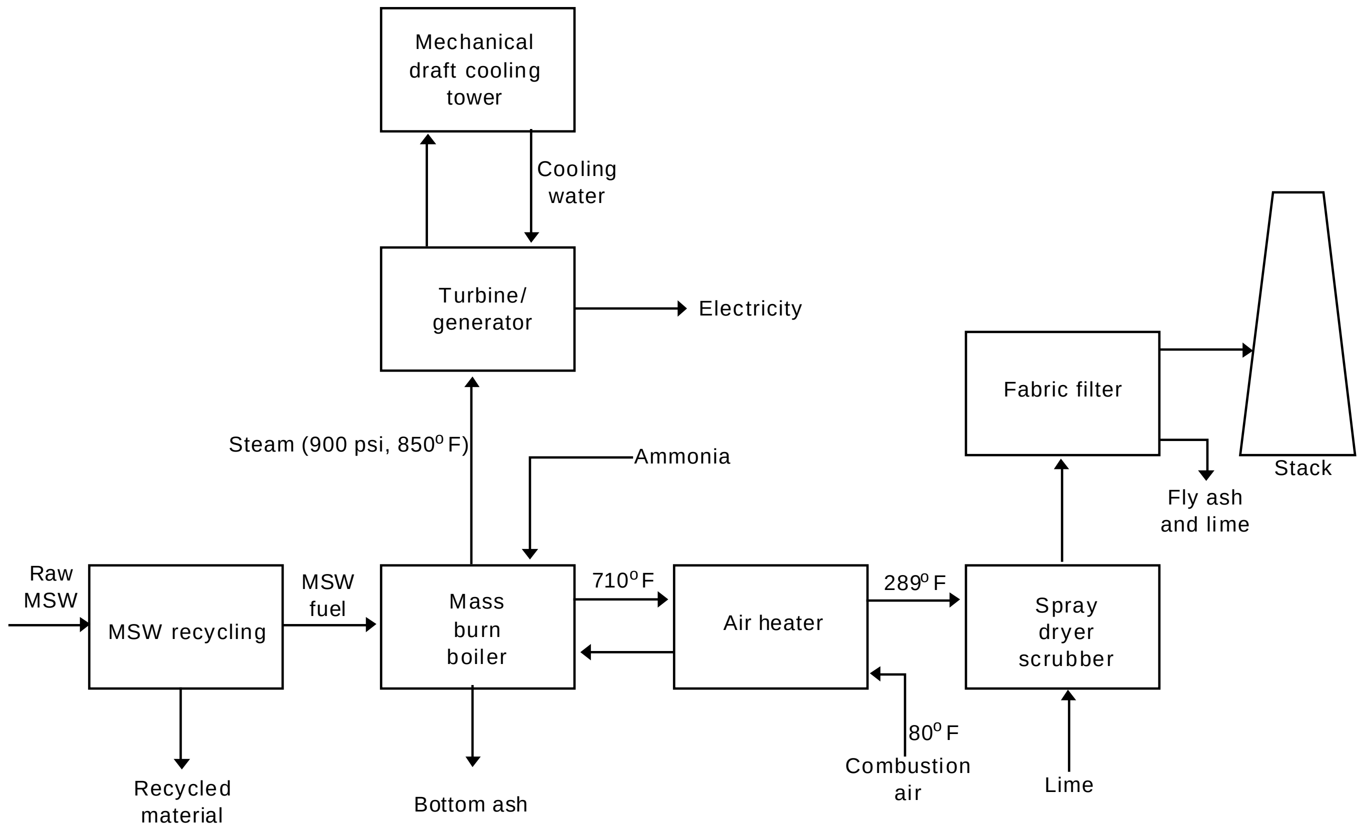
A WTE facility has many environmental controls. Ammonia is injected into the boiler convection pass to control nitrogen oxide emissions. A lime spray dry scrubber removes sulfur dioxide, hydrochloric acid, and other acid gases and a baghouse removes lime solids and fly ash, which may contain heavy metals, dioxins, furans, and other toxic substances. Bottom ash and fly ash are landfilled. Combusting the waste reduces the amount that has to be landfilled by about 90 percent. Thus, WTE facilities may be justified not on electricity generation costs alone but as a means to eliminate a major social problem and a growing expense.

A second type of WTE facility is a modular controlled-air incineration system, generally prefabricated and shipped to the site, with a capacity of less than 50 tons per day. Modular systems feed MSW into a primary chamber where incomplete combustion produces a combustible gas that is burned in a second chamber, usually in conjunction with oil or gas. This technology produces very low particulate emissions, but its low-pressure steam is not suitable for the generation of electricity for sale to utilities.

Refuse-Derived Fuel (RDF) facilities consist of an RDF processing area and an RDF-fired stoker boiler. RDF processing includes flail milling, trommel screening, magnetic separation, and size reduction. The resulting fuel, with a heat content of 5,900 Btu per pound, is transported by conveyor to the power plant, where it is injected by the spreader stroker and combusted in suspension and on the grate. The other parts of the plant are similar to those of a mass burn plant. Assuming a moisture content of 28.2 percent and heat value of 5,663

The Bristol Resource Recovery Facility, which began commercial operation in May 1968, converts up to 650 tons of solid waste to saleable energy each day. At maximum output, the plant generates over 16 megawatts; remaining electricity is sold to a local utility and used to power area homes and businesses. (Source: Ogden Martin Systems of Bristol, Inc.)

Figure 10. Schematic of a Typical MSW-Fired Mass Burn Boiler Power Plant



Note: psi is pounds per square inch.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.

Btu per pound, a 40-megawatt RDF plant can consume 1,396 tons of fuel per day. The plant has a thermal efficiency of 20.7 percent, gross capacity of 46 megawatts, and a heat rate of 16,464 Btu per kilowatthour.

A fourth WTE technology is pyrolysis. A pyrolysis system decomposes organic waste in a high-temperature, oxygen-deficient chamber. Efforts to continue to commercialize this technology have declined, and operating facilities using this technology have closed down.

Infrastructure

Waste-to-energy facilities are very capital-intensive undertakings; in many cases, they are the single most expensive public works project confronting a municipality. Most facilities are developed as a result of an alliance between a developer/vendor and a municipality. Usually, a municipality contracts with a full-service vendor/developer to construct and operate a facility. The facility may be publicly or privately owned. Waste streams may be secured with private contracts or flow control contracts. Flow control may be legislated (waste streams directly controlled by local ordinances) or economic (indirectly controlled and financed with local property taxes, levies, or fees on property owners). In recent years, several companies have constructed merchant facilities that are completely or partially independent of a municipality. These are high-risk, high-profit facilities vulnerable to the whims of the market. They must compete on a tipping fee[53] basis with other waste disposal choices and new firms entering the market.

In the WTE field, most vendors also serve as developers and owners/operators of a facility. The industry has consolidated in recent years. This movement to larger diversified companies and a more concentrated industry, both horizontally and vertically, is driven by changing market conditions. Contract negotiations are long and intricate; obtaining proper permits is cumbersome. Siting the facility is controversial and usually requires public participation. Even if a facility does not directly participate in recycling, it must coordinate the size of the facility with anticipated markets for

[53]A tipping fee is a per-ton charge for discharging waste material at a WTE facility or a landfill.

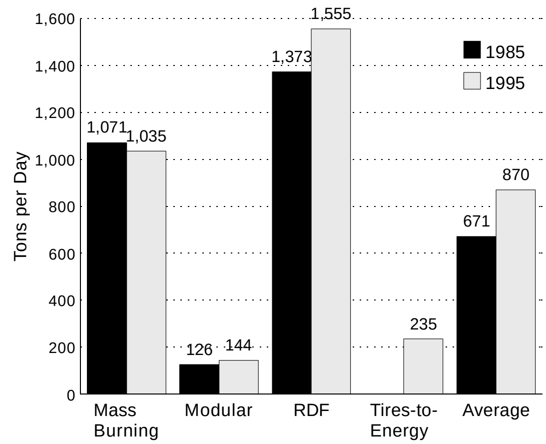
recycling. Methods of obtaining funding have been modified as a result of the Tax Reform Act of 1986, and the recent U.S. Supreme Court flow control decisions have created uncertainty and raised interest rates in the capital markets. Great expertise is required to deal with increasingly stringent environmental regulations covering emissions and ash disposal.

As the industry has become more concentrated, the average size of a facility has increased from 671 tons per day in 1985 to 870 tons per day in 1995 (Figure 11). Although RDF facilities, on average, have increased in size from 1,373 tons per day to 1,555 tons per day during the 10-year period, the average capacity by process type (mass burning, modular, RDF) is not the primary cause of the increase in average capacity for all WTE facilities. The primary factor has been the changing mix of facilities by process type. Mass burn facilities have increased their share of the market at the expense of much smaller modular facilities. Mass burn capacity grew from approximately 16,000 tons per day in 1985 to more than 71,000 tons per day in 1995, increasing its share of the market's capacity from 57 percent to 71 percent during this period (Figure 12). At the same time, modular capacity, as a percent of total market capacity, declined from almost 9 percent to approximately 4 percent.

Another factor that has contributed to the increase in average size of WTE facilities over the past 10 years is the trend toward construction of facilities that generate only electricity, at the expense of facilities that generate only steam. In 1995, an average facility generating only electricity was more than four times the size of a facility generating only steam. Of the 87 facilities in existence in 1995 that came on line after 1985, 58, or two-thirds of them, generate only electricity; another 15 facilities generate steam and electricity. Only 14 of the 87, or 16 percent, of the facilities generate only steam, compared with 57 percent at the end of 1985. During this 10-year period, the total capacity of electricity-only generating facilities grew from less than 15,000 tons per day to almost 74,000 tons per day, increasing its market share from 52 percent to 73 percent (Figure 13). In 1995, steam-only generating capacity accounted for less than 8 percent of the market. Most of the remaining capacity generated both steam and electricity. The guaranteed market for electricity under PURPA is the primary factor influencing the trend toward electricity generation.

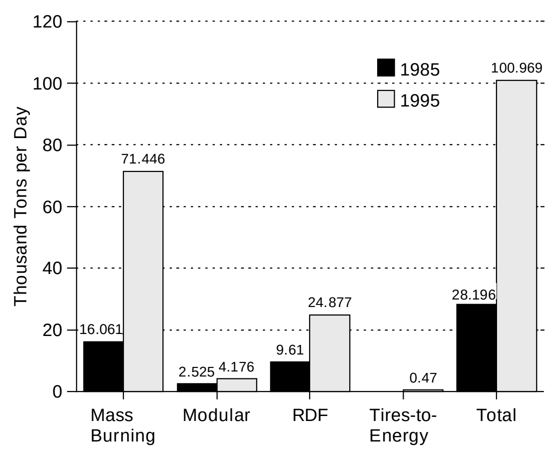
Another change in the industry's structure during the past 10 years is the trend toward private rather than public ownership. In 1985, approximately 62 percent of the WTE capacity was publicly owned, compared with approximately 46 percent in 1995 (Figure 14). In 1985,

Figure 11. Average Waste-to-Energy Capacity by Process Type, 1985 and 1995



Source: Figure developed by the Energy Information Administration, based on data from Eileen B. Berenyi and Robert N. Gould, *Resource Recovery Year* (New York, NY: Government Advisory Associates, Inc., 1993), pp. 229-670, updated with 1994 and 1995 data by telephone.

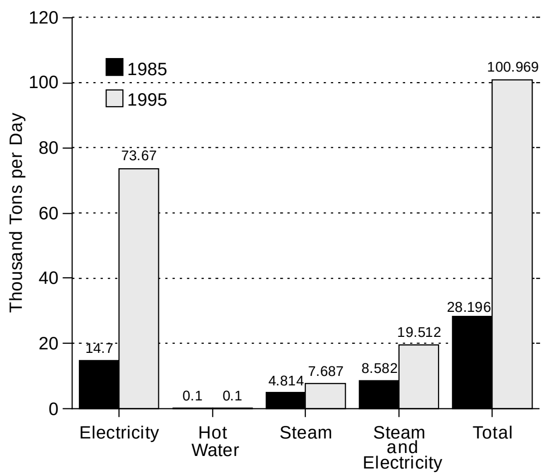
Figure 12. Total Waste-to-Energy Capacity by Process Type, 1985 and 1995



Note: Tires-to-energy is less than 1 percent of total capacity.
Source: Figure developed by the Energy Information Administration, based on data from Eileen B. Berenyi and Robert N. Gould, *Resource Recovery Year* (New York, NY: Government Advisory Associates, Inc., 1993), pp. 229-670, updated with 1994 and 1995 data by telephone.

only 8 of the 42 facilities in operation were privately owned; in 1995, 53 of 116 were privately owned. The increase in private ownership after 1985 can be attributed to the Tax Reform Act of 1986. The Act eliminated many of the financial advantages of private ownership, but its flexible grandfathering clauses

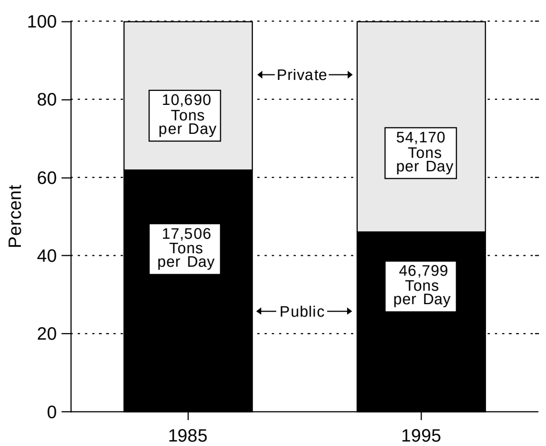
Figure 13. Total Waste-to-Energy Capacity by Type of Energy Production, 1985 and 1995



Note: Hot water is less than 1 percent of the total.

Source: Figure developed by the Energy Information Administration, based on data from Eileen B. Berenyi and Robert N. Gould, *Resource Recovery Year* (New York, NY: Government Advisory Associates, Inc., 1993), pp. 229-670, updated with 1994 and 1995 data by telephone.

Figure 14. Percentage of Waste-to-Energy Capacity by Ownership Type, 1985 and 1995



Source: Figure developed by the Energy Information Administration, based on data from Eileen B. Berenyi and Robert N. Gould, *Resource Recovery Year* (New York, NY: Government Advisory Associates, Inc., 1993), pp. 229-670, updated with 1994 and 1995 data by telephone.

permitted facilities that were in initial planning stages to qualify under the old, more favorable tax laws. If a private entity was contemplating the construction of a WTE facility, it needed to start the facility promptly. Almost all of the facilities built since the Act was passed have been grandfathered-in under the pre-1986 tax laws.

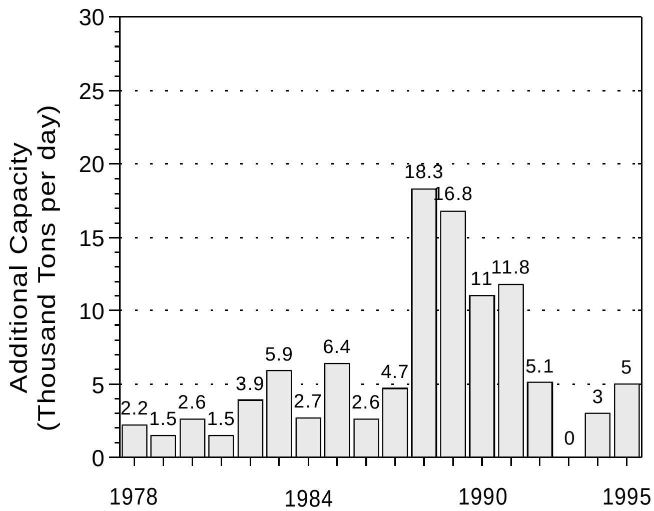
Historical Status

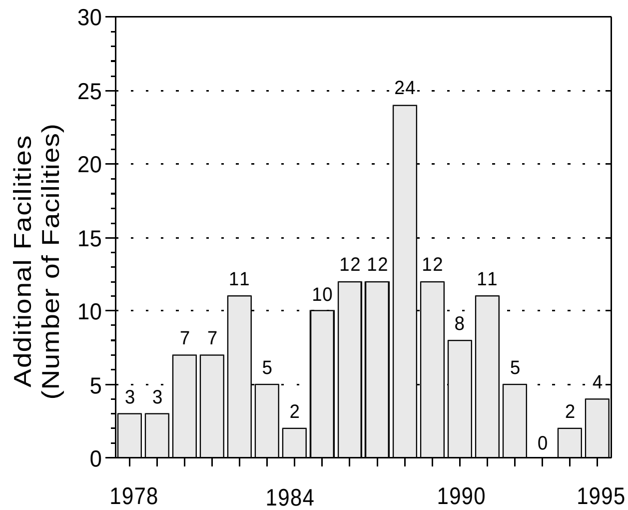
During the 1970s, the U.S. Navy, Wheelabrator, and Ogden licensed European mass burn technologies. Despite the availability of functional mass burn technology, the EPA funded about 10 other experimental technology developments in RDF combustion and pyrolysis. As a result of PURPA and the energy crisis in 1979, many of those technologies were rushed to market prematurely. Early commercial facilities were characterized by poor performance and overly complex designs; most had closed by 1984, with a total combined loss of over $300 million to investors.

During the same era, the Resource Conservation and Recovery Act of 1976 (RCRA) empowered the EPA to regulate residues from solid waste incinerators. Ambiguous wording limited the application of this law to MSW combustion ash, because MSW was specifically exempted from consideration as a hazardous waste. Thus, there was a question as to whether the ash should be considered exempt from hazardous waste regulation. The issue quickly went to court; however, it was not until 1994 that the U.S. Supreme Court deemed that ash should be exempt from waste regulation under Subtitle C of the RCRA, and that it must be regularly tested to determine if it is hazardous.

Several events in the mid- to late 1980s converged to create an environment conducive to the adoption of modern MSW power technology and the subsequent growth of the industry: environmental concern over landfilling as a safe disposal method, rising tipping fees, PURPA, and the soon-to-expire (or soon-to-be-limited) investment tax credits and tax-free financing for development bond issues. Communities were becoming concerned about the environmental impact of landfills on groundwater. MSW power offered the sole alternative to landfilling at the time, with the additional benefit of producing renewable energy. Throughout the early to mid-1980s, MSW power enjoyed a 10-percent energy investment tax credit and tax-free development bond issues that reduced financing costs. The Tax Reform Act of 1986 eliminated the tax-free status of MSW combustion plants financed with industrial development bonds, their accelerated depreciation, and the 10-percent renewable energy tax credit. Not surprisingly, the number of permits for new facilities peaked at the end of 1986, the last year for facilities to qualify for such benefits. The Act also phased in, to be completed by 1988, reduced State caps on private tax-exempt bonds. At least eight new facilities became operational each year from 1985 through 1991, and there were large annual additions to capacity from 1988 through 1991 (Figure 15).

Figure 15. Annual Additions of Waste-to-Energy Capacity and Facilities, 1978-1993





Source: Figure developed by the Energy Information Administration, based on data from Eileen B. Berenyi and Robert N. Gould, *Resource Recovery Year* (New York, NY: Government Advisory Associates, Inc., 1993), pp. 229-670, updated with 1994 and 1995 data by telephone.

In the 1990s, the fortunes of MSW power began to change. First, several States and the EPA began to promote recycling rather than combustion. Second, waste import restrictions and flow control legislation enacted by States to secure MSW supplies came under review by the U.S. Supreme Court and were overturned. Congress is currently considering legislation to protect the financial integrity of existing plants using flow control, and to allow States to restrict the flow of waste across State lines. Third, the Court also determined that MSW combustion ash had to be tested for toxicity and, if found toxic, to be disposed of in special, more expensive landfills. Finally, in 1994, the EPA published new proposed air emission rules to cover small MSW combustion facilities. All of these events slowed the growth in MSW developments from 1992 to 1995. Although six new facilities with a combined capacity of 8,030 tons per day came on line in 1994 and 1995, this growth was partially offset by the closing of four facilities that had been combusting 3,800 tons per day. The outlook is unclear.

As of October 1995, there are 116 WTE facilities operating and marketing energy in the United States, with a combined capacity of more than 100,000 tons per day. Seventy-five percent of the facilities and 88 percent of the capacity are located in States east of the Mississippi River (Figure 16). The six States with the largest amount of capacity—Florida, New York, Massachusetts, Pennsylvania, Virginia, and Connecticut—represent almost 60 percent of the total capacity in the Nation. Incinerating waste reduces its volume by approximately 90 percent, preserving scarce landfill space, and landfill space is at a premium in these States because of high water tables or high population densities or for other reasons.

Major Issues Affecting Growth

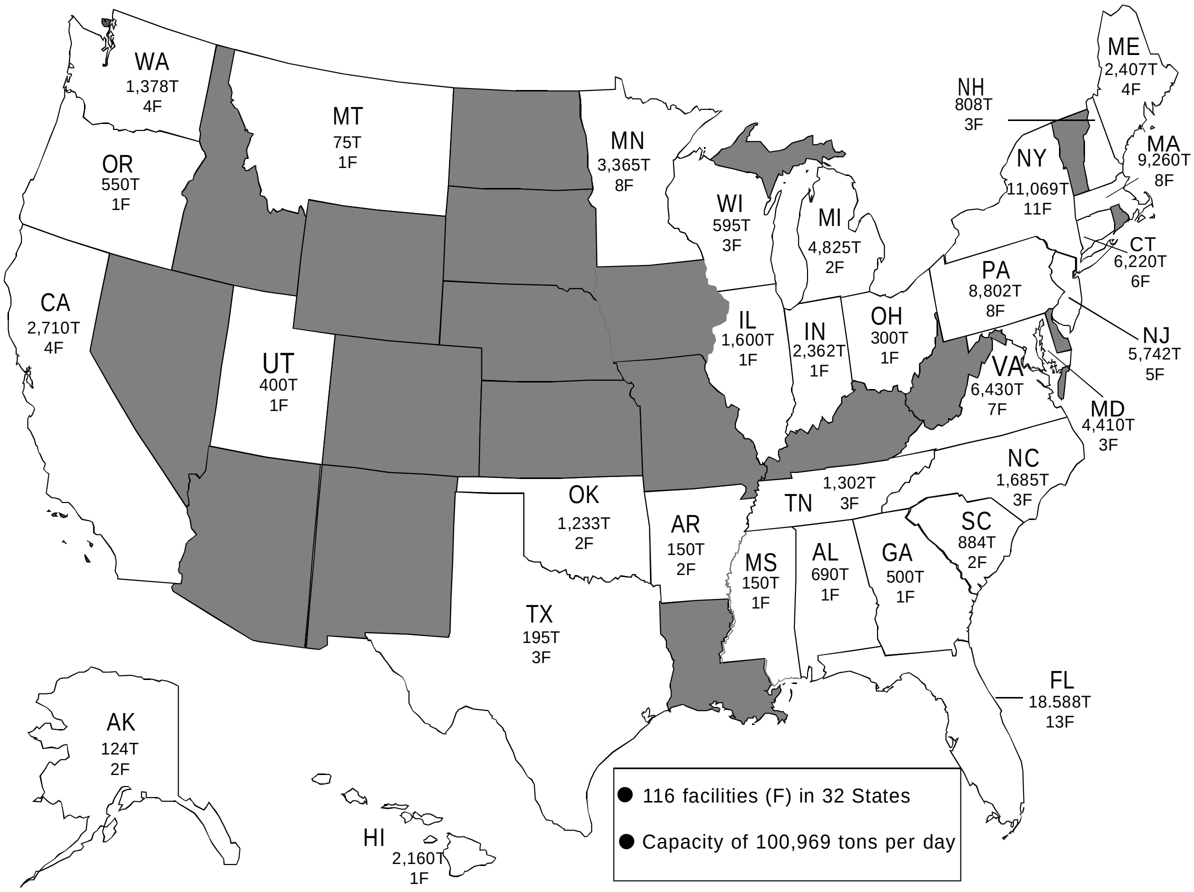
The primary factors affecting the growth of the WTE industry are alternative uses of MSW (such as recycling, composting, and landfilling), increasingly stringent and more costly environmental standards, the Tax Reform Act of 1986, and the ability to control the flow of waste supplies to particular facilities to ensure efficient operation of the facilities and the timely payment of debt.

Integrated Waste Management

The desire of communities to dispose of their waste in the most cost-effective manner has given rise to the concept of "integrated waste management" or managing waste options (recycling, composting, waste-to-energy, and landfilling) to minimize total cost. Reducing the quantity of materials entering the waste stream in the first place (source reduction) may also be considered an aspect of integrated waste management.

Probably the most significant use of waste that has influenced the amount of waste available for combustion is recycling. More than 140 recycling laws were enacted by 38 States in 1990. Thirty-three States and the District of Columbia have comprehensive recycling

Figure 16. Capacity and Number of Waste-to-Energy Facilities by State, 1995



T = Tons per day.
F = Facility.
Source: Figure developed by the Energy Information Administration, based on data from Eileen B. Berenyi and Robert N. Gould, *Resource Recovery Year* (New York, NY: Government Advisory Associates, Inc., 1993), pp. 229-670, updated with 1994 and 1995 data by telephone.

laws.[54] Today, 22 percent of the MSW in the country is recycled (including composting).[55] The goal of the EPA is to have at least 25 percent of total U.S. MSW directed to recycling by the year 2000.

Recycling may or may not lessen the energy efficiency of MSW combustion. Recycling of newspapers, other paper, and paperboard reduces both the volume and Btu content of MSW, making it less attractive as a fuel. On the other hand, removing yard trimmings reduces the volume but increases the per-unit energy content of MSW. It also reduces the moisture content of the waste stream, thus improving the overall combustibility of the mix. Furthermore, recycling of glass, aluminum, and other metal noncombustibles reduces the volume of trash while leaving its energy content unaffected, which raises its per-unit energy value.

With the emphasis on integrated waste management today, communities take into account the goals of their

[54]National Solid Waste Management Association, *Recycling in the States, 1990 Review* (Washington, DC, September 1991).

[55]Data on waste-to-energy facilities used in this chapter were obtained from E.B. Berenyi and R.N. Gould, *Resource Recovery Yearbook,* (New York, NY: Government Advisory Associates, Inc., 1993). Updated data for 1994 and 1995 were obtained from Eileen B. Berenyi in September 1995. The yearbook is published biennially.

recycling programs when planning the size of WTE plants. In other words, planning for WTE facilities increasingly occurs in the context of coordinated recycling, composting, WTE, and landfilling, with projected plant loads designed with the expectation that some MSW will be directed to recycling and composting.

Even optimistic projections for recycling and composting continue to forecast increasing quantities of MSW requiring disposal, either directly to landfills or by combustion. If the EPA goal of 25 percent recycling (including composting) were achieved, at current rates of MSW production, more than 150 million tons of MSW per year[56] would remain for energy conversion or landfilling.

It is also important to recognize that recycling and composting impose costs and are not always the most efficient components of integrated waste management. Recycling incurs financial costs for collection, sorting, and processing; recycling also has environmental consequences, including emissions from collection vehicles and processing centers, and uncertain environmental effects during remanufacturing. Finally, lack of demand in the markets for some recycled materials or limitations in market development could restrict the growth in recycling. Composting also faces obstacles, particularly when specialized composting facilities are used. Although a number of smaller facilities are operating, larger facilities have, so far, been much less successful.

Historically, the largest proportion of waste has been directed to its cheapest method of disposal, landfilling. Much of the recent scare concerning the shortage of landfills has not materialized. The increased recycling and composting rates have extended the life of existing landfill capacity, and court decisions prohibiting States from closing their borders to other States' wastes are the major factors that have alleviated landfill shortages.

Environmental Concerns and Regulations

Generally, WTE facilities are near large sources of MSW and, consequently, near population centers. A barrier to the growth in WTE facilities has been and continues to be problems associated with siting, or the so-called "not in my back yard" (NIMBY) phenomenon. Even in communities that agree to build WTE facilities, finding sites acceptable to nearby residents remains a problem. Objections include exclusion from the decisionmaking process; fears of negative effects on property values and on traffic patterns; concerns about noise, dirt, and danger of truck traffic; expected plant odor; and, in particular, fears of actual or perceived negative health effects.

Health concerns center on both airborne emissions from exhaust stacks and groundwater contamination from landfilled combustion ash. They include fears of harmful health effects, particularly cancer, from emissions of dioxins, furans, arsenic, beryllium, cadmium, chromium, chlorobenzenes, chlorophenols, formaldehyde, polycyclic aromatic hydrocarbons, and polychlorinated biphenyls, as well as more general health concerns about emissions of sulfur and nitrogen oxides, hydrogen chlorides, heavy metals (including lead and mercury), and particulates.

Air pollution control regulations have become increasingly stringent since the early 1970s, requiring municipal waste combustors to make continual technological adjustments. The Clean Air Act of 1970 provided the regulatory groundwork for the 1971 New Source Performance Standards, which regulated particulate emissions and led to the replacement of low-energy wet scrubbers with electrostatic precipitators. The Clean Air Act Amendments of 1990 required the EPA to establish solid waste combustion standards consistent with the maximum achievable control technology (MACT).

The EPA issued proposed standards in September 1994 and expects to issue final standards by the end of 1995. These standards will affect new plants at startup; existing facilities will have to comply within 1 to 3 years. For the first time, Federal limits will be placed on cadmium, lead, mercury, and fugitive dust from ash systems. Dioxin, sulfur dioxide, hydrogen chloride, and particulate matter will be more stringently controlled than under the 1991 Revised New Source Performance Standards. Some facilities will have to replace spray driers and electrostatic precipitators with high-efficiency scrubbers. Those over 250 tons per day will have nitrogen oxide emission limits for the first time. New facilities will be required to have recycling plans, as well as site analyses that include early public involvement.

Concerns about groundwater contamination from landfilled combustion ash have recently been clarified by a May 1994 U.S. Supreme Court decision. The RCRA, enacted in 1976, led to the development of separate regulations for hazardous waste (Subtitle C) and nonhazardous waste (Subtitle D). It had not been clear which set of regulations applied to MSW ash. The issue had been debated at the Federal, State, and local policymaking levels, among municipalities, industry, environmental groups, and in the courts, for approximately 6 years.

[56]U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, *Characterization of Municipal Solid Waste in the United States: 1994 Update,* EPA/530-R-94-042 (Washington, DC, November 1994).

The May 1994 U.S. Supreme Court decision ruled that ash from WTE facilities must be regulated as a hazardous waste under Subtitle C of the RCRA and, therefore, tested for toxicity. After a year of testing at all WTE facilities, combustion ash has developed an excellent record of nontoxicity. A key regulation promulgated by the EPA allows WTE facilities to mix fly and bottom ash before testing and disposal. Fly ash, which is captured from stack gases, tested by itself, may have a much higher proportion of heavy metals, polyaromatic hydrocarbons, and dioxins than bottom ash. However, environmentalists may challenge these testing procedures in the future. Although the long-awaited May 1994 Supreme Court decision ruled that combustion ash must be regulated as a hazardous waste, it has had little impact on the industry to date.

In 1991, EPA issued subtitle D regulations setting requirements for MSW landfills (Volume 40 of the Code of Federal Regulations, Part 258). These regulations provide minimum standards for all operating landfills. In States that already have EPA-approved permitting programs, groundwater must meet drinking water standards. In States without EPA-approved programs, landfills must be designed with a synthetic composite liner covering a 2-foot clay liner. All groundwater must be monitored and, if necessary, cleaned to meet acceptable standards. Many States have already implemented these or more stringent standards. States without standards, or with less stringent ones, will have to incorporate the EPA standards to ensure that landfills are operated safely.[57] To the extent that the standards cause the cost of landfilling to rise, more waste will be directed to the WTE industry.

Tax Reform Act of 1986

The 1986 Act modified several decades of earlier tax laws.[58] It lowered the rate of return on capital investments by eliminating the tax credits and lengthening the depreciation schedules on capital investments. In addition, the Act placed allocation caps on tax-free private activity bonds (PABs). Both of these sections have had major impacts on the pattern of growth in the WTE industry. The Act has influenced ownership decisions (private versus public) in the WTE industry and waste disposal choices (capital-intensive WTE versus less capital-intensive options such as landfilling) in the MSW industry as a whole.

The prospect of increased taxes lessens the amount of capital private companies can invest at the outset of a project and still maintain a competitive rate of return on their investment. Reduced up-front capital investment requires the issuance of additional bonds, which must be financed with increased tipping fees. In these circumstances, the more capital-intensive WTE options are at a disadvantage relative to less capital-intensive waste disposal options, such as landfilling.

The Tax Reform Act of 1986 also divided State and local bonds into government bonds and PABs (Table 28). The definition of private activity was changed by further limiting private activity to qualify for issuance of public bonds. Under the Act, a private entity could use no more than 10 percent of the bond proceeds, nor secure more than 10 percent of the bonds with private property or revenues, to maintain the preferred government bond classification and the assurance of tax-exempt status. PABs (bonds that exceed the 10-percent limitation) could maintain tax status provided they were used for qualified investments (such as WTE facilities) and were within the State's volume cap of $50 per capita or $150 million per State, whichever is greater. To the extent that investments in unpopular WTE facilities did not fit under the State cap because of increasing requirements for investments in other environmental infrastructure (solid waste, wastewater treatment, and drinking water facilities), States could choose public ownership of WTE facilities so that they could maintain tax-exempt status.

Facilities completed after the Act became law but prior to March 2, 1986, could still qualify for the pre-tax depreciation schedules and investment tax credits, provided there was a written binding contract between the parties and a commitment of at least $200,000 had been made to finance or construct the facility. (Some States had other criteria for qualifying for treatment under the old tax laws, but the ones mentioned above appear to be the most commonly used.) Almost 90 percent of the municipal bonds issued for solid waste facilities in 1986 were for privately owned facilities, compared with about 50 percent in 1993. The private sector's large share of the market during this period can be partially attributed to accelerated activity aimed at getting projects started so that they could qualify under the more favorable old tax laws. In 1985 alone, permits to construct 42,620 tons per day of new WTE capacity were issued, compared with permits for 53,790 tons per day in all the years prior to 1985. Almost all of the privately owned WTE facilities that have come on line since 1986 have reaped the tax benefits of the old tax laws. The private sector's declining annual share of the

[57]Environmental Protection Agency, Office of Solid Waste and Emergency Response, *Municipal Landfill Regulations Mean Safer Disposed of Solid Waste*, EPA/530-5W-91-066 (Washington, DC, September 1991), pp. 1-3.

[58]For more details on the Tax Reform Act of 1986 and its impacts, see "The Impact of Flow Control and Tax Reform on Ownership and Growth in the U.S. Waste-to-Energy Industry," *Monthly Energy Review*,, DOE/EIA-0035(94/09) (Washington, DC, September 1994).

Table 28. Rules Governing Tax Exempt Bonds for Private Activities Before and After 1986

Issue	Before the 1986 Tax Act	After the 1986 Tax Act
Definition of a Private Activity	More than 25 percent of bond proceeds used by a private entity and used to secure property used by or revenues derived from a private entity	More than 10 percent of bond proceeds used by or revenues derived from a private concern
Volume Cap	No unified volume cap; cap on certain private activities	Phased-in unified volume cap; in 1986, $75 per capita or $250 million; in 1988 and later, $50 per capita or $150 million
Investment Tax Credit	10 percent of certain investments	None
Depreciation	5-year depreciation schedule	Depreciation schedule lengthened, depending on type of environmental facility

Source: U.S. Government Accounting Office, *Environmental Infrastructure: Effects of Limits on Certain Tax-Exempt Bonds,* GAO/RCED-94-2 (Washington, DC, October 1993).

market from 1986 to 1993 is probably attributable to the declining opportunities to qualify for the favorable tax benefits.

All in all, the Tax Reform Act of 1986 favored public ownership and less capital-intensive waste disposal options. In the future, to the extent that privately owned facilities are constructed, it is possible that more merchant facilities will be constructed, as opposed to those facilities that are closely affiliated with a municipality. Merchant facilities are potentially high-profit, high-risk facilities that operate purely at the whim of market forces and rely on neither legislated nor economic flow control.

Flow Control and Interstate Movement of MSW

Generally, flow control can be defined as the laws, regulations, and economic incentives or disincentives used by waste managers to direct waste generated in a specific geographic area to a designated landfill, recycling, or WTE facility. In some cases, the waste may be delivered first to a transfer station, then sorted and reshipped. The specific form and mix of controls instituted by State and local governments depend on the objectives desired.

By far the most frequently used rationale for choosing flow control is to ensure the financial viability of a WTE facility by providing a reliable, long-term supply of raw materials. This assures the facility of obtaining revenues from tipping fees (charges for waste disposal at the facility), from the sale of electricity or steam or both, and, in some cases, from the sale of materials for recycling, depending on the type of waste disposal facility designated to receive the waste. This assurance is critical in raising capital to finance the construction of a facility.

Legal and regulatory flow control (legislated) can be implemented in several ways. The municipality may collect and dispose of the waste with government employees and vehicles, contract with private haulers for some portion of the process, or grant permits, licenses, or franchises for the collection, transportation, and disposal of waste only to those entities that deliver the waste to a designated facility. Local laws and ordinances to direct waste flows are usually authorized, required, or supported by State governments.

Economic flow control combines market forces with tools such as subsidies, grants, fees, and taxes to the extent necessary to control waste flows. It attempts to direct the movement of waste without legal or regulatory controls. The distinction between legislated and economic flow control is critical to the development of defense strategies against legal challenges.

Publicly owned WTE facilities and certain privately owned facilities that are affiliated with municipalities can engage in either legislated or economic flow control. By contrast, merchant facilities are independently constructed by entrepreneurs without municipal involvement in guaranteeing waste flows. Merchant facilities usually employ private contracts to secure waste supplies.

From 1990 through 1993, only three non-flow-control facilities became operational, with a total capacity of less than 1,200 tons per day. Two had private contracts.

The third, built with city revenues, did not contractually secure waste supplies. During the same period, 21 flow control facilities with almost 27,000 tons per day total capacity became operational. Based on testimony by State and local officials at EPA-sponsored public meetings in late 1993, municipalities overwhelmingly believe that directing the flow of waste to specific facilities helps them achieve recycling goals and meet increasingly stringent environmental standards for waste disposal. Of the 61 commenters, 59 supported flow control as a waste management tool. (Two local governments preferred free markets.)[59]

On May 16, 1994, the U.S. Supreme Court declared unconstitutional a Clarkstown, New York, flow control ordinance on the grounds that it unfairly regulated interstate commerce and, therefore, violated the Commerce Clause of the U.S. Constitution. As a result of this ruling, legislative flow control contracts across the country could be interpreted to be illegal and nonbinding and, therefore, unavailable as a means of securing financing and investment in new and existing capacity. By using its authority to regulate interstate commerce, however, Congress could enact a law authorizing legislated flow control. The 103rd Congress came close to passing legislation authorizing flow control, and the 104th Congress is considering several flow control bills. The Senate has actually passed flow control legislation that would grandfather any community that had used flow control or met other conditions prior to May 15, 1994. This bill would also provide States the authority to limit imports of waste from other States.

If legislated flow control is not authorized by Congress, some States may resort to economic flow control (which is vulnerable to legal challenges as a violation of antitrust laws) and raising property taxes or other indirect taxes to cover capital costs and to avoid bond downgrading or default. Six solid waste bond issuers have been downgraded and five others have been given a negative outlook by the Standard & Poor's financial rating firm. Several other communities have had their bond ratings downgraded, causing the value of their bonds to decline. Two WTE facilities in Ohio (Columbus and Akron), with 3,000 tons per day combined capacity, have stopped operations because of the inability to control the flow of waste.

In addition to flow control, a U.S. Supreme Court ruling prohibiting waste import restrictions will detrimentally affect the growth of the WTE industry. Like flow control, such restrictions have been declared to violate the Commerce Clause of the Constitution. Given this ruling, and barring any action by Congress to authorize States to restrict import of waste, waste will flow out of many States to the least-cost waste disposal option of landfilling.

[59]U.S. Environmental Protection Agency, *Municipal Solid Waste Flow Control: Summary of Public Comments*, EPA 530-R-94-008 (Washington, DC, February 1994).

MSW Power Milestones

1898	First energy recovery in the United States	Energy recovery from garbage incineration started in New York City. The primary focus for the next eight decades was on waste volume reduction through incineration, and energy recovery was used primarily for process heat.
1970s	Commercialization	First-generation research was followed by construction of refuse-derived fuel systems and pyrolysis units in the late 1970s. The first commercial units were characterized by poor performance and overly complex technology and were subsequently closed. Writeoffs during 1980-1984 were estimated at $300 million.
1970s	U.S. firms' licensing of European mass burn technology	U.S. Navy, Wheelabrator, and Ogden acquired the European mass burn technologies that would dominate the U.S. industry by the late 1980s.
1976	Resource Conservation and Recovery Act (RCRA)	RCRA empowered the Environmental Protection Agency (EPA) to regulate residues from solid waste incinerators. Unclear wording made application of the law to MSW power plants uncertain, and the issue was taken to court.
1978	Public Utility Regulatory Policies Act (PURPA) enacted	PURPA mandated the purchase of electricity from qualifying facilities (QFs) at a utility's avoided cost of energy and capacity. This legislation was used to require utilities to pay a higher price for power from MSW power plants than the plants had traditionally received.
1978	City of Philadelphia vs. New Jersey	The U.S. Supreme Court defined waste to be an article of interstate commerce that cannot be discriminated against unless there is some reason, apart from its origin, to treat it differently, or unless Congress specifies otherwise for particular articles of commerce.
1986	Tax Reform Act	The Tax Reform Act of 1986 eliminated the tax-free status of MSW power plants financed with industrial development bonds, reduced accelerated depreciation, and eliminated the 10-percent tax credit. The Act also reduced State caps on private tax-exempt bonds in 1988, further reducing funding sources and increasing the cost of capital.
1987	Doubling of landfill tipping fees	Landfill tipping fees doubled, and doubled again about every 2 years due to rising landfill costs resulting from the RCRA. Siting issues became increasingly difficult.
1989	EPA report on recycling	*The Solid Waste Dilemma: An Agenda for Action* advocated recycling as a waste management tool.

1990	Clean Air Act Amendments	The EPA recognized MSW power as a renewable fuel that would qualify for up to 30,000 sulfur dioxide emission allowances from a special pool of 300,000 designed to promote conservation and renewable energy. The EPA also required MSW power plants over 250 tons per day to employ best available control technology (BACT). Retrofit costs caused some facilities to close.
1991	Resource Conservation and Recovery Act, Subtitle D	The EPA announced that small, unlined landfills would be required to close by December 31, 1993. This action spurred the infant recycling industry and increased tipping fees around the country. Most landfills requested and received extensions.
1992	EPA ash memo	An EPA memorandum excluded ash from regulation as a hazardous waste under Subtitle C of the RCRA, as long as it was not characterized as toxic. This action did very little to clarify legal issues.
1992	Boom in State recycling legislation	In 1988, only Washington had recycling legislation mandating a state MSW reduction goal through recycling. By 1992, 15 States had adopted recycling legislation. Today, there are over 7,000 recycling programs, covering one-third of the U.S. population; more than 1,000 bills are proposed per year that endorse some type of recycling law, incentive, or program. Many State goals are to reduce MSW by 50 percent or more by 2000.
1992	Fort Gratiot Sanitary Landfill vs. Michigan Department of Natural Resources	The U.S. Supreme Court ruled that State-imposed waste import restrictions were illegal "economic protectionist" measures that violated the Commerce Clause and were, therefore, unconstitutional. The Court's decision stated that "a State (or one of its political subdivisions) may not avoid the strictures of the Commerce Clause by curtailing the movement of articles of commerce through the subdivisions of the State, rather than through the State itself." The stage was set for a similar ruling in a flow control case.
1994	EPA vs. City of Chicago	In May 1994, the U.S. Supreme Court ruled that the exemption of MSW (from a hazardous waste definition) under the RCRA did not extend to ash. MSW ash must be tested and disposed of in hazardous waste landfills if found to exceed EPA regulations on hazardous wastes under RCRA.
1994	Carbone vs. Clarkstown	Also in May 1994, the U.S. Supreme Court upheld challenges to flow control. As a result, existing flow control contracts could be rendered invalid under specific situations (on a case-by-case basis). Several plants have shut down as a result. The California Supreme Court also ruled against flow control.

1994	New air emission regulations proposed by EPA	In September 1994, the EPA strengthened air emission standards for MSW combustion plants by requiring maximum achievable control technologies (MACT). It also included plants as small as 40 tons per day under regulations.
1995	Senate flow control bill	The Senate passed a flow control bill to grandfather in existing flow control contracts to prevent the major risk of MSW bond default in 14 States.

8. Biomass-Derived Liquid Fuels

Background

The use of biomass to produce liquid fuels has a long history in the United States. Automobile pioneer Henry Ford first championed the use of fuel alcohol in the 1920s. During the 1930s, more than 2,000 Midwestern service stations offered gasoline containing anywhere from 6 to 12 percent ethanol made from corn. Because of its high cost, however, such "power alcohol" disappeared in the 1940s.[60]

The current corn ethanol industry traces its beginnings to the power alcohol movement. Ethanol-gasoline blends were reintroduced in 1979 in response to oil supply disruptions. Today, fuel ethanol manufacturing is the largest consumption sector among the industrial markets for corn.

Fuel Ethanol

Production and Market Conditions

Ethanol is consumed as fuel in the United States primarily as "gasohol"—a blend containing 10 percent ethanol and 90 percent gasoline by volume. Gasohol currently receives a reduction of 5.4 cents per gallon from the Federal motor fuel excise tax rate of 18.4 cents per gallon for regular gasoline. The Energy Policy Act of 1992 (EPACT) amended the Internal Revenue Code to allow extension of the reduction, on a pro rata basis, to gasoline mixtures containing 5.7 and 7.7 percent ethanol by volume. The Internal Revenue Service (IRS) issued a Notice of Proposed Rulemaking on October 19, 1994, which, when finalized, will implement the directives of EPACT and the Omnibus Budget Reconciliation Act of 1993. (See Appendix F for a detailed discussion of these topics.)

The use of ethanol in gasoline blends increases the oxygen content of the fuels and permits more complete combustion of the hydrocarbons in gasoline. For this reason, ethanol is called an "oxygenate." The U.S. Environmental Protection Agency (EPA) mandates the use of oxygenates in winter gasoline formulations in areas of the Nation that are prone to carbon monoxide pollution. The 10 percent, 7.7 percent, and 5.7 percent ethanol proportions, by volume, impart approximate oxygen content levels of 3.7 percent, 2.7 percent, and 2.0 percent to their respective fuel mixtures.

While "neat" ethanol[61] is one of the alternative fuels defined by EPACT, ethanol in this form has to date been consumed only on a limited basis in demonstration vehicles and fleets. Representative "nearly neat" ethanol/gasoline blends are E85 and E95—gasoline mixtures containing 85 and 95 percent ethanol, respectively. Ethanol has been tested extensively in heavy-duty diesel engines, such as those used in buses and heavy trucks, and has displayed favorable environmental characteristics. While E85-powered passenger cars are being used in some government fleets, manufacturers' production quantities have been limited. Ford Motor Company authorized production of a limited number of E85-powered Taurus model cars in 1995 and will make E85 a standard flexible-fueled vehicle option in 1996.[62]

U.S. production of fuel ethanol was about 1.15 billion gallons in 1993 and 1.28 billion gallons in 1994. Ethanol shares the gasoline oxygenate market with methyl tertiary butyl ether (MTBE). Other oxygenate additives

Corn for ethanol production.

[60]National Renewable Energy Laboratory, *The American Farm: Harnessing the Sun to Fuel the World,* NREL/SP-420-5877, DE94000217 (Golden, CO, March 1994).

[61]"Neat" refers to the pure, undiluted form of a mixture.

[62]Alternative Fuels Data Center, "Auto Manufacturers Offer a Variety of AFVs in MY 1995," *AFDC Update* (February 1995), p. 6.

are manufactured,[63] but MTBE and ethanol are the major commercial oxygenate products. A Federal motor fuel excise tax reduction, similar to the one for ethanol, has been provided for ethyl tertiary butyl ether (ETBE) by recent legislation, giving ETBE a reduction at the point of blending with gasoline, based on the volume of ethanol consumed as a feedstock in its production (see Appendix E).

Manufacturing and Distribution Infrastructure

Fuel ethanol manufacturing is the largest industrial market for corn. Sixty-four percent of total U.S. fuel ethanol manufacturing capacity is owned by the three largest manufacturers, and the largest manufacturer owns 50 percent (Table 29).

Most manufacturing is clustered in the Midwest, reflecting close proximity to good supplies of the primary ethanol feedstock, corn. (About 95 percent of ethanol manufacturing is corn-based.) In addition, many plants are located in close proximity to major rivers, making economical shipment by barge of both feedstocks and finished product viable. Wider distribution of the finished fuel is usually made by tank truck, because phase separation (absorption of moisture) can occur during pipeline shipment. In addition to significant consumption near the sources of production in the Midwest, areas prone to winter carbon monoxide pollution from motor vehicles require ethanol as a gasoline additive to comply with EPA standards.

Near-Term Outlook

On June 30, 1994, the EPA issued a Renewable Oxygenate Standard (ROS) final regulation. The ROS, as it was promulgated, would have required that 15 percent of the oxygenates added to reformulated gasoline in 1995 be derived from renewable sources. The regulation would have increased this percentage to 30 percent after January 1, 1996. EPA analysis projected an increase in ETBE plant capacity by the end of 1996.[64] The U.S. Department of Agriculture estimated that full implementation of the ROS would contribute to a net increase in ethanol demand of 500 million gallons annually (about one-third of current capacity) and require an increase in corn production of 200 million bushels.[65] However, the U.S. Court of Appeals, District of Columbia, handed down a stay of implementation of the ROS on September 13, 1994, in response to a suit filed by the American Petroleum Institute and the National Petroleum Refiners Association.

While this development was clearly a setback for the ethanol industry, it may be offset to some extent by the favorable IRS ruling, mentioned above, and recent market factors related to MTBE, including:

- Tight supplies due to caution on the part of MTBE producers in proceeding with plant development and expansion plans as a result of uncertainty
- Higher prices
- Uncertainty of near-term methanol supplies (from which MTBE is manufactured).

Table 29. U.S. Fuel Ethanol Manufacturing Capacity, 1994

Company	State	Process	Production Capacity (million gallons per year)
Archer Daniels Midland Company	IL, IA, ND	Wet/Dry	782
Minnesota Corn Processors	NE, MN	Wet	127
Pekin Energy Company	IL	Wet	100
New Energy Company of Indiana	IN	Dry	89
South Point Ethanol	OH	Dry	74
Midwest Grain Products	KS, IL	--	72
High Plains Corporation	KS, NE	--	54
A.E. Staley Manufacturing Co.	TN	Wet	47
Cargill, Inc.	IA	Wet	29
Chief Ethanol Fuels, Inc.	NE	Wet	28
Other	--	Dry	176
Total			**1,578**

Source: Energy Information Administration, Form EIA-819A, "Annual Oxygenate Capacity Report."

[63]Namely, tertiary butyl alcohol (TBA), isopropyl alcohol (IPA), and ethyl tertiary butyl ether (ETBE).

[64]EPA regulations do not permit the use of ethanol as an oxygenate in RFG because the Reid vapor pressure of gasoline/ethanol blends exceeds allowable limits. Reid vapor pressure is a measure of fuel volatility, which is a factor in ozone pollution.

[65]U.S. Department of Agriculture, Economic Research Service, *Industrial Uses of Agricultural Materials*, IUS-4 (Washington, DC, December 1994), p. 8.

This ethanol-powered truck in Hennepin, Minnesota, was part of a trial and evaluation project managed by the U.S. Department of Energy.

Before the ROS reversal, various estimates placed demand for fuel ethanol as high as 3 billion gallons a year by 1998. Under current circumstances, however, it appears unlikely that demand will exceed 2 billion gallons by the end of the century. The Federal motor fuel tax reduction currently in effect, authorized by the Omnibus Budget Reconciliation Act of 1990 until 2000, has been a subject of continuing controversy and could become a target of Congressional budget reduction.

Other Biomass-Derived Liquid Fuels

Biomass-Derived Methanol

Because it is cheaper to synthesize methanol from natural gas, only a minuscule manufacturing and market infrastructure for biomass-derived methanol currently exists. Most fuel methanol is consumed by fleets in conjunction with alternative fuel / alternative vehicle programs under Federal or State sponsorship in response to clean air laws and regulations.

Biodiesel

Biomass-derived diesel fuel can be synthesized from soybeans, other oil crops, and animal tallow. Like biomass-derived methanol, biodiesel has a very small manufacturing base. It is currently used mainly for demonstration bus fleets. Although biodiesel has good environmental characteristics in terms of particulate matter reduction and fuel oxygenation, its exhaust emissions profile, like those of most alternative fuels, is not flawless. The EPA has not yet granted biodiesel "substantially similar" status, which would likely permit its commercialization on a more significant scale.

Metropolitan buses are a large contributor to particulate matter pollution, a serious health hazard. Demonstration fleets have shown that a 20 to 30 percent mixture of biodiesel with petroleum-based diesel fuel reduces particulate emissions. EPA's Urban Bus Retrofit / Rebuild Program requires bus operators in metropolitan areas with populations of more than 750,000 to operate under tighter particulate emission standards in 1995. The use of biodiesel is one option for compliance with the program. However, the cost of manufacture does not yet permit biodiesel to compete on an equal basis with conventional diesel fuel.

Ethanol Milestones

1876-1908	Ethanol fuel used in automobiles	Otto Cycle (1876) was the first combustion engine designed to use alcohol and gasoline, followed by Henry Ford's Model T (1908), which was designed to use ethanol, gasoline, or any combination of the two fuels.
1940s	First U.S. fuel ethanol plant built	The U.S. Army built and operated an ethanol plant in Omaha, Nebraska, to produce fuel for the army and to provide ethanol for regional fuel blending.
1973	Yom Kippur war, OPEC oil embargo	OPEC raised crude oil prices by 70 percent, embargoed the United States for its support of Israel, and threatened to reduce production by 5 percent per month until Israel withdrew from Palestine.
1974	Oil embargo ends	The embargo and gasoline lines shocked the world, and Project Independence was initiated to review strategic energy options.
1974	Solar Energy Research, Development, and Demonstration Act	The Act (Public Law 93-473) provided legislative support for research and development for the conversion of cellulose and other organic materials (including wastes) into useful energy or fuels.
1977	Food and Agricultural Act	The Act (Public Law 95-113) authorized U.S. Department of Agriculture (USDA) loan guarantees for the first four biomass pilot plants (none actually built) and expanded USDA research for renewable fuels or fossil substitutes.
1978	Energy Tax Act	The Energy Tax Act of 1978 (H.R. 5263) gave a 4-cents-per-gallon exemption from Federal excise taxes to motor fuels blended with ethanol (minimum 10 percent ethanol) and granted a 10-percent energy investment tax credit for biomass-ethanol conversion equipment (in addition to the 10-percent investment tax credit available).
1979	Fuel ethanol blends marketed	Amoco Oil Company began marketing commercial alcohol-blended fuels, followed by Ashland, Chevron, Beacon, and Texaco, which also owned ethanol production facilities.
1979	Interior and Related Agencies Appropriation Act	The Act (Public Law 96-126) appropriated $19 billion for an Energy Security Reserve to stimulate production of alternative fuels, $100 million for product development feasibility studies, and $100 million for cooperative agreements to support commercial development of alternative fuel plants.
1980	First U.S. ethanol survey	The survey found that fewer than 10 facilities existed, producing approximately 50 million gallons of ethanol per year.

1980	Supplemental Appropriation and Rescission Act	The Act (Public Law 96-304) earmarked another $100 million for further feasibility studies and another $200 million for cooperative agreements. The U.S. Department of Energy (DOE) made 47 feasibility study grants during 1980 and 1981, as well as cooperative agreements with ethanol producers.
1980	Crude Oil Windfall Tax Act	The Act (Public Law 96-223) extended the 4-cents-per-gallon Federal excise tax exemption to December 31, 1992, and extended the energy investment tax credit to December 31, 1985. An income tax credit was also provided to alcohol fuel blenders—40 cents per gallon for 190 proof alcohol and 30 cents per gallon for 150-190 proof. The excise tax exemption and the income tax credit were either / or alternatives: both could not be used.
1980	Energy Security Act	The Act (Public Law 96-294) offered insured loans for small ethanol producers (less than 1 million gallons per year), loan guarantees that covered up to 90 percent of construction costs on ethanol plants, price guarantees for biomass energy projects, and purchase agreements for biomass energy used by Federal agencies. It also established the DOE Office of Alcohol Fuels and authorized $600 million for both USDA and DOE for biomass research. Subsequent rescissions altered this allocation to $20 million for USDA and $800 million for DOE to use for alcohol fuel loans. The Consolidated Farm and Rural Development Act of 1980, which rescinded the $505 million allocated to USDA, appropriated $250 million for alcohol loan guarantees that were used to support 12 firms.
1982	Surface Transportation Assistance Act	The Act (Public Law 97-424) raised the gasoline excise tax to 9 cents per gallon and increased the tax exemption for gasohol to 5 cents per gallon (9 cents for fuels containing 85 percent alcohol or more). The blender's income tax credit was increased to 50 cents per gallon for 190-proof alcohol and 37.5 cents for 150-190 proof.
1984	Tax Reform Act	The Act (Public Law 99-198) raised the gasohol exemption from 5 to 6 cents per gallon, with the overall tax unchanged at 9 cents per gallon of retail fuel. The blender's income tax credit was increased to 60 cents per gallon for 190-proof alcohol and 45 cents for 150-190 proof.
1985	Industry shakeout	Of the 163 commercial ethanol plants existing in 1985, only 74 (45 percent) were operating, producing 595 million gallons per year. The high failure rate was partially the result of poor business judgment and bad engineering.
1988	First use of ethanol as an oxygenate	Denver, Colorado, mandated oxygenated fuels for winter use to control carbon monoxide emissions. Other cities followed.
1990	Omnibus Budget Reconciliation Act	The Act (Public Law 101-508) decreased the gasohol tax exemption from 6 to 5.4 cents per gallon. Tax credits for neat ethanol sales remained unchanged at 6 cents per gallon. The expiration date was extended to 2002.

1990	Clean Air Act Amendments	The Amendments (Public Law 101-549) mandated the winter use of oxygenated fuels in 39 major carbon monoxide nonattainment areas (areas where EPA emissions standards for carbon dioxide had not been met) and required year-round use of oxygenates in 9 severe ozone nonattainment areas in 1995.
1990	Ethanol industry changes	Ethanol plants began switching from coal to natural gas and adopting other cost-reducing technologies, estimated to reduce costs as by much as 10 cents per gallon. High-fructose corn syrup prices and markets increased, also encouraging expansion of wet mills and ethanol capacity.
1992	Energy Policy Act	The Act (Public Law 102-486) modified the excise tax exemption to accommodate blends of less than 10 percent ethanol resulting from more sophisticated blending strategies for pollution control. The tax exemption was set at 4.16 cents per gallon for mixtures containing 7.7 percent ethanol and 3.08 cents per gallon for mixtures containing 5.5 percent ethanol.
1994	Favorable Internal Revenue Service ruling	The IRS ruling extended the excise tax exemption and income tax credits to ethanol blenders producing ETBE. Previously, the blended ethanol product had to be sold to final consumers for the credits to be received.
1994	EPA Renewable Oxygen Standard (ROS)	The ROS required that 30 percent of the oxygenates contained in fuels be produced from renewable sources—a provision generally considered a boon for the corn-ethanol industry.
1994	Conversion of corn fiber to ethanol achieved in a commercial facility	New Energy Ethanol Company of Indiana, in cooperation with the National Renewable Energy Laboratory, successfully achieved ethanol production from cellulose. Several other cellulosic ethanol conversion facilities have been proposed, using a wide variety of technologies, but none is commercial yet.
1995	American Petroleum Institute and National Petroleum Refining Association vs. EPA	A U.S. court ruled that the EPA's ROS was an unconstitutional constraint on commerce.
1995	Highest U.S. ethanol production capacity ever	U.S. ethanol production capacity has risen to 1.5 billion gallons per year, primarily through expansions in wet milling capacity. Of the existing capacity, 70 percent is wet milling (low cost with high-value coproducts), and 30 percent is from dry mills (higher cost, limited coproducts).

9. Geothermal

Background

Geothermal energy is the naturally occurring heat from the interior of the Earth. Volcanoes are the most spectacular manifestation of the Earth's capacity to provide heat. Other, less dramatic physical evidence is embodied in geysers, fumaroles,[66] and hot springs. The earliest human use of geothermal energy was for bathing, which has been a cultural phenomenon for millennia. Thermal water has also been used for aquaculture,[67] greenhousing,[68] industrial process heat,[69] and for space heating.[70] Electricity was first produced from geothermal resources at Larderello, Italy, in 1904.[71]

The U.S. geothermal industry has a 45-year history of producing electric power for utilities. Early developments were centered around a geothermal resource in northern California called "The Geysers." The Geysers is the most significant geothermal development in the United States. It produces dry-steam geothermal energy and has been tapped for substantial electrical power output since the 1970s. Pacific Gas & Electric installed the first 10 power plants at the Geysers between 1960 and 1974.

Geothermal power is a commercially proven renewable resource. The industry expanded successfully from its initial site in the United States, the dry-steam fields at The Geysers, to tackle the more challenging hot liquid reserves in other parts of California, Nevada, Utah, and Hawaii (Figures 17 and 18). U.S. plants operate on 19 fields in those States. The generating capacity of geothermal hydrothermal (steam and hot water) grew rapidly in the 1980s, quadrupling between 1980 and 1994. Most of this capacity was installed in the mid- to late 1980s; about half was installed as independently owned projects under the Public Utility Regulatory Policies Act of 1978 (PURPA), while the others are owned by electric utilities. PURPA required utilities to buy electrical power from qualifying facilities (QFs) at the utility's full avoided cost.

In the United States, public sector involvement in the geothermal industry began with the passage of the Geothermal Steam Act of 1970 (Public Law 91-581). This Act authorized the U.S. Department of Interior to lease geothermal resources on Federal lands. The industry was subsequently influenced by other events, including the Organization of Petroleum Exporting Countries (OPEC) embargo of 1973 and the passage of the Federal Geothermal Energy Research, Development and Demonstration Act of 1974 (Public Law 93-410), which established a Federal interagency task force—the Geothermal Energy Coordination and Management Project—providing for research, development, and demonstration of geothermal energy technologies and establishing a loan guarantee program for financing geothermal energy development.

Geothermal Resources

Geothermal energy resources result from complex geologic processes that lead to heat concentration at accessible depths.[72] The different forms of geothermal energy resources—hydrothermal, hot dry rock, geopressured, magma, and earth heat—all result from this

[66]A fumarole is a vent from which steam or gases issue.

[67]W.C. Johnson, *Culture of Freshwater Prawns Using Geothermal Waste Water* (Klamath Falls, OR: Oregon Institute of Technology, Geo-Heat Center, 1978).

[68]K. Rafferty, *Some Considerations for the Heating of Greenhouses with Geothermal Energy* (Klamath Falls, OR: Oregon Institute of Technology, , Geo-Heat Center, 1985).

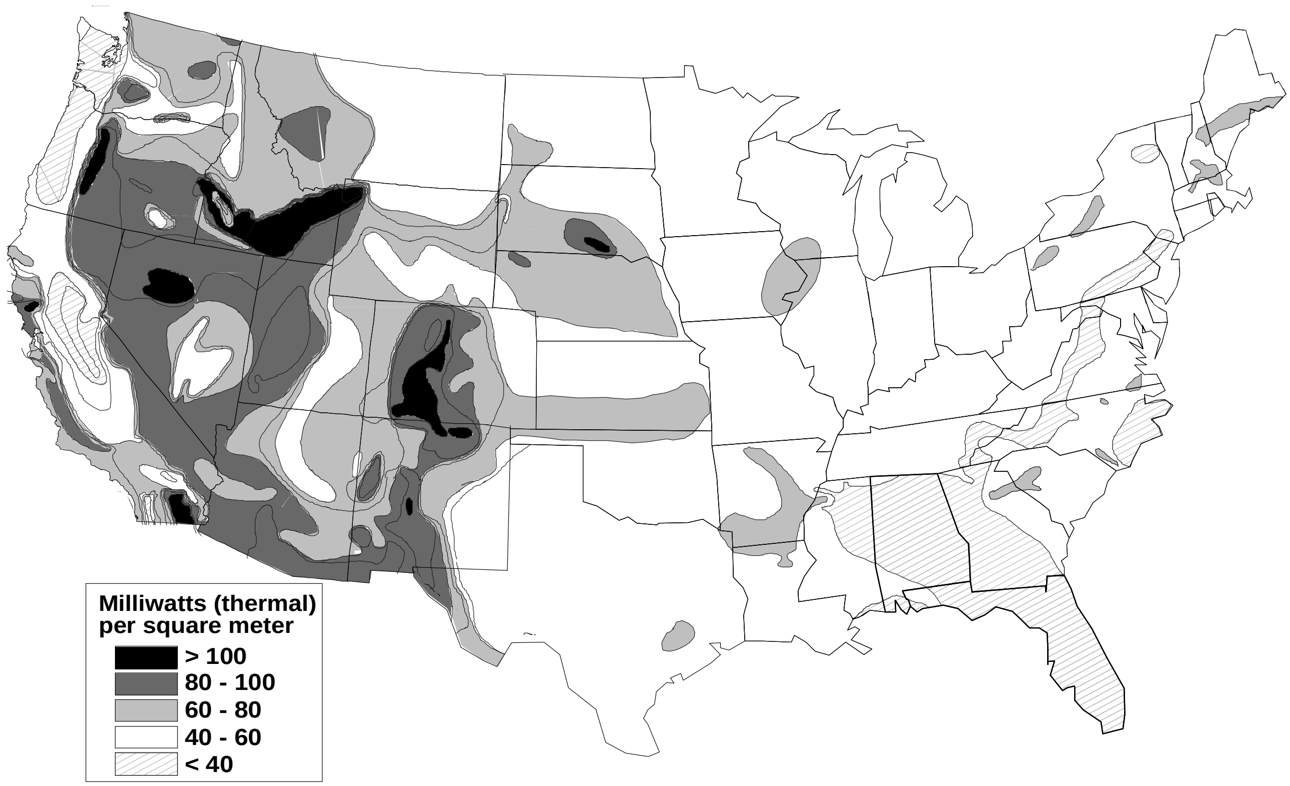
[69]Such as an onion dehydration plant in Brady Hot Springs, Nevada. See J.C. Austin, CH2M Hill, Inc., *Direct Utilization of Geothermal Energy Resources in Food Processing, Final Report*, May 17, 1978 - May 31, 1982, Report No. DOE/ET/28424-6, Cooperative Agreement No. DE-FC07-78ET28424 (May 1982).

[70]Such as the district heating system in Boise, Idaho, developed in the early 1900s and expanded in the 1980s. See P.J. Hanson, Boise Geothermal, *Boise Geothermal District Heating System, Final Report March 1979-September 1985*, Report No. DOE/ET/27053-6, Cooperative Agreement No. DE-FC07-79ET27053 (October 1985).

[71]R.D.P. *Geothermal Energy as a Source of Electricity: A Worldwide Survey of the Design and Operation of Geothermal Power Plants* (061-000-00390-8) (Washington, DC, January 1980), p. 8.

[72]See Appendix G for more information on geological processes and forms of geothermal resources.

Figure 17. Heat Flow Contours of the United States



Note: Drawing not to scale. Heat flow contours are patterned in intervals of 20 milliwatts per square meter (mW/m^2). Highest temperatures will be associated with areas that have both high heat flow and rock strata with high thermal conductivity. The area along the San Andreas fault has moderate to high heat flow. In fact, The Geysers geothermal system is associated with the tectonic effects of the San Andreas fault system. The Sierra Nevada Mountains are notable as one of the lowest heat flow and crustal temperature areas on earth. A milliwatt (thermal) is a unit of power in the metric system, expressed in terms of energy per second. See “Watt (Thermal)” in the Glossary.

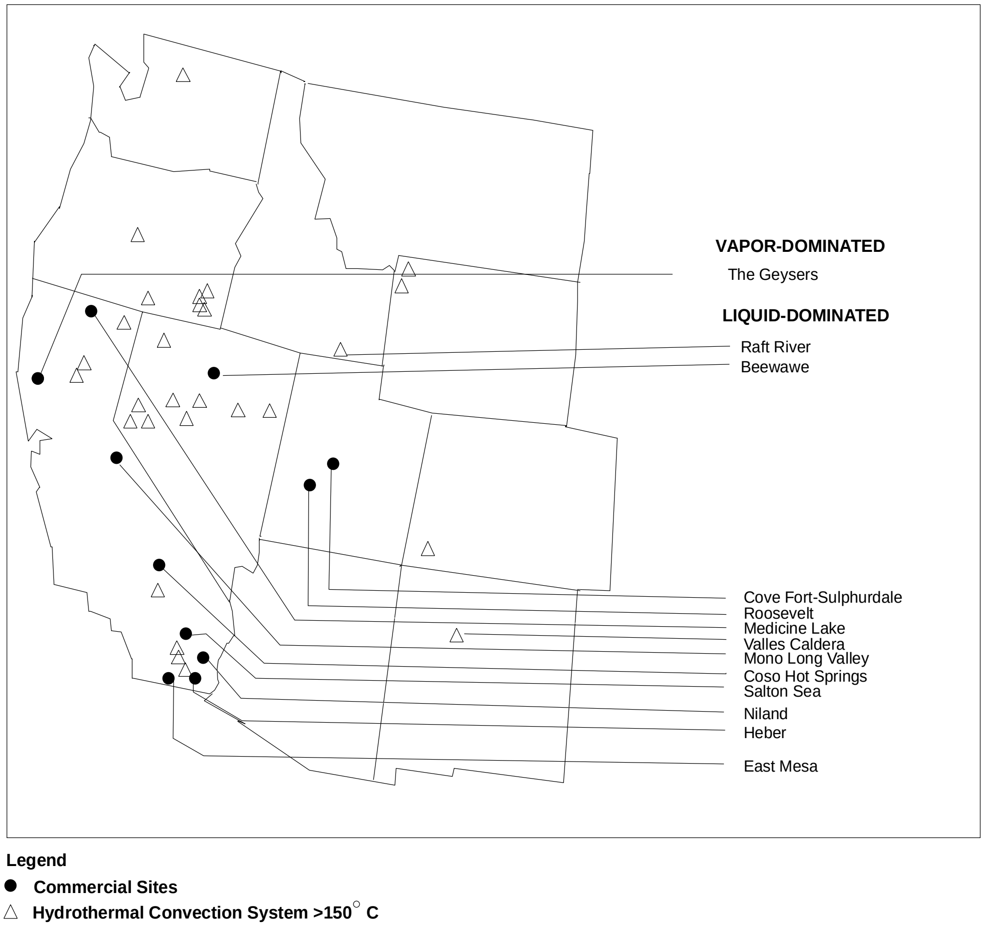
Source: Energy Information Administration, *Geothermal Energy in the Western United States and Hawaii: Resources and Projected Electricity Generation Supplies,* DOE/EIA-0544 (Washington, DC, September 1991); Modified after the *Geothermal Map of North America,* prepared as part of the Geological Society of North America Decade of North America Geology (DNAG), from Blackwell, D.D., and Steel, J.L., *Mean Temperature in the Crust of the United States for Hot Dry Rock Resource Evaluation* (Southern Methodist University, May 1990), pp. 6-8, updated by D.D. Blackwell.

concentration of Earth’s heat in discrete regions of the subsurface. Temperature within the Earth increases with increasing depth (Figure 19). Highly viscous or partially molten rock[73] at temperatures between 1,200 and 2,200ºF (650 to 1,200ºC) is postulated to exist everywhere beneath the Earth’s surface at depths of 50 to 60 miles (80 to 100 kilometers), and the temperature at the Earth’s center, nearly 4,000 miles (6,400 kilometers) deep, is estimated to be 7,200ºF (4,000ºC) or higher. Heat flows constantly from its sources within the Earth to the surface.

Three sources of internal heat are most important: (1) heat released from decay of naturally radioactive elements; (2) heat of impact and compression released during the original formation of the Earth by accretion

[73]Viscous rock is rock that flows in an imperfectly fluid manner upon application of unbalanced forces. The rock will change its form under the influence of a deforming force, but not instantly, as more perfect fluids appear to do.

Figure 18. Selected Geothermal Resource Areas in the Western United States



Note: Drawing not to scale.

Source: Energy Information Administration, *Geothermal Energy in the Western United States and Hawaii: Resources and Projected Electricity Generation Supplies*, DOE/EIA-0544 (Washington, DC, September 1991).

of in-falling meteorites; and (3) heat released from the sinking of abundant heavy metals (iron, nickel, copper) as they descended to form the Earth's core. An estimated 45 to 85 percent of the heat escaping from the Earth originates from radioactive decay of elements concentrated in the crust.[74,75] The remainder results from slow cooling of the Earth, with heat being brought up from the core by convection in the viscous mantle.[76]

The different forms of geothermal resources have different characteristics that are important to geothermal energy development:

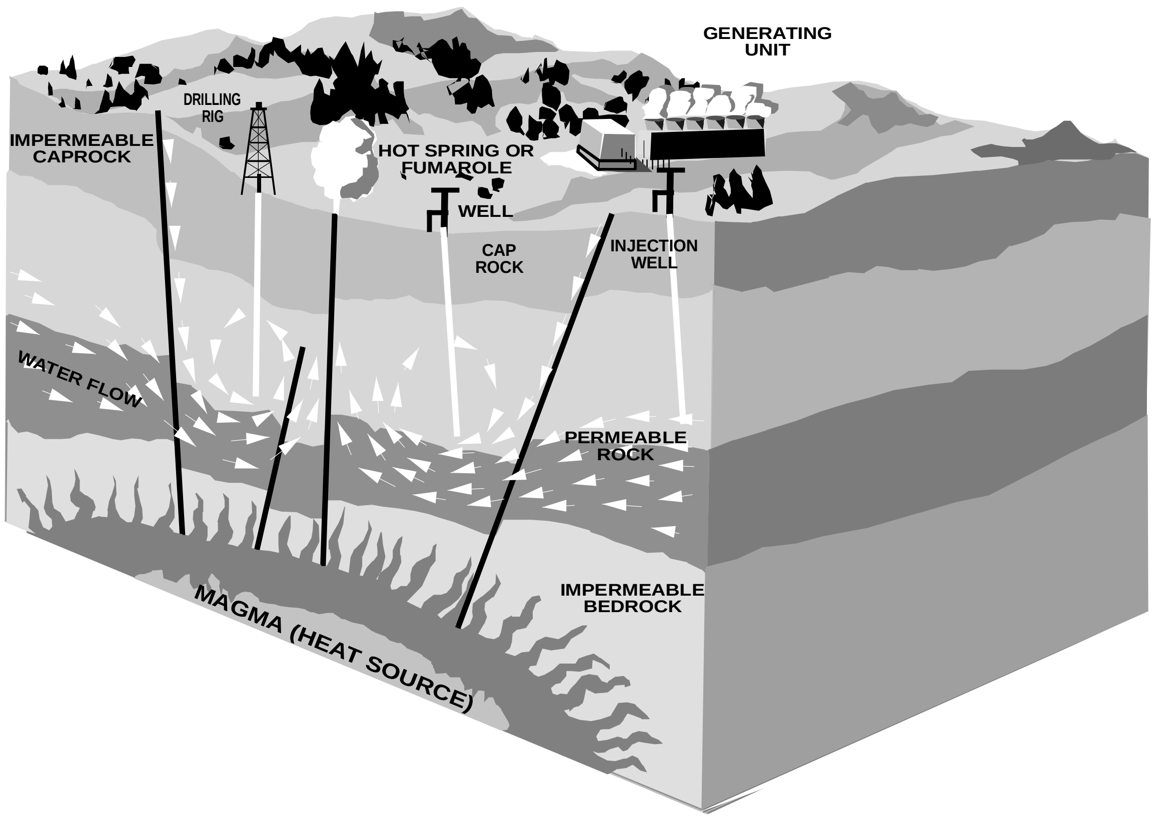
- *Hydrothermal resources* are steam or hot water reservoirs that can be tapped by drilling to deliver heat to the surface for thermal use or generation of electricity. Technologies to tap hydrothermal resources are proven commercial processes. Dry steam resources are relatively rare.

[74]The crust (crustal zones) is the outer layer of the Earth, originally considered to overlay a molten interior, now defined in various ways (lithosphere, tectonosphere, etc.).

[75]M.H.P. Bott, *The Interior of the Earth—Its Structure, Constitution and Evolution* (London, UK: Edward Arnold, 1982), pp. 403.

[76]The mantle is the layer of the Earth lying between the crust and the core. The mantle extends from depths of about 19 miles (30 kilometers) in the continental areas to 1,790 miles (2,800 kilometers), where the core begins.

Figure 19. Schematic of Earth's Interior



Note: Drawing not to scale.

Source: Energy Information Administration, *Geothermal Energy in the Western United States and Hawaii: Resources and Projected Electricity Generation Supplies*, DOE/EIA-0544 (Washington, DC, September 1991).

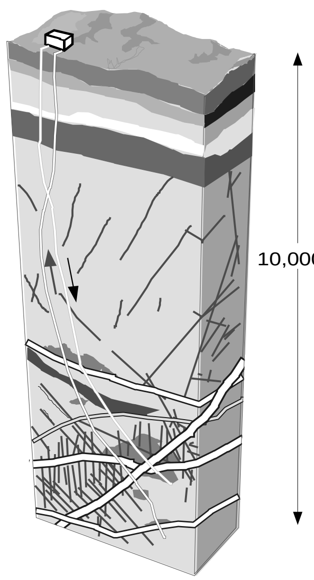
- *Hot dry rock resources* are defined as heat stored in largely impermeable rocks (Figure 20). Access to these resources involves fracturing rock injecting cold water down one well, circulating it through the hot fractured rock, and drawing off the now hot water from another well. Since the current technologies are entering a development phase, this is not a commercial process at this time.

- *Geopressured resources* consist of deeply buried brines at moderate temperature that contain dissolved methane. Three sources of energy are available: thermal, mechanical, and chemical (methane gas). While technologies are available to tap geopressured brines, they are not currently economically competitive. No funds are currently being directed toward accessing these resources.

- *Magma (molten rock) resources* offer extremely high-temperature geothermal opportunities, but existing technology does not allow recovery of heat from these resources.

- *Earth heat* itself can be used as the source and/or sink of heat for the operation of geothermal heat pumps, a proven technology.

Figure 20. Hot Dry Rock Geothermal System Concept for Low-Permeable Formations



Note: Drawing not to scale.
Source: Energy Information Administration, *Geothermal Energy in the Western United States and Hawaii: Resources and Projected Electricity Generation Supplies*, DOE/EIA-0544 (Washington, DC, September 1991).

Infrastructure

Manufacturing Industry

The geothermal manufacturing industry makes use of technologies that had their start in the oil and gas drilling industry and in the traditional electrical power plant industry. The geothermal industry developers have taken these early technologies and improved them to meet the needs of geothermal production.

Many U.S. geothermal developers were involved in technology advances to meet the challenges of new sites and the extent of their recoverable energy. The challenges also include lower temperature liquid resources and dealing with highly corrosive and scale prone liquid brines. Advances have resulted in lower capital and operating costs, reduced leadtimes for plant construction, and additional geographic regions with available resources.

Developers

There are approximately 14 active geothermal developers in the United States. Historically, most nonutility geothermal resource developers viewed their business as exploring, developing, and selling steam to utilities. After the passage of PURPA, however, developers began to build their own generating plants, selling the generated electricity to utilities under PURPA rules. Several developers began to use proprietary conversion technologies to exploit hot water geothermal reservoirs with very corrosive liquid brines.

Many of the original, large, diversified players, particularly oil or minerals companies, have now left the geothermal business. Since 1986, a class of medium-sized firms has emerged, outgrowing the small entrepreneurial classification through substantial growth of individual companies, mergers, and acquisitions.

Electric Utilities

Most direct utility involvement in geothermal electricity generation in the United States is at The Geysers resource area. Pacific Gas & Electric Company is the utility leader in geothermal development, with more than 1,200 megawatts of capacity. Other utilities owning geothermal capacity in the United States include the Northern California Power Agency, the Sacramento Municipal Utility District, and the Utah Municipal Power Authority. Other utilities purchasing electricity or steam for power production from geothermal resources include Southern California Edison Company, Sierra Pacific Power Company, and Hawaii Electric Light Company. Several utilities are active in geothermal development through for-profit subsidiaries in the independent power marketplace.

Access to utility transmission systems has been an important asset to geothermal resource development. Where access has not been available, several projects have installed their own plant transmission outlet. In the future, electric utilities are expected to prearrange power purchases from planned geothermal projects. For example, the Bonneville Power Administration has offered power contracts for geothermal development at two sites in Oregon, and other developers expect to sell output to the Los Angeles Department of Water and Power.

Current Status

Geothermal development overall has declined in recent years. As the prices of fuels used in competing generating technologies—primarily natural gas—decreased, so too has the competitive viability of geothermal energy. Another major reason for the slowdown in geothermal development is slow growth in demand for electricity. The primary geothermal resources exist in

Overview of The Geysers, Unit 13, a 135-megawatt power plant with Stretford primary abatement system.

the Western United States, a region where there has been a surplus of generating capacity for a number of years. Moreover, due to relatively high electricity prices, California is facing significant competitive market forces. The utility sector, as a whole, is facing a serious reevaluation of its market. Contractual arrangements that would have been considered routine 3 years ago are not acceptable under current conditions. Consequently, a main source of support for geothermal resource development has been undermined, posing a threat to continued growth in the geothermal arena for geothermal electricity generation.

Economics

Before the passage of PURPA, there was little if any incentive for public and private regional electricity monopolies to purchase power generated by independent producers. Under the provisions of PURPA, however, utilities were required to buy power from independent producers that are QFs at the utility's avoided cost (the amount the utility would otherwise have to spend to generate or procure power).

One of the PURPA contract options provided a period of fixed payments for both energy and capacity in order to allow projects to obtain financing. At the time of the issuance of these contracts, especially the Interim Standard Offer No. 4 (ISO4), oil prices were near a historic high and were expected to continue to increase. The geothermal power industry executed almost 30 of these contracts for over 600 megawatts of additional capacity in California. Under the provisions of the ISO4 contracts, a facility would receive energy payments for 10 full years, based on the long-run avoided costs to the utility anticipated at the time the contract was awarded.

The end of the 10-year period is now approaching for many projects. At that time, energy payments will be determined by short-run avoided costs for the remainder of the contracts. Mid-1990s avoided costs, which are largely tied to the price of natural gas, are considerably lower in current dollars than the avoided costs calculated in the mid-1980s. Therefore, many of the projects built under ISO4 contracts may no longer be economically viable.[77] The independent power industry in California, including geothermal stakeholders, has

[77]C.L. Wardlow, "The History and Future of Geothermal Energy as Independent Power Producer," *Geothermal Resources Council Transactions*, Vol. 19 (October 1994), p. 17.

approached the utilities and the California Public Utility Commission to renegotiate the contracts.

Hydrothermal energy, which is used primarily to produce baseload electricity, competes with other baseload electricity power production, such as hydropower. Feasibility studies are being conducted to assess the potential for hydrothermal electricity to be used in other dispatching modes, but natural-gas-fired facilities—with generating costs of 3 to 4 cents per kilowatthour—would appear to be better suited.

Competition with other energy sources is an important factor for geothermal developers. Many States are experimenting with competitive bidding systems as a means of awarding power purchase contracts, with potentially adverse impacts on renewables. Currently, only five new geothermal electric power plants with 105 megawatts total generating capacity are planned for operation by 1999[78]—down from 517 megawatts being planned in 1994 for the same time period. The three primary drivers of growth during the 1980s have faded: demand for new capacity, ISO4 contracts, and additional capacity at The Geysers. In addition, as power sales agreements end, as utilities terminate their contracts with independent power producers, and as avoided cost rates in California reach equilibrium with current natural gas prices, other geothermal plants may shut down.

Technological Issues

Direct extraction of energy from magma has been the subject of research for many years.[79] While a single volcano contains a huge concentration of energy within a relatively small geographical area, formidable technical problems prevent the exploitation of magma resources. The very high temperatures encountered around magma bodies can cause drilling equipment to fail. The reaction of dissolved gases to a sudden release of pressure by the drillhole can be explosive. Even if some method of penetrating the rock immediately adjacent to the magma body is found, a heat extraction technology must be developed. The underlying assumption is that the great quantity of heat within magma bodies will yield sufficient quantities of energy to justify the anticipated high cost of extraction.[80] However, commercial development of magma resources remains in the distant future.

Research on the extraction of energy from geopressured geothermal resources culminated in the construction of one small demonstration plant (1 megawatt capacity) near Pleasant Bayou, Texas, in 1989. The plant was operated for 1 year using methane from the brine to drive a gas turbine, and heat from the brine to power a binary cycle generator. To support a commercially viable enterprise, the pressurized fluid must be sufficiently hot and must contain a sufficient quantity of dissolved methane, and the reservoir must be sufficiently large and permeable to allow adequate production of fluids over an extended period of time. In addition, the deep wells required to extract the highly pressurized brines are very expensive. These issues have led to reasoned speculation that only a limited portion of U.S. geopressured resources may be economically exploitable in the foreseeable future.

Hot dry rock technology has progressed beyond the feasibility stage. Research has shown that the resource can be reached at moderate depths, that hydraulic fracturing can be effectively used to create man-made reservoirs in hard rock, and that heat can be extracted from such reservoirs, using water as a working fluid. However, the geology of hot dry rock resource areas varies, and the technology to develop manmade reservoirs in different geologic conditions is unproven and potentially expensive. Although hot dry rock resources have the potential to yield enormous quantities of energy, the path to exploitation still requires significant technological developments.

The term “heat mining” was coined to describe the process of extracting heat energy from hot dry rock.[81] Three requirements must be satisfied before “heat mining” will be commercially viable: (1) the development of inexpensive high-temperature hard-rock drilling techniques, (2) improvements in three-dimensional rock fracturing, and (3) mastery of methods for maintaining low-impedance fluid circulation through the fracture system. The DOE geothermal programs is reviewing the status of hot dry rock research in the context of industry interest in the resource.

A major technical obstacle to heat mining is the development of a method for extracting heat from deeply buried rock. The hot dry rock resource base typically occurs in igneous and metamorphic terrains containing rocks that lack sufficient matrix or fracture permeability

[78]Unalaska, AK—12 megawatts; Fishlake, NV—14 megawatts; Dixie Valley, NV—19 megawatts; Bend, OR—30 megawatts; Glass Mountain, CA—30 megawatts.

[79]H.C.H. Armstead, *Geothermal Energy: Its Past, Present, and Future Contribution to the Energy Needs of Man,* Second Edition (London, UK: E.F. Spoon, 1983), p. 361.

[80]National Research Council, *Geothermal Energy Technology: Issues, Research and Development Needs, and Cooperative Arrangements* (Washington, DC: National Academy Press, 1987).

[81]H.C.H. Armstead, *Geothermal Energy: Its Past, Present, and Future Contribution to the Energy Needs of Man*, p. 348.

for the migration of fluids. Under those circumstances, it is necessary to create an extensive interconnected fracture system that will allow sufficient fluid circulation, removal, and reinjection. Recent tests have shown that hydraulically created fracture systems can produce adequate circulation. However, after a permeable zone has been created, water must be injected into the formation, and the quantity of water needed is not certain, nor is it known to what extent circulating fluids will precipitate scale in fracture systems.

Since operating experience for most geothermal technologies is limited, reservoir life expectancies are an important unknown.[82] Hydrothermal resources can be depleted on a local scale, and several fields—including Wairakei (New Zealand), Larderello (Italy), The Geysers (California), and Heber (California)—have had slow declines in temperature and pressure over time. The decline in generating capacity and electricity production at The Geysers is shown in Figure 21. While factors affecting the depletion rates are known, their effect at each field is not—nor is it clear whether the fields will ever recover. Thus, reservoir management techniques are a key area for technology development.

Finally, current drilling technology for the development of hydrothermal resources is both expensive and risky for the driller. Reducing the cost and the risk is likewise critical.

Environmental Issues

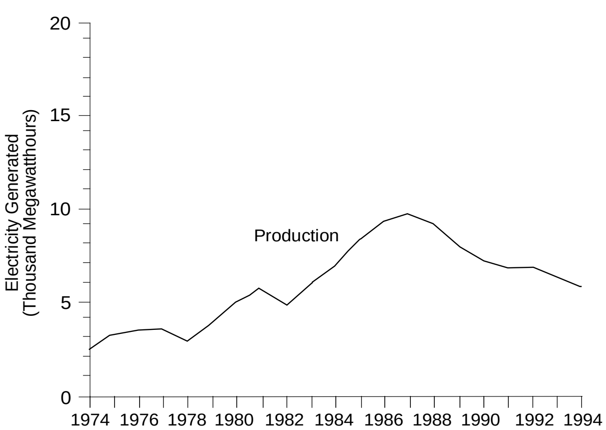
Environmental considerations provide a significant impetus for the development of geothermal resources. Hydrothermal geothermal technology is relatively "clean," with minimal adverse impact on the environment.[83] Since geothermal development entails no combustion, its atmospheric emissions are limited to the dissolved gases that are released during depressurization in open-cycle systems. Carbon dioxide is released in direct steam and flash systems at a typical rate of 55.5 metric tons per gigawatthour, or at approximately 11 percent of the rate for gas-fired steam electric plants. Moreover, some recent plants, particularly those at Coso Hot Springs, California, reinject noncondensible gases into the reservoir, limiting emissions of greenhouse gases to well testing and unplanned outages. For projects that use lower temperature, binary-cycle technology, emissions from the closed-cycle systems are negligible. Similarly, the technologies being developed to exploit hot dry rock and magma resources will not entail any significant emissions of carbon dioxide.

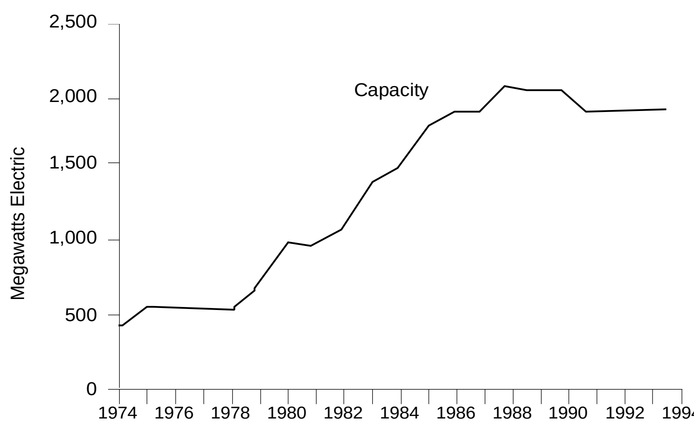
Environmental issues that could adversely affect the future development of geothermal resources include water requirements, air quality, waste disposal, subsidence, noise pollution, and location.

Water Requirements

Some geothermal power plants use large quantities of cooling water.[84] For example, a 50-megawatt water-cooled binary-cycle plant requires more than 5 million gallons of cooling water per day (100,000 gallons per megawatt per day). Since many geothermal resources are located in arid regions where water is a scarce and regulated commodity, long-term access to water could be an important constraint on their development. At

Figure 21. Annual Geothermal Electricity Production and Capacity at The Geysers, 1974-1994





Source: Energy Information Administration, Form EIA-759, "Monthly Power Plant Report."

[82]S. Williams and K. Porter, *Power Plays: Geothermal* (Washington, DC: Investor Responsibility Research Center, 1989), pp. 165-181.
[83]U.S. Department of Energy, *Geothermal Progress Monitor*, No. 12 (December 1990), pp. 15-16.
[84]S. Williams and K. Porter, *Power Plays: Geothermal* (Washington, DC: Investor Responsibility Research Center, 1989), p. 178.

The Geysers in California, for example, it is believed that production declines could be substantially reversed by injection of water from external sources; however, competition for limited local water supplies has prevented recharging of the aquifer. Currently, a pipeline to bring treated sewage effluent from 26 miles away, and from Clear Lake, is under construction. The fluids will be injected into one corner of the geothermal reservoir.

Air Quality

There are no air emissions where closed-loop binary technology is used, because the system does not allow exposure of the hydrothermal fluid to the atmosphere. However, naturally occurring chemical compounds may be released into the atmosphere as a byproduct of the extraction of geothermal energy at sites using flash steam technology for energy conversion,[85] including varying concentrations of hydrogen sulfide, hydrogen chloride, carbon dioxide, methane, ammonia, arsenic, boron, mercury, and radon. Emissions of hydrogen sulfide are often a concern at steam and flash plants, because the gas has a characteristic "rotten egg" odor at low concentrations, and at high concentrations it is toxic. Air quality standards can be met inexpensively by installing hydrogen sulfide abatement systems, which range in cost from 0.1 to 0.2 cents per kilowatthour of electricity generated. Noncondensible gas emissions such as carbon dioxide and hydrogen sulfide can be reduced by reinjection into the reservoir, but the long-term effects of this practice on the geothermal reservoir are not known.

Waste Disposal

To date, all waste streams from geothermal facilities in California have satisfied State standards through either treatment or emission control. Research on methods to alleviate disposal problems is continuing. At some sites, such as the Salton Sea field in California, geothermal fluids can contain large quantities of dissolved solids. The energy extraction process produces a heat-depleted liquid stream that must be disposed of in accordance with the appropriate regulations. Most often, the liquid is reinjected as part of the total reservoir management strategy. In the Imperial Valley, California, high-salinity brines are processed by flash crystallizers, which produce sludge containing potentially toxic heavy metals such as arsenic, boron, lead, mercury, and vanadium.[86] For example, a 34-megawatt double-flash geothermal power plant tapping the high-temperature resource in the Imperial Valley could produce up to 50 tons of sludge every 24 hours.[87] Valuable metals might be extracted from such sludge before its disposal, and this option has been explored at some Imperial Valley projects. DOE research and development efforts are investigating the use of bacteria to remove heavy metals from the sludge materials. Some hydrogen sulfide abatement systems produce elemental sulfur that is sold or hauled away by sulfur producers.

Disposal problems become much more difficult when the waste is toxic. Federal statutes establish land disposal (including reinjection) as the least desirable method of disposal. The Hazardous and Solid Waste Amendments (Public Law 98-616) to the Resource Conservation and Recovery Act (Public Law 94-580) mandate pretreatment of toxic waste to minimize hazards to human health and the environment.

Subsidence and Noise Pollution

Subsidence (sinking land surface) and noise pollution have been avoided or controlled at existing U.S. geothermal energy facilities. Noise from power generation equipment is routinely reduced by blanketing and insulating. Development of resources near population centers may require the type of noise abatement measures used by the oil drilling industry for town-site drilling.

Location Issues

Many of the most promising geothermal resources are located in or near protected areas such as national parks, national monuments, and wilderness, recreation, and scenic areas. The average amount of surface area disturbed for the development of geothermal resources is slight in comparison with other forms of energy extraction. The disturbance usually takes the form of clearcutting of vegetation, grading, and road paving for well pads, pipelines, transmission lines, and generation facilities. Erosion and landsliding may be a problem, depending on the local terrain.

Geothermal resource development in Hawaii, although technologically promising, has been intensely opposed by some environmental and public interest groups, claiming that such development would do irreparable damage to the tropical rain forest while violating local religious beliefs and cultural mores. The controversy has slowed the pace of development in Hawaii.

[85]H.C.H. Armstead, *Geothermal Energy: Its Past, Present, and Future Contribution to the Energy Needs of Man*, Second Edition (London, UK: E.F. Spoon, 1983), p. 330.

[86]H.C.H. Armstead, *Geothermal Energy: Its Past, Present, and Future Contribution to the Energy Needs of Man*.

[87]National Research Council, *Geothermal Energy Technology: Issues, Research and Development Needs, and Cooperative Arrangements* (Washington, DC: National Academy Press, 1987).

Geothermal Milestones

Early 1900s	First geothermal electricity commercialization	Conversion of high-grade hydrothermal resources to electricity began in Italy in the early 1900s.
1960	U.S. commercialization	The first commercial-scale development tools were placed at The Geysers in California, a 10-megawatt unit owned by Pacific Gas & Electric.
1970	Reinjection of geothermal fluids	Injection of spent geothermal fluids back into the production zone began as a means to dispose of waste water and maintain reservoir life.
1972	Deep well drilling	Technology improvements led to deeper reservoir drilling and access to more resources.
1977	Hot dry rock demonstrated	In 1977, scientists developed the first hot dry rock reservoir at Fenton Hill, New Mexico.
1978	Federal research and development (R&D) funding exceeds $100 million	U.S. Department of Energy (DOE) funding for geothermal research and development was $106.2 million (1995 dollars) in fiscal year 1978, marking the first time the funding level surpassed $100 million. It remained above $100 million until fiscal year 1982, when it was reduced to $56.4 million (1995 dollars). Currently, the budget is in the $30 million to $40 million range.
1978	Public Utility Regulatory Policies Act (PURPA) enacted	PURPA mandated the purchase of electricity from qualifying facilities (QFs) meeting certain technical standards regarding energy source and efficiency. PURPA also exempted QFs from both State and Federal regulation under the Federal Power Act and the Public Utility Holding Company Act.
1980	First commercial binary system	The first commercial-scale binary plant in the United States, installed in Southern California's Imperial Valley, began operation in 1980.
1980s	California Standard Offer Contracts	California's Standard Offer Contract system for PURPA QFs provided renewable electric energy systems a relatively firm and stable market for output, allowing the financing of such capital-intensive technologies as geothermal energy facilities.
1982	Hydrothermal generating capacity of 1,000 megawatts	Geothermal (hydrothermal) electric generating capacity, primarily utility-owned, reached a new high level of 1,000 megawatts.

1989	Geopressured power plant demonstrated	In 1989, DOE and the Electric Power Research Institute operated a 1-megawatt demonstration plant in Texas, extracting methane and heat from brine liquids.
1990	Drop in Federal funding for geothermal R&D to $15 million	DOE funding for geothermal energy research and development declined throughout the 1980s, reaching its low point in fiscal year 1990.
1991	Magma drilling project reaches a depth of 7,588 feet	The world's first magma exploratory well was drilled in the Sierra Nevada Mountains to a depth of 7,588 feet. It did not encounter magma at that depth inside the caldera.
1994	Industry consolidates and looks at new markets	California Energy became the world's largest geothermal company through its acquisition of Magma Power. Near-term international markets gained the interest of U.S. geothermal developers.
1985-95	Capacity outside The Geysers exceeds 1,000 megawatts	Since 1985, U.S. geothermal developers have added nearly 1,000 megawatts of geothermal electric generating capacity outside The Geysers.
1995	Worldwide geothermal capacity of 6,000 megawatts	Worldwide geothermal capacity currently totals 6,000 megawatts in 20 countries.

10. Wind

Introduction

Wind energy is a form of solar energy. Winds are created by uneven heating of the atmosphere by the sun, the irregularities of the Earth's surface, and rotation of the Earth. As a result, winds are strongly influenced and modified by local terrain, bodies of water, weather patterns, vegetative cover, and other factors. This wind flow, or motion energy, when "harvested" by wind turbines, can be used to generate electricity.

Recent studies have shown that there is sufficient wind resource in the United States potentially to develop electricity generating capacity roughly equivalent to twice the amount of existing U.S. generating capacity.[88] However, given economics, land use, the intermittent nature of wind energy, and other constraints, the usable portion of this resource is considerably less. Wind energy technology has progressed dramatically from the early days of California wind farms. Largely through a combination of improved design, accumulated operating experience, and better siting, wind turbines have established a track record of solid reliability and declining cost.[89] Yet the integration of wind capacity into electric utility systems continues to be hampered by a number of barriers, including the current and projected low cost of electricity from natural-gas-fired power plants, the intermittent nature of wind, the lack of data on viable wind resource areas, the distance of wind resources from demand centers, relatively high financing costs for wind energy projects, and overall reliability problems for individual utilities as wind capacity begins to increase its share of total generating capacity.

Background

Wind-based electricity generating capacity has increased markedly in the United States since 1970, although it remains a small fraction of total electric capacity. Technological improvements in wind turbines have helped reduce capital and operating costs. Some new turbines are reported to generate electricity for less than 5 cents per kilowatthour.[90] Although there are several constraints limiting wind energy's contribution to the U.S. energy supply, significant wind energy resources, some of which are currently economical, are located near existing high-voltage transmission lines, resulting in large potential wind energy capability.

Wind is an emerging renewable energy resource that produces no air or water pollution, involves no toxic or hazardous substances, and poses minimal threats to public safety. These and other potential benefits have prompted encouragement of wind energy projects by means of Federal and State tax credits, including a tax credit of 1.5 cents per kilowatthour established by the U.S. Congress as part of the Energy Policy Act of 1992 (EPACT).[91]

Major U.S. wind energy development to date has been in areas such as the Altamont and Tehachapi passes in California, which are characterized by favorable wind resources, relatively high-priced long-term power purchase contracts from utilities, and close proximity to existing electricity transmission corridors. In 1994, California had about 16,000 operating wind turbines, which produced approximately 3.5 billion kilowatthours of electricity.[92] As the cost of wind generating equipment declines and performance improves, interest in deploying significant amounts of wind energy elsewhere in the United States is expected to increase.

This chapter provides an overview of wind energy resources in the United States. Proximity of favorable sites to transmission lines and possible constraints on their use in the form of land-use restrictions and environmental exclusions are examined. State-level activity related to wind development initiatives is reviewed, and estimates of the potential usable resources and electric generation capability are presented in terms of land availability for wind development.

[88]J.P. Doherty, Energy Information Administration, "U.S. Wind Energy Potential: The Effect of the Proximity of Wind Resources to Transmission Lines," *Monthly Energy Review* (Washington, DC, February 1995), pp. vii-xiv.

[89]Union of Concerned Scientists, *Powering the Midwest: Renewable Electricity for the Economy and the Environment* (Washington, DC, 1993).

[90]Assuming 13-mile-per-hour winds and typical utility financing arrangements.

[91]Energy Policy Act of 1992, Public Law 102-485, Section 1212, 42 U.S.C. 13317, enacted October 24, 1992.

[92]Energy Information Administration, *Annual Energy Review 1994*, DOE/EIA-0384(94) (Washington, DC, July 1995).

Wind as a Renewable Energy Resource

Wind resources at particular sites are described in terms of wind power classes that range from class 1 (the least amount of energy) to class 7 (the greatest amount of energy). This classification scheme takes into account three factors that influence the energy available from the wind: the variability of wind speed (how widely and how often the wind speed varies), the average wind speed, and the average density of the air. The effect of these three factors is expressed as the wind power density (in watts per square meter of turbine rotor swept area) or its equivalent mean (average) wind speed (shown at hub heights of 10 and 50 meters in Table 30).[93]

Other things being equal, a site with steady winds may yield more energy than another location with the same average wind speed but more variable winds. Likewise, higher average wind speeds and air densities usually yield more energy than lower ones. Because air density decreases with altitude, somewhat higher average wind speeds are required at high altitudes to yield the same energy as lower altitude sites with lower average wind speeds. On the other hand, trees, plants, buildings, and topographical irregularities tend to impede the flow of air near the ground and thus reduce wind speed. Consequently, wind power turbines are mounted on towers to raise them well above ground level.

Wind resource maps usually identify areas by wind power class. In general, areas identified as class 4 and above are regarded as potentially economical for wind energy production with current technology. Nevertheless, some areas identified with class 3 wind resources are being developed in the United States.

Many regions of the country offer at least some usable wind resources. The Great Plains States have abundant wind resources, followed by other parts of the Midwest, the West, and the Northeast. Although there is some potential for wind energy development in the South, the wind resources there are not as significant as in the other regions of the United States.

Generating Power Potential and Land Available for Wind Development

The availability of wind resources for development in close proximity to transmission lines is plentiful. There is a total potential power output of 734,073 megawatts from wind available for development in the contiguous United States[94] on the 625,488 square kilometers of land in the contiguous United States having class 3 or greater wind resources and within 10 miles of transmission lines.

Table 30. Classes of Wind Power at Heights of 10 and 50 Meters

Wind Power Class	Wind Speed (meters per second)	Wind Power Density (watts per square meter of rotor-swept area)	Wind Speed (meters per second)	Wind Power Density (watts per square meter of rotor-swept area)
	10 Meters		50 Meters	
1	0.0-4.4	0-100	0.0-5.6	0-200
2	4.4-5.1	100-150	5.6-6.4	200-300
3	5.1-5.6	150-200	6.4-7.0	300-400
4	5.6-6.0	200-250	7.0-7.5	400-500
5	6.0-6.4	250-300	7.5-8.0	500-600
6	6.4-7.0	300-400	8.0-8.8	600-800
7	7.0-9.4	400-1,000	8.8-11.9	800-2,000

Source: Pacific Northwest Laboratory, *Wind Energy Resource Atlas of the United States*, DE86004442 (Golden, CO: Solar Energy Research Institute, October 1986), p. 3.

[93]Pacific Northwest Laboratory, *Wind Energy Resource Atlas of the United States*, DE86004442 (Golden, CO: Solar Energy Research Institute, October 1986), p. 2.

[94]National Renewable Energy Laboratory, *U.S. Wind Reserves Accessible to Transmission Lines*, Draft DOE Task 94-001 (Golden, CO, September 1994), supported by the Energy Information Administration.

In the North Central region, 318,813 megawatts of potential wind power output is available, assuming class 3 and above wind development, the highest for any region in the United States (Table 31). Kansas and Texas, followed by North Dakota, have the greatest potential power output for wind generating capability. The North Central region also has the most land (264,968 square kilometers) available for potential wind development within 10 miles of transmission lines. Texas, Kansas (South Central region), and Nebraska (North Central region) are the States with the greatest amount of land available within 10 miles of transmission lines for potential wind development.

Wind Energy in the U.S. Electricity Supply

Until 1970, facilities powered by wind were small, isolated, experimental, and/or disconnected from electric power networks. By the end of 1990, wind electric generation capacity in the United States had grown to 2,267 megawatts. In 1994, wind electric generation capacity dropped to 1,745 megawatts, largely because of the retirement of several wind turbines in California. The 1994 total was less than 2 percent of the total renewable electric generating capacity of 94,826 megawatts and less than 0.3 percent of U.S. total electric generating capacity in 1994. The American Wind Energy Association estimates that wind electric generation in the United States reached 3.5 billion kilowatthours in 1994, up more than 25 percent from 1992-1993, and double the output of the late 1980s. Among electric utilities, Pacific Gas & Electric is one of the largest purchasers of wind-generated electricity. That electricity is produced from 660 megawatts of nonutility-owned nameplate capacity.[95]

Improvements in Wind Energy Technology

Wind energy technology has improved considerably since the 1970s. Initial federally funded research focused on large machines of 1 to 5 megawatts capacity that operated at a constant speed as wind speed varied. The high unit costs of the machines and their unsatisfactory performance led to their gradual abandonment as the industry turned to smaller wind turbines, resulting in a dramatic decrease in the cost per kilowatt of wind capacity. The cost of wind energy, estimated at 50 cents per kilowatthour in 1980, dropped to a range of 5 to 7 cents per kilowatthour by the end of 1993.[96]

Today, installed grid-connected wind turbine capacity worldwide totals roughly 4,000 megawatts.[97] Installed capacity includes intermediate-size turbines (100 to 400 kilowatts) and some small turbines (1 to 50 kilowatts). Small turbines have proven to be reliable in off-grid applications and now compete in markets for remote power supply worldwide. These machines usually deliver direct current (DC) power for battery charging, water pumping, refrigeration, and other uses.

There are two types of wind turbine design: the horizontal-axis wind turbine, which resembles a windmill, and the vertical-axis wind turbine, which resembles an upright eggbeater. Horizontal-axis wind turbines, the most commonly used, capture the wind's energy with a rotor, usually consisting of two or three blades mounted on a shaft (Figure 22). The rotating shaft is connected to a generator to produce electricity. New wind turbines incorporating incremental improvements in design and construction have continued to reduce the cost of wind energy. Among these features are improved blades, variable-speed generation, simplified mechanisms, state-of-the-art controls, and aerodynamic braking to protect turbines in high winds. The new designs offer improved performance in the form of better energy capture, reduced stress on machine components, and longer life for turbine drive train hardware.

Wind Development Costs

Technological improvements have reduced the capital costs and operating and maintenance costs associated with wind energy development. Several of the new turbines, which range in capacity from 275 to 600 kilowatts, reportedly produce electricity for as little as 5 or less per kilowatthour.[98,99,100] The Electric Power Research Institute (EPRI) currently estimates that by the

[95]Information obtained from Pacific Gas & Electric Company by telephone, August 16, 1995.

[96]Costs for 1993 are estimated for 100 225-kilowatt wind turbines with operating lives of 30 years, total capital costs of $23.6 million ($1,049 per kilowatthour), and operating and maintenance costs of 1 cent per kilowatthour. For more information, see U.S. Department of Energy, *Wind Energy Program Overview Fiscal Year 1993*, DOE/CH10093-279 (Washington, DC, May 1994), p. 3; and U.S. Department of Energy, "Wind Technology Characterization," internal review document (December 9, 1993).

[97]International Energy Agency, *CADDET Mini Review: Wind Energy* (Oxford, United Kingdom, April 1995).

[98]"Competitive Wind Energy," *EPRI Journal*, Vol. 18, No. 8 (December 1993), p. 2.

[99]"Wind Systems for Electrical Power Production," *Mechanical Engineering* (August 1994), p. 75.

[100]Assuming 13-mile-per-hour winds and typical utility financing arrangements.

Table 31. Land Available for Potential Wind Development by Region and State, and Average Megawatts of Wind Generating Capability

Regions/States	Moderate Land Use and Environmental Restrictions, Within 10 Miles of Transmission	
	Area Exposed to Wind (square kilometers)	Potential Power Output at a 50-Meter Hub Height (megawatts)
Northwest	**79,311**	**101,383**
Idaho	1,667	2,151
Montana	37,028	43,753
Oregon	2,063	2,724
Washington	2,454	3,417
Wyoming	36,099	49,339
North Central	**264,968**	**318,813**
Iowa	42,425	46,898
Minnesota	43,520	54,020
Nebraska	67,614	72,510
North Dakota	59,125	81,342
South Dakota	52,284	64,043
Great Lakes	**14,524**	**14,990**
Illinois	5,753	5,926
Indiana	27	28
Michigan	3,915	4,063
Ohio	333	343
Wisconsin	4,496	4,631
Northeast	**14,721**	**16,099**
Connecticut	621	652
Maine	191	294
Massachusetts	2,096	2,225
New Hampshire	417	528
New Jersey	905	993
New York	6,116	6,432
Pennsylvania	4,001	4,491
Rhode Island	50	52
Vermont	324	432
East Central	**2,061**	**2,283**
Delaware	249	256
Kentucky	41	42
Maryland	235	256
North Carolina	249	308
Tennessee	140	159
Virginia	652	706
West Virginia	493	555
Southeast	**92**	**107**
Alabama	0	0
Florida	0	0
Georgia	51	62
Mississippi	0	0
South Carolina	41	44

See notes at end of table.

Table 31. Land Available for Potential Wind Development by Region and State, and Average Megawatts of Wind Generating Capability (Continued)

Regions/States	Moderate Land Use and Environmental Restrictions, Within 10 Miles of Transmission: Area Exposed to Wind (square kilometers)	Moderate Land Use and Environmental Restrictions, Within 10 Miles of Transmission: Potential Power Output at a 50-Meter Hub Height (megawatts)
South Central	**213,085**	**236,423**
Arkansas	1,239	1,305
Kansas	78,369	88,406
Louisiana	0	0
Missouri	3,064	3,156
Oklahoma	50,562	56,270
Texas	79,851	87,285
South Rocky Mountain	**32,420**	**37,604**
Arizona	164	190
Colorado	19,067	23,350
New Mexico	12,754	13,262
Utah	435	803
Southwest	**4,306**	**6,371**
California	3,753	5,546
Nevada	553	826
Contiguous U.S. Total	**625,488**	**734,073**

Note: Potential generating capability is presented in average megawatts per square kilometer. Capacity denoted in average megawatts should not be confused with nameplate capacity in megawatts. The nameplate capacity rating represents peak output at the rated wind speed, while average megawatts is the normalized actual power production (average megawatts multiplied by 8,760 hours per year results in the annual energy production in kilowatthours per year).

Source: National Renewable Energy Laboratory, "U.S. Wind Resources Accessible to Transmission Lines" (August 5, 1994).

Figure 22. Wind Turbine Configurations

Source: U.S. Department of Energy, Office of Solar Technologies, *Five-Year Research Plan 1985-1990, Wind Energy Technology: Generating Power From the Wind*, DOE/CE-T11 (Washington, DC, January 1985), p. 2.

year 2005 the installed cost for total plant investment will be $620 per kilowatt of capacity, a decrease of $452 per kilowatt from the 1993 projection.[101] The Energy Information Administration's *Annual Energy Outlook 1995* also assumes that costs will continue to decline as new plants are built in the future.

Transmission Line Costs

In addition to the power plant construction and operating and maintenance costs, there are costs for connection to the transmission grid. The further a wind energy development project is from transmission lines, the higher the cost of connection to the transmission and distribution system (Tables 32 and 33).

The distance from transmission lines at which a wind developer can profitably build depends on the cost of the specific project. Consider, for example, the cost of construction and interconnection for a 115-kilovolt transmission line that would connect a 50-megawatt wind farm with an existing transmission and distribution network.[102] The cost of building 1 mile of 115-kilovolt line is assumed to be $286,000, the midpoint of the range for the relevant voltages (Table 32).[103] That amount includes the cost of the transmission line itself and the supporting towers. It also assumes relatively ideal terrain conditions, including fairly level and flat land with no major obstacles or mountains. (More difficult terrain would raise the cost of erecting the transmission line.) The cost of constructing a new substation for a 115-kilovolt transmission line is estimated at $1.08 million. The cost of connection for a 115-kilovolt transmission line with a substation is estimated at $360,000 (Table 33).

Representative costs of a wind energy project and connection to existing transmission lines are as follows: Assuming that a 50-megawatt wind farm costs $50 million, 10 miles of transmission line (at $286,000 per mile of line) adds $2.86 million to the total cost, construction of a new substation costs $1.08 million, and connection to an existing substation for a 115-kilovolt line is $360,000. These costs add 8 percent to the total cost.[104] The costs of construction of 10 miles of transmission line and interconnection to an existing substation would add 6 percent to the total cost.

Table 32. Estimated Costs of Single-Circuit Alternating Current Transmission Lines

Voltage (kilovolts)	December 1989 Installed Cost (thousand dollars per mile)
115	125-375
138	125-375
230	150-375
345	350-700
500	400-800

Source: Electric Power Research Institute, *Technical Assessment Guide: Electric Supply, 1989*, Vol. 1, Revision 6 (Golden, CO, November 1989), p. B-4.

Table 33. Estimated Costs for Substation Construction and Connection to Wind Energy Project

Voltage (kilovolts)	Construct New Substation	Connect With Substation
69	$750,000	$250,000
115	$1,080,000	$360,000
138	$1,200,000	$400,000
161	$1,410,000	$470,000
230	$1,770,000	$590,000
345	$2,820,000	$940,000
500	$4,380,000	$1,460,000

Source: Data calculated by National Renewable Energy Laboratory, based on Western Area Power Administration, 2 "Conceptual Planning and Budget Cost Estimating Guide," Internal Review Document (January 1, 1993).

Although 10 miles was chosen for purposes of illustration, a wind developer might economically build closer to or farther from transmission lines, depending on site-specific conditions, including the voltage of the transmission line constructed, cost of interconnection to higher voltage transmission lines, the project's overall capital costs, specific wind resource characteristics, and project economics. There are, however, land and environmental constraints on transmission line construction, such as the existence of densely populated urban areas,

[101]Estimation for 2005 is given in 1993 dollars. Cost does not include substation and interconnection. See Electric Power Research Institute, *Technical Assessment Guide, Electric Supply, 1993*, EPRI-102276-V1R7 (June 1993), pp. 8-106 and 8-108.

[102]The majority of circuit miles of overhead electric line of 115 kilovolts through 230 kilovolts in 1992 were 115-kilovolt lines. The cost assumptions for this analysis therefore considered 115-kilovolt transmission lines for construction and interconnection. See Edison Electric Institute, *Statistical Yearbook of the Electric Utility Industry 1992* (Washington, DC, October 1993), p. 97.

[103]Cost estimates are from Electric Power Research Institute, *Technical Assessment Guide, Volume 1, Electric Supply, 1989*, Revision 6 (Palo Alto, CA, November 1989), and are the most recent data available.

[104]Cost assumptions are based on information from National Renewable Energy Laboratory, *U.S. Wind Reserves Accessible to Transmission Lines*, Draft DOE Task 94-001 (Golden, CO, September 1994), supported by the Energy Information Administration.

national parks, reserves or recreation areas, national forests and grasslands, national scenic waterway and wilderness areas, wetlands, lakes, marshes, and terrain that is steeply sloped or inaccessible to roads. These factors, which were not considered in the above example, can also increase the cost of connecting to transmission lines. Although the costs for wind development in the United States are significant, efforts are being made to develop wind resources in some States.

Constraints on Integration of Wind Energy into Electric Utility Systems

Although there have been many improvements in wind technology and costs, there remain some constraints which affect the economic competitiveness of wind energy for integration into the electric utility systems. One is the intermittent nature of wind. Without storage capability, wind turbine systems can supply electricity only when the wind blows. The intermittency of wind energy, coupled with the fact that the times of peak availability of wind resources in a given location may not coincide with the times of peak demand for electricity, makes wind energy less attractive to electric utilities than power sources that are available at all times. However, if wind patterns tend to match load profiles (as in California), wind farms can earn capacity value.

Another constraint is financing for wind energy projects, which tends to be somewhat less readily available and more costly than financing for conventional energy facilities. Wind energy projects are typically developed by independent power producers, which obtain financing on the strength of power purchase agreements with electric utilities. At the current avoided cost for electricity (i.e., what the utility would have to pay for additional capacity using another fuel source), standard power purchase agreements are generally insufficient to support investment in wind farms. Only in very special cases can wind energy compete against conventional power. Also, lenders perceive risks in wind technologies and their performance. For example, if the technical estimates of the performance of a wind energy project prove overly optimistic, revenues may fall short of expectations, and the borrowing independent power producer may be unable to service its debt. To compensate for this risk, lenders typically charge comparatively high rates of interest for such projects and demand relatively large amounts of equity.[105] Investors demand higher rates of return on their equity. Overall capital costs may be moderately higher than for utilities or less risky power plant investments.

Horizontal-axis wind turbines, developed by Enertech Corp. and the U.S. Department of Energy, located in Altamont Pass near Livermore, California.

Vertical-axis wind turbines in Altamont Pass.

A third constraint on the integration of wind capacity into electric utility systems is the variability of wind energy potential by geographic region and daily weather conditions. Wind-driven electricity generating facilities must be located at specific sites to maximize the amount of wind energy captured and electricity generated. However, many good wind energy sites are on ridges or mountain passes, where siting and permitting difficulties, land restrictions, aesthetic objections, the potential for bird kills, and harsh weather conditions often constrain development. Further, transmitting electricity from good resource sites to population centers, where demand is greatest, can result in

[105]Lawrence Berkeley Laboratory, “Comparison of Financing Terms for Wind Turbine and Fossil Power Plants,” (Berkeley, CA, September 1994), supported by the Energy Information Administration.

higher costs. These obstacles, as well as those imposed by environmental exclusion areas, bear critically on the development of wind energy capacity in this country.

A fourth constraint on the integration of wind power into electric utility system applies once wind capacity exceeds about 15 to 20 percent of installed system capacity. At this level of penetration, utility system studies indicate that additional spinning reserve[106] and load-following generation may be needed. These forms of support are necessary to maintain system area control in the event of fluctuations in wind farm output. Because of these requirements, the value of wind power may decline markedly once wind system penetration exceeds about 15 to 20 percent of a utility system's installed capacity. No utility has reached this level of penetration thus far.

Finally, while wind power is considered to be environmentally benign relative to conventional energy technologies, it does face certain environmental hurdles. First, some consider large-scale commercial wind farms to be an aesthetic problem; second, high-speed wind turbine blades can be very noisy, although technological advancements continue to improve this problem; and third, differential pressure gradients around operating turbines can cause birds to be drawn into the path of the blades.

Outlook for Wind Power

Although there are constraints on wind energy development, a recent analysis[107] indicates that there are 240,000 square miles (625,000 square kilometers) of land with the potential for wind development within 10 miles of transmission lines to support wind energy development in the United States (Figure 23). Assuming class 3 and above wind resources and turbines with 50-meter hub heights centered on plots 10 rotor diameters by 5 rotor diameters in size,[108] that land area could potentially accommodate 734,000 average megawatts[109] of wind energy generation capability.[110] This is roughly equivalent to the installed capacity of all the power plants in the United States. Site-specific, transmission-related questions do remain, but the need for proximity to transmission lines does not overly constrain wind energy development in the United States.

The future of wind electricity is far from certain. Currently, planned additions to wind capacity will be built almost equally by utilities and nonutilities (Table 34). Of the five utility-planned units, two are located in Wisconsin and three in Texas. Completion dates of 2000 are scheduled by Wisconsin Electric Power Company and Wisconsin Public Service Corporation for both of that State's wind projects. In Texas, wind projects are scheduled for completion in 1999, 2003, and 2004 by Texas Utilities Electric Company.

In many cases, the planned projects were not selected because of their economic competitiveness, but were initiated because State governments or Public Utility Commissions provided additional incentives for development. Among the States with special incentives are California, New York, Wisconsin, Minnesota, Iowa, Rhode Island, and Massachusetts.

In addition, many utilities are contracting for small amounts of wind energy on an experimental basis because wind holds considerable promise over the long run, especially as turbine costs come down and fossil fuel prices potentially increase. Since renewables generally are not cost-competitive for utility applications, information about some State incentives is highlighted below. Examples of wind projects are discussed, with emphasis on the reasons for project selection.

[106]Spinning reserve refers to a generating unit (typically a combustion turbine) that is operating and synchronized with the transmission system but not supplying power to meet load. It is available to take on load on very short notice, for example, if a large generating unit goes off line unexpectedly. The greater the amount of capacity that can be lost, the greater the spinning reserve requirement.

[107]J.P. Doherty, Energy Information Administration, "U.S. Wind Energy Potential: The Effect of the Proximity of Wind Resources to Transmission Lines," *Monthly Energy Review* (Washington, DC, February 1995), pp. vii-xiv.

[108]For more information, see Pacific Northwest Laboratory, *An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States*, DE91018887 (Richland, WA, August 1991), p. 43.

[109]Potential generating capability is presented in average megawatts per square kilometer. Capacity denoted in average megawatts should not be confused with nameplate capacity in megawatts. The nameplate capacity rating represents peak output at the rated wind speed, while average megawatts is the normalized actual power production (average megawatts multiplied by 8,760 hours per year results in the annual energy production in kilowatthours per year).

[110]J.P. Doherty, Energy Information Administration, "U.S. Wind Energy Potential: The Effect of the Proximity of Wind Resources to Transmission Lines," *Monthly Energy Review* (Washington, DC, February 1995), pp. vii-xiv.

Table 34. Operable and Planned Wind Projects as of December 31, 1994

Ownership and Location	Operable		Planned[a]	
	Number	Megawatts	Number	Megawatts
Utility Owned				
Arkansas	3	0.03	0	0
California	1	6.80	0	0
Iowa	11	0.08	0	0
Kansas	2	0.05	0	0
Maine	8	0.32	0	0
Minnesota	3	0.20	0	0
Texas	0	0.00	3	300
Vermont	2	0.20	0	0
Wisconsin	1	0.04	2	15
Total	**21**	**7.72**	**5**	**315**
Nonutility Owned				
California	76	1,693	W	W
Other[b]	4	45	W	W
Total	**80**	**P1,738**	**7**	**P335**

[a]Utility plans, 1995 through 2004; nonutility plans, 1995 through 1997.
[b]Other includes Hawaii, Iowa, Maine, Minnesota, and New Hampshire.
P = preliminary data.
W = withheld to avoid disclosure of individual company data.
Source: Preliminary numbers for 1994 nonutility wind capacity from Energy Information Administration, Form EIA-867, "Annual Nonutility Power Producer Report."

State-Supported Wind Energy Programs

California

Although California is host to 97 percent of wind energy development in the United States, it contains less than 1 percent of total U.S. wind energy potential.[111] Sixteen States have a wind resource base greater than or equal to that of California,[112] and 37 States have defined potential for utility-scale wind energy development. Many of the California projects were built when natural gas prices were high and projected to go higher, and Federal and State tax incentives for wind were also high. These conditions made qualifying facilities (QFs) using wind power economical, given the electric utility's projected avoided cost.

The immediate outlook for renewables in California, however, is less favorable. Early in 1995, the Federal Energy Regulatory Commission (FERC) ruled that the Biennial Resource Plan Update of the California Public Utilities Commission (CPUC) improperly prevented nonrenewable resources from competing with renewable resources in the bidding for power purchase agreements. The FERC ruling prevents the CPUC from establishing rates for power supplied by QFs above the most broadly defined avoided cost—not just an avoided cost based on a preferred group of resources. By forcing California to open the power purchase bidding to all resources, renewable QFs are forced to compete with nonrenewable facilities, such as gas-fired power plants. Because this ruling is highly adverse to renewables and contrary to the State's intention to support renewables, the CPUC is considering measures to support renewables without mandating rates above avoided cost. Currently, the CPUC is considering mandating that utilities that sell at retail in the State obtain 12 percent of their energy from renewable resources. Such a ruling, which would have the effect of mandating the quantity of renewables instead of the price paid for renewables, is designed to circumvent the FERC order

[111]American Wind Energy Association in cooperation with the U.S. Department of Energy and the National Renewable Energy Laboratory, *Removing Barriers to Wind Energy: Directions for State Regulatory Action* (Washington, DC, 1993), pp. 5-6.
[112]Pacific Northwest Laboratories, *An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States*, DE91018887 (Richland, WA, August 1991), p. 43.

rejecting QF rates above avoided cost.[113] This issue is further discussed in the feature article "Renewable Resource Electricity in the Changing Regulatory Environment" in this report.

Wisconsin

The Wisconsin Public Service Commission has been a leader in environmental policies associated with electricity production. Since 1989, electric utilities in Wisconsin have been directed to incorporate environmental externality costs in their evaluation of demand and supply options. Because of the current low natural gas prices, however, renewables were not selected when Wisconsin Electric developed its 1994 plans based on least costs. Wisconsin Electric decided to incorporate renewable energy resources, including wind, in its plan in the belief that improvements in technology and cost could render renewables more attractive in the future.

Currently, Wisconsin is in the process of adopting incentives for wind. It is the only State that offers an incentive payment for electricity generated from renewables. Advance Plan 6, passed in 1992, provides for a payment of 0.75 cents per kilowatthour for qualifying wind power, solar thermal electric, or photovoltaic generation, and 0.25 cents per kilowatthour for all other qualifying renewable generation to shareholders of investor-owned Wisconsin utilities. The incentive payment applies to facilities that receive construction authority by December 31, 1998. It also applies to utility purchases of nonutility renewable power. The Wisconsin Commission recognized that utility ratepayers would ultimately cover the costs of these incentives but accepted the tradeoff in the interests of promoting renewable energy and obtaining the benefits of fuel diversity and emissions reduction.

The Wisconsin payments could be challenged, however, before the Federal Energy Regulatory Commission. In its ruling against the California Public Utility Commission on QF rates above avoided cost, FERC said that while a State could support renewables through broad tax or other mechanisms, it could not use environmental adders on rates. This rejection of the rate-based environmental adder (or externality) approach directly challenges the justification Wisconsin provides for its Advance Plan 6.

Minnesota

Minnesota has been working to promote the development of renewable energy since the early 1980s. Efforts in this area have intensified in recent years, resulting in a number of new incentives and renewable mandates within the State. Minnesota currently expects that over 30 percent of its new and refurbished capacity scheduled for construction between now and 2002 will utilize renewable resources.[114]

Minnesota recently mandated that Northern States Power (NSP) install or contract to purchase 425 megawatts of wind generation capacity and 125 megawatts of "closed loop, farm-grown" biomass capacity by 2002 as part of legislation authorizing the utility to store its spent nuclear fuel in an above-ground, dry cask storage facility. An additional 400 megawatts of wind capacity must be installed by 2002 if the Commission finds that wind is a least-cost resource, subject to Integrated Resource Plan requirements.[115] The mandates are set out in stages and NSP must achieve each stage in order to receive its next increment of nuclear waste storage casks.

NSP intends to install 143 turbines at a site near Lake Benton in southwestern Minnesota. Wind data collected since 1985 show that targeted areas of the State have an annual average wind speed of 16.1 miles per hour. At these speeds the project is expected to deliver wind energy to NSP for about 3 cents per kilowatthour averaged over the 30-year term of the power purchase agreement.[116]

Maine

In the Northeast region, Central Maine Power (CMP)[117] signed a 3-year contract, with options, to purchase 10 megawatts of power from a proposed wind plant development in the Boundary Mountains of Maine. The New England Electric System has already

[113]The Public Utilities Regulatory Policies Act of 1978 (PURPA), Section 210, requires utility companies to buy power from qualifying facilities, including renewable plants. There is a proposal to repeal this section of PURPA. The legislation has pitted some of the Nation's major utilities against independent producers. The utilities argue they are forced to subsidize sometimes uneconomical private producers at high cost to consumers, while the independent producers argue that the utilities are seeking to shore up a monopoly. The price for QF power, known as the "avoided cost," is based on how much money the utility would have spent to generate the same amount of energy that is supplied by the independent producer.

[114]B. Engelking, "Minnesota's Policy and Incentives for Renewable Energy," paper presented at NARUC-DOE Conference on Renewable and Sustainable Energy Strategies in a Competitive Market (Madison, WI, May 1995).

[115]1993 Renewable Energy and Integrated Resource Planning Act (Minnesota Laws 1993, Chapter 356).

[116]The cost of 3 cents per kilowatthour includes a tax credit of 1.5 cents per kilowatthour.

[117]NARUC Subcommittee on Renewable Energy, *State Renewable Energy News*, Vol. 4, No. 1 (Winter 1995).

signed a contract to purchase 20 megawatts of power from the project under its "Green RFP." The first phase of the project is expected to be on line by the end of 1996. Maine has 191 square kilometers for class 3 and above wind development, equal to a potential 294 megawatts of generating capacity.

The wind energy from this project will replace more expensive resources on cold winter days. The wind energy closely matches the utility's load during the winter season. CMP has been working to reduce its level of expensive QF purchases, and the price that the utility will pay for wind energy will be considerably lower than the average of its current QF contracts.

The staff of the Maine Public Utility Commission supported the utility proposal, noting that the projects represent a regulatory "insurance policy" because they add valuable diversity to the fuel mix, avoid more expensive fossil fuels, hedge against fuel price increases and more stringent environmental restrictions, and help to assure that future renewables applications will be cost-effective. The staff also noted that, even in the restructured utility industry, these "green" electric sources would have value both for environmentally conscious customers and for those seeking diversity.

Texas

Texas Utilities Electric has made a commitment to wind energy in anticipation of decreasing renewable energy costs over the next 10 years and as a hedge against potential future fuel price escalation and the possibility of changing environmental standards. A 40-megawatt nonutility-owned wind project is already in place, with startup expected in late 1996. In addition, the utility plans to build a total of 300 megawatts of wind electricity generation capacity, representing approximately 7 percent of its total resource additions over a 10-year period, as part of its 1995 Integrated Resource Plan.[118]

In early 1995, a U.S. company announced that it had signed contracts to develop and finance a project called Windplant™ in West Texas to sell electricity to the Lower Colorado River Authority. It will be the largest wind energy facility in the United States outside California. The company previously announced plans to develop up to 250 megawatts of wind capacity at the site.[119]

[118]NARUC Subcommittee on Renewable Energy, *State Renewable Energy News*, Vol. 4, No. 1 (Winter 1995).
[119]"Kenetech Announces Sale of West Texas Windplant," *Solar Letter* (January 25, 1995), pp. 24-25.

Wind Power Milestones

Early 1900s to 1950	Early wind power in the United States	Windmills were used to pump water and were also used for remote electricity generation.
1941	First grid-connected electricity	On a hilltop in Rutland, Vermont, “Grandpa’s Knob” wind generator supplied power to the local grid for several months during World War II. The Smith-Putnam machine was rated at 1.25 megawatts in winds of about 30 miles per hour. It was removed from service in 1945.
1973	OPEC oil embargo	Oil and gas prices rose, increasing interest in alternative energy sources.
1974-1975	NASA’s MOD-0 developed	The MOD-0, a horizontal axis wind turbine was developed at the NASA Lewis Research Center in Cleveland, Ohio.
1977-1981	MOD-0, MOD-1, and MOD-2 developed and tested	Four MOD-0As, rated at 200 kilowatts each, were placed at utility sites around the country for tests between 1977 and 1980. The MOD-1, with a 2-megawatt capacity rating, the first wind turbine rated over 1 megawatt, began operating in 1979.
1978	Public Utility Regulatory Policies Act (PURPA) enacted	PURPA mandated the purchase of electricity from qualifying facilities (QFs) meeting certain technical standards regarding energy source and efficiency. PURPA also exempted QFs from both State and Federal regulation under the Federal Power Act and the Public Utility Holding Company Act.
1979	Federal funding for wind power research and development (R&D) exceeds $50 million	U.S. Department of Energy (DOE) funding for wind power R&D was $59.6 million in fiscal year 1978 (current year dollars), marking the first time the funding level surpassed $50 million. It remained above $50 million until fiscal year 1982, when it was reduced to $16.6 million (current year dollars).
1980	Crude Oil Windfall Profits Tax Act	The Act increased the business energy tax credit to 15 percent. Combined with an investment tax credit passed earlier, the total Federal tax credit for a wind turbine was 25 percent. In addition, California had a 25-percent State tax credit in the early 1980s, bringing the effective tax credit to nearly 50 percent.

1983	Interim Standard Offer Number 4 (ISO4) contracts in California	Because of a projected capacity shortfall, California utilities contracted with facilities that qualified under PURPA to generate electricity independently. The ISO4 contracts set a price based on long-run costs avoided by not building the coal plants that had been planned. The contracts, combined with favorable tax incentives mentioned above, encouraged the installation of many hastily designed wind turbines in California in the early 1980s.
1985	California wind capacity at 1 gigawatt	Most of California's wind capacity, which totaled more than 1,000 megawatts in 1985, was installed on the Tehachapi and Altamont Passes.
1988	Decline in cumulative wind capacity	Many of the hastily installed turbines of the early 1980s were removed and later replaced with more reliable models.
1989	Low point in Federal funding for wind power	Throughout the 1980s, DOE funding for wind power R&D declined, reaching its low point in fiscal year 1989.
1990	California wind capacity in excess of 2 gigawatts	In 1990, more than 2,200 megawatts of wind energy capacity was installed in California—more than half of the world's capacity at the time.
1992	Energy Policy Act	The Act reformed the Public Utility Holding Company Act and many other laws dealing with the electric utility industry. It also authorized a performance tax credit of 1.5 cents per kilowatthour for wind-generated electricity.
1993	33M-VS commercially available	The 33M-VS was one of the first commercially available, variable-speed wind turbines. U.S. Windpower developed the 33M-VS over a period of 5 years, with final prototype tests completed in 1992. The $20 million project was funded mostly by U.S. Windpower, but also involved Electric Power Research Institute (EPRI), Pacific Gas & Electric, and Niagara Mohawk Power Company.
1995	FERC prohibition on QF contracts above avoided cost	In a ruling against the California Public Utility Commission, FERC refused to allow a bidding procedure that would have the effect of allowing rates above avoided cost from renewable QFs.
Mid-1990s	ISO4 contract rollover in California at lower rates	Ten-year QF contracts written during the mid-1980s at rates of 6 cents per kilowatthour and higher began rolling over at mid-1990s avoided costs of about 3 cents per kilowatthour. This " 11th-year cliff" creates financial hardship for most QFs on ISO4 contracts.

1995	DOE wind program lowers technology costs	DOE's advanced turbine program, funded at $49 million, has led to new turbines with energy costs of 5 cents per kilowatthour of electricity generated.

11. Solar and Photovoltaic

Introduction

Using the sun's energy to produce heat or electricity is not a new idea. Technologies that capture the radiation of the sun and use it to produce energy have been available in one form or another for centuries, and they continue to be refined and developed today. Currently, solar thermal devices do everything from heating swimming pools to creating steam for electricity generation, while photovoltaic devices use semiconducting materials to convert sunlight directly into electricity.

Solar energy technologies carry along important advantages for electric utility and other users. First, the solar resource has no "fuel" cost and is abundantly available. In many parts of the world, the sun shines intensely on a daily basis, providing a nearly unlimited power resource for devices that convert the sun's insolation[120] into useful energy. Second, solar daily output often matches air conditioning loads, and thus provides high value. Third, most solar equipment is modular, meaning that capacity can be increased or decreased incrementally depending on demand. Solar power plants can, therefore, be readily matched to changes in load growth, decreasing the risk and cost associated with capacity additions. Fourth, most photovoltaic technologies can easily be operated in remote off-grid areas. There is no need for connection to transmission and distribution lines and minimal need for maintenance and monitoring. Finally, solar technologies are environmentally cleaner than conventional energy technologies. Solar thermal and photovoltaic devices produce no operating wastes, no air pollution, and little or no noise.

Even with these advantageous characteristics, solar energy technologies currently face some limitations for widespread use. While the cost for solar thermal and photovoltaic devices has declined substantially over the past few decades, many applications still are not fully cost-competitive with conventional technologies. Also, like wind power, solar energy relies on a fuel source (sunlight) that reaches the Earth's surface intermittently, resulting in storage and load-matching problems. Nevertheless, solar energy currently plays an important role in some energy sectors (for example, off-grid electricity applications) and is expected to have a broader role as the development and commercialization of solar technologies continue.

Solar Resource

Solar radiation is nearly constant outside the Earth's atmosphere, but the amount of solar energy, or insolation, reaching any point on the Earth varies with changing atmospheric conditions (such as clouds and dust) and the changing position of the Earth relative to the sun. Insolation is greatest in the West and Southwest regions of the United States. Average direct-beam solar radiation in parts of Nevada is more than twice that found through most of the eastern States or in the Northwest.[121] Nevertheless, almost all U.S. regions have useful solar resources that can be accessed for various applications (Figure 24).[122]

Historical Background

While the various solar energy technologies in use today were developed primarily within the last 100 years, the use of the sun to provide energy for human needs actually dates back several centuries.[123] As long ago as 100 A.D., people around the world recognized the usefulness of the sun for such diverse purposes as heating homes and setting fire to enemy ships.

The Swiss scientist Horace de Saussure is credited with inventing the world's first solar collector or "solar hot box" in 1767, and the French scientist Augustin Mouchot patented his solar engine in 1861. At that time, the primary uses of solar technologies ranged from cooking food and distilling water to pumping water for irrigation.

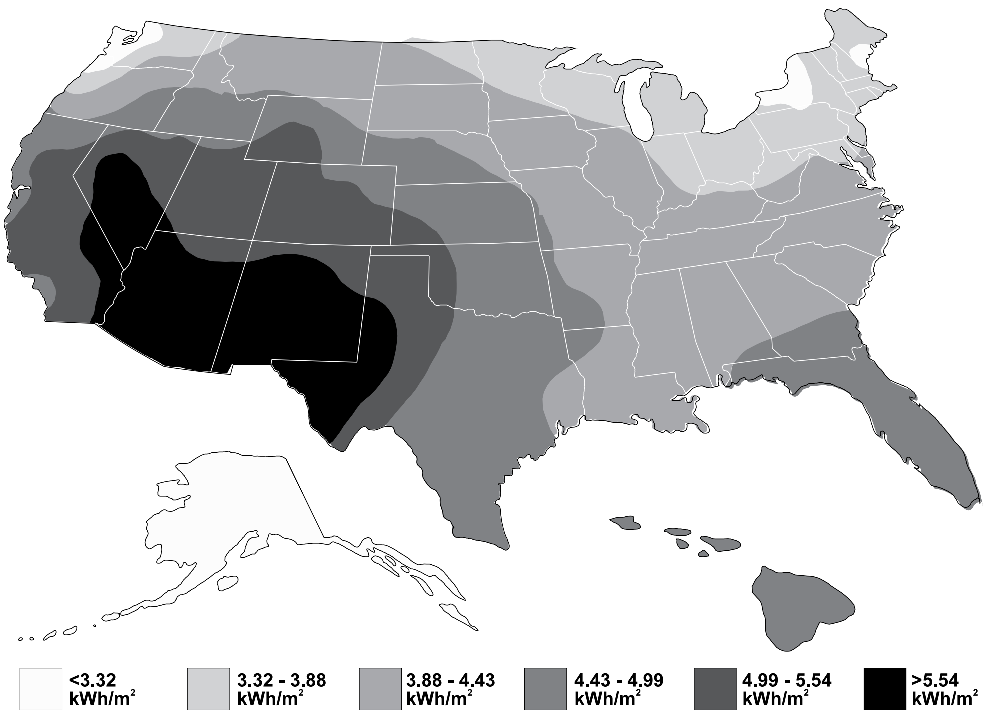
[120]Insolation is the radiation from the sun received by the Earth's surface, or the rate of such radiation per unit of surface.

[121]Energy Information Administration, *Renewable Resources in the U.S. Electricity Supply*, DOE/EIA-0561 (Washington, DC, February 1993).

[122]The amount of global (direct plus diffuse) sunlight only varies by plus or minus 25 percent within the continental United States from an average value in Kansas.

[123]Information for this section, unless otherwise noted, is taken from S. Sklar and K. Steinkopf, *Consumer Guide to Solar Energy* (New York, NY: Bonus Books, 1991).

Figure 24. Average U.S. Daily Global Solar Radiation



Source: National Renewable Energy Laboratory.

In the early 1880s, American engineer John Ericsson launched the solar energy industry in the United States. Ericsson developed several solar-driven engines to power steam generators for ships. But the man considered to be the father of solar energy in the United States was Clarence Kemp, who patented the first solar water heater in 1891. His invention was marketed in California, where in 1897 it became popular enough to heat the water of 30 percent of the houses in Pasadena.

In 1908, William J. Bailey of the Carnegie Steel Company invented the solar collectors that were to become the predecessors of those popularly used today. By the end of World War I, more than 4,000 rooftop solar water heaters had been sold, and more than 60,000 were in place by 1941. By the late 1940s, the demand for "solar homes" became so great that a large number of housing developments across the United States were built with both active and passive solar applications.

In 1954, Bell Telephone researchers discovered the sensitivity of a properly prepared silicon wafer to sunlight, and the "solar cell" was developed. Beginning in the late 1950s, photovoltaic cells were used to power U.S. space satellites, and they continue to be the prime power source for both manned and unmanned space projects today. The success of photovoltaics in space also spawned commercial applications for the technology that continue to be used and developed today.

The oil embargoes of 1973 and 1979, and the accompanying severe increases in the price of petroleum, created a new climate for the development of all renewable energy technologies, especially solar technologies. President Jimmy Carter stressed the importance of solar energy in reducing U.S. dependence on foreign oil, and he did everything from installing solar panels on the White House to promoting a wide range of incentives for solar energy systems to stimulate their use. By the early 1980s, the U.S. solar industry had grown to more than 100 national solar manufacturers and component suppliers producing solar water heating, solar thermal-electric, and photovoltaic equipment.

Other factors spurring the increase in solar energy use and development in the 1970s were the creation of the U.S. Department of Energy (DOE) and the Solar Energy Research Institute (now the National Renewable Energy Laboratory [NREL]), as well as several Federal initiatives, including investment tax credits for solar equipment and the enactment of the Public Utility Regulatory Policies Act of 1978 (PURPA).

One of the stated functions of DOE and NREL was to provide support for research and development of solar and photovoltaic technologies. This Federal assistance boosted the industry and advanced the technologies. PURPA greatly simplified the process of connecting small power sources to a utility grid and obtaining power purchase contracts from the utility. It exempted certain small power producers, called qualifying facilities (QFs), from rate regulation, mandated electric utility interconnection, mandated power purchases from QFs at the avoided cost (the amount the utility would have paid to generate or obtain the power elsewhere), and led to standardized contracting processes.

Luz International, the pioneering solar electric company in the United States during the 1980s, was created in 1980 and completed its first solar power plant in 1985 in California's Mojave Desert (see box on page 102). By 1991, Luz had brought 354 megawatts of solar electricity on line at nine different sites. Although the company went out of business in 1992, its plants continue to produce electricity today. During Luz's existence, the cost of solar electricity was cut from 25 cents per kilowatthour to less than 8 cents.[124] Luz's Solar Energy Generating Station failed economically because: (1) natural gas prices and electricity costs did not rise as expected; (2) operating and maintenance costs for the station did not decline as rapidly as had been expected; and (3) key tax incentives were expiring or uncertain.

Technology Characterization

Solar energy technologies are separated into two major categories by the type of energy used: solar thermal devices, which use the sun's heat energy, and photovoltaic devices, which use the energy inherent in the solar photons and convert it directly into electricity.

Small-scale solar thermal collector technologies use sunlight to heat swimming pools or water for domestic or industrial use. Solar thermal technologies designed to produce electricity encompass a group of different devices that use mirrors to concentrate heat from the sun to create steam for electricity generation.

In the case of solar thermal-electric devices, reflective surfaces are designed to track the movement of the sun, either vertically or horizontally (single-axis tracking), or both (dual-axis tracking). The heat generated by the concentrated sunlight, which can reach temperatures of 3,600°F, is transferred to a working fluid such as water, oil, or molten salt and turns the fluid into steam. The steam drives a turbine-electric generator or heat engine, and the waste steam is condensed and returned to the collector to absorb more heat.

Solar thermal-electric system concepts include parabolic troughs, parabolic dishes, and heliostats (highly reflective mirrors). The parabolic trough system, which has single-axis tracking, focuses solar radiation onto a fluid-filled pipe running the length of the trough. The modular troughs can be grouped together to produce large amounts of heated fluid. The dish / engine system uses a dish-shaped reflector with dual-axis tracking to concentrate the solar energy and ultimately heat a fluid powering a small engine / generator mounted at the focal point of the dish. The "power tower" system uses an array of heliostats to focus sunlight onto a tower-mounted central receiver filled with a working fluid. The heated fluid produces steam that drives a turbine to produce electricity.

Photovoltaic technologies use semiconducting materials to convert sunlight directly into electricity. Photovoltaics is the only renewable technology that does not convert resource energy into mechanical energy to generate electricity. Photovoltaic cells operate best during the peak hours of sunlight, but they also have the ability to produce electricity under almost any lighting conditions.

The basic unit in a photovoltaic system is a solid-state device called the solar cell (or photovoltaic cell). Solar cells are composed of semiconducting materials that produce electricity when sunlight is absorbed. Several solar cells are interconnected to form a module, which is then mounted on a frame with other modules to form panels and arrays. The array may be fixed (e.g., on a roof) or mounted to track the sun. Photovoltaic technologies use a variety of materials to generate electricity, including wafers of single-crystal or polycrystalline silicon; thin-film materials such as amorphous silicon or polycrystalline silicon; and high-efficiency, multijunction cells such as gallium arsenide alloys.

Perhaps the most basic model of the photovoltaic effect is the single-crystal silicon cell and module. The cells and modules are composed of a symmetrical lattice of silicon atoms that share electrons with four neighboring silicon atoms. When a photon of sunlight is absorbed by the cell, it may transfer enough energy to an electron to free it from its position, allowing it to move in the crystal lattice. The space left by the freed electron is

[124] D. Escobedo, "Luz Blames Government for Bankruptcy Filings," *Public Utilities Fortnightly*, Vol. 129, No. 2 (January 15, 1992).

The Luz Experience

In 1984, Luz International built its first Solar Electric Generating System (SEGS) plant and immediately became the world leader in solar power generation.[a] Luz put eight more plants into operation over a period of less than 7 years. A number of factors contributed to its success: tax credits, a quick move up the experience curve, the ability to provide bulk power, and several market factors, including expectations of rising natural gas prices and high avoided-cost rates for utilities. Initially, the company received 25-percent Federal tax credits, which were matched by the State. As successive plants were built, costs decreased and performance increased (the first plant had an installed cost of $5,979 per kilowatt of capacity, compared with $3,011 per kilowatt for the ninth). Natural gas was used to supplement 25 percent of the solar generating capacity, so that plant output could be tailored to meet utility peaking requirements. And expectations of higher fossil fuel prices in the future made Luz's alternative energy projects more desirable. Yet Luz went bankrupt while constructing its 10th plant.

Although Luz relied heavily on tax credits and property tax exemptions to reduce costs, it was still fighting an uphill battle in some areas of tax equalization with conventional fuel power plants. Under most State tax codes, solar plants face heavier tax burdens than conventional fuel plants because their "fuel" supply and sourcing are the same. Most States treat solar collectors as capital equipment, with the solar field representing real property. Solar plants can thus incur both a recurring property tax liability and sales taxes on the purchase of equipment for plant construction. Because conventional fuel plants buy fuel directly and own no equipment to "create" the plant's fuel, they pay no property or sales taxes at the time a plant is built.

Luz was also hampered by changes in the tax codes that helped it become successful in the first place. The uncertainty associated with the continuation of beneficial State and Federal tax policies added to construction risk and increased the cost of financing. This type of uncertainty in various aspects of the solar energy industry continues today, and it continues to add risk to commercial solar development.

While uncertainty in tax policy and the elimination of tax credits contributed to Luz's downfall, its financial failure can also be attributed to changing forces and price expectations in the electric power market. As natural gas prices fell in the late 1980s, utilities' short-run avoided costs for new electricity generation also fell. As a result, it became more difficult to finance new SEGS projects, and in the end Luz simply could not compete with the continuing decline of natural gas prices.

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[a]National Renewable Energy Laboratory, *Profiles in Renewable Energy: Case Studies of Successful Utility-Sector Projects*, DOE/CH10093-206 (Golden, CO, August 1994).

called a hole. An electric current is generated in the cell because the free electrons and the holes are attracted to each other by their opposite charges. This process enables photovoltaic cells to provide electricity for external needs. Two other types of photovoltaic technologies are thin-film cells and modules (made from a number of layers of photovoltaic materials such as amorphous silicon) and concentrator cells and modules (in which a lens is used to gather and converge sunlight onto the cell or module surface).

Infrastructure

The United States is one of the technological leaders in photovoltaic and solar thermal technologies.[125] More than 500 companies in the solar industry generate over 8,000 jobs, and thousands of other companies indirectly employ thousands more.[126] Public and industry demand for solar equipment has grown steadily over the past few decades, propelling the solar industry to grow and the rate of commercialization to increase. Solar

[125]Unless otherwise noted, the material in this section is taken from Energy Information Administration's *Solar Collector Manufacturing Activity 1993*, DOE/EIA-0174(93) (Washington, DC, August 1994). See Appendix H for more information on the infrastructure of the solar-thermal and photovoltaic industries.

[126]B. Buttler, "Government Solar," *Solar Industry Journal*, Vol. 6, No. 1 (First Quarter 1995).

systems have now been installed to heat the water in 1.2 million houses and buildings across the country, and more than 300,000 swimming pools are heated with solar systems.[127]

In 1994, 41 solar thermal collector manufacturers shipped 7.6 million square feet of collectors, an increase of 9 percent from 1993 (Table 35). Pool heating equipment represented 89 percent of the shipments and water heating 10 percent. The residential sector accounted for 92 percent of the shipments and the commercial sector 8 percent. In 1993, 91 percent of the solar thermal devices were shipped to only four States and Puerto Rico, but in 1994 the same five localities accounted for only 78 percent of the destination locations (Table 36). The number of wholesale distributors increased from 3,710 in 1993 to 5,504 in 1994 (Table 37).

In 1994, shipments of photovoltaic cells and modules increased by 25 percent over 1993 shipments, to 26 peak megawatts (Table 38). Shipments of single-crystal silicon cells and modules almost doubled between 1993 and 1994, and shipments of cast and ribbon silicon units increased by 60 percent. The industrial sector was the largest buyer of photovoltaic cells and modules in both 1993 and 1994, with generation both on- and off-grid representing the largest end use. Industry shipments have increased by an average of 18 percent

Table 35. Shipments of Solar Collectors by Market Sector, End Use, and Type, 1993 and 1994
(Thousand Square Feet)

	Low-Temperature	Medium-Temperature				High-Temperature		
	Liquid/Air		Liquid					
Market Sector/End Use	Metallic and Nonmetallic	Air	ICS/Thermosiphon	Flat-Plate (Pumped)	Evacuated Tube	Parabolic Dish/Trough	1994 Total	1993 Total
Market Sector								
Residential	6,268	1	209	545	2	0	**7,026**	**6,694**
Commercial	547	2	6	29	0	0	**583**	**215**
Industrial	7	0	0	8	0	1	**16**	**31**
Utility	0	0	0	1	0	1	**2**	**28**
Other[a]	0	0	0	0	0	0	**0**	**1**
Total	**6,823**	**3**	**215**	**583**	**2**	**2**	**7,627**	**6,968**
End Use								
Pool Heating	6,802	0	0	11	0	0	**6,813**	**6,040**
Hot Water	7	2	215	564	2	0	**790**	**880**
Space Heating	14	1	0	4	0	0	**19**	**15**
Space Cooling	0	0	0	0	0	0	**0**	**0**
Combined Space and Water Heating	0	0	0	4	0	0	**4**	**4**
Process Heating	0	0	0	0	0	0	**0**	**17**
Electricity Generation	0	0	0	0	0	2	**2**	**11**
Other[b]	0	0	0	0	0	0	**0**	*****
Total	**6,823**	**3**	**215**	**583**	**2**	**2**	**7,627**	**6,968**

[a]Other market sectors include shipments of solar thermal collectors to other sectors such as government, including the military but excluding space applications.
[b]Other end uses include shipments of solar thermal collectors for uses such as cooking, water pumping, water purification, desalinization, and distilling.
ICS = Integral Collector Storage.
*Less than 500 square feet.
Note: Totals may not equal sum of components due to independent rounding.
Source: Energy Information Administration, Form CE-63A, "Annual Solar Thermal Collector Manufacturers Survey."

[127]S. Sklar, "No Time for Apologies," *Solar Industry Journal*, Vol. 6, No. 1 (First Quarter 1995).

Table 36. Shipments of Solar Collectors Ranked by Top Five Origins and Destinations, 1993 and 1994

Origin/Destination	1993 Shipments		1994 Shipments	
	Thousand Square Feet	Percent of U.S. Total	Thousand Square Feet	Percent of U.S. Total
Origin[a]				
California	2,074	42	1,989	34
Florida	194	4	873	15
New Jersey, New York, and Puerto Rico	2,563	52	2,812	48
Top Five Total	**4,831**	**98**	**5,674**	**98**
Destination[b]				
Florida	3,701	56	3,612	50
California	1,540	23	1,352	19
Arizona	286	4	254	4
Puerto Rico	253	4	156	2
Hawaii	197	3	205	3
Top Five Total	**5,977**	**91**	**5,579**	**78**

[a]Represents only shipments manufactured in the United States.
[b]Based on the total shipped each year to the United States and Territories shown in Appendix G, Table G3.
Notes: Totals may not equal sum of components due to independent rounding. U.S. total includes territories.
Source: Energy Information Administration, Form CE-63A, "Annual Solar Thermal Collector Manufacturers Survey."

Table 37. Distribution of Solar Thermal Collector Shipments, 1993 and 1994

Recipient	Shipments (thousand square feet)	
	1993	1994
Wholesale Distributors	3,710	5,504
Retail Distributors	2,410	1,406
Exporters	343	385
Installers	313	185
End Users and Other[a]	191	146
Total	**6,968**	**7,627**

[a]Other includes minimal shipments not explained on Form CE-63A.
Note: Totals may not equal sum of components due to independent rounding.
Source: Energy Information Administration, Form CE-63A, "Annual Solar Thermal Collector Manufacturers Survey."

per year over the past 10 years, and their value in 1994 totaled $106 million. Unit prices per peak watt have declined by 71 percent and 36 percent for cells and modules, respectively, over the same period.

Solar thermal-electric technologies also continue to be refined and advanced. Between 1985 and 1991, the industry installed nine parabolic trough plants in the Mojave Desert, with a total generating capacity of 354 megawatts. A cost-shared program between DOE and the operating company successfully reduced operating and maintenance costs by up to 50 percent in 1995. Solar One, a 10-megawatt power tower, operated on-grid between 1983 and 1988. It met most of its technical objectives but was not economical. In 1992, a utility consortium began converting it from a water/steam system to a molten salt system, which will enable heat to be stored during periods without sun. This newest on-line baseload solar thermal plant, called Solar Two, began testing subsystems in 1995. Once the technical checkout is complete, the consortium plans to operate the plant for 3 years. A 7-kilowatt dish/engine system has been under development since 1991, and 10 of the systems are to be delivered in 1996. A second-generation 25-kilowatt system is scheduled to be built in 1996, with a goal of limited commercial production by 1998.

Photovoltaics are used the world over as completely independent sources of electricity. In remote areas, the cost of using photovoltaics can be much smaller than the cost of installing transmission and distribution lines to carry electricity from conventional sources. Remote applications include everything from providing electricity for domestic use to powering freeway call boxes and communications systems. In remote or inaccessible areas, photovoltaics provide long-term cost-effective power for many uses.

While small photovoltaic systems (mostly for remote applications) are already commercialized, large-scale

Table 38. Shipments of Photovoltaic Cells and Modules by Market Sector, End Use, and Type, 1993 and 1994

Market Sector/End Use	Crystalline Silicon[a]	Thin-Film Silicon	Concentrator Silicon	1994 Total	1993 Total
Market Sector					
Industrial	6,532	323	0	6,855	5,352
Residential	6,527	100	6	6,632	5,237
Commercial	5,199	208	22	5,429	4,115
Transportation	2,115	58	1	2,174	2,564
Utility	1,965	199	200	2,364	1,503
Government[b]	2,082	31	2	2,114	1,325
Other[c]	366	144	0	510	856
Total	**24,785**	**1,061**	**231**	**26,077**	**20,951**
End Use					
Electricity Generation					
Grid Interactive	1,890	195	211	2,296	1,096
Remote	9,031	204	18	9,253	5,761
Communications	5,516	54	0	5,570	3,846
Consumer Goods	3,070	169	0	3,239	946
Transportation	2,077	51	0	2,128	4,238
Water Pumping	1,381	27	2	1,410	2,294
Cells/Modules to OEM[d]	1,593	256	0	1,849	2,023
Health	63	16	0	79	674
Other[e]	163	90	0	254	74
Total	**24,785**	**1,061**	**231**	**26,077**	**20,951**

[a]Includes single-crystal and cast and ribbon types.
[b]Includes Federal, State, and local governments, excluding military.
[c]Other market sectors includes shipments that are manufactured for private contractors for research and development projects.
[d]Original equipment manufacturers.
[e]Other end uses include shipments of photovoltaic cells and modules for uses such as cooking food, desalinization, and distilling.
Source: Energy Information Administration, Form CE-63B, "Annual Photovoltaic Module/Cell Manufacturers Survey" (1994).

systems are currently in the demonstration phase. Thirty-nine electric utilities are testing grid-connected photovoltaic systems in the United States. The 1,000-megawatt Solar Enterprise Zone in Nevada may represent the next phase of growth. The photovoltaic industry and 85 utilities have teamed together to form cost-shared partnerships totaling more than $385 million of startup capital over a 5-year period (more detailed discussion follows). Another partnership program called PV for Utility Scale Applications or PVUSA was formed in 1989 to test hardware for utility applications. Public and private research and development projects also continue to lower the costs and increase the level of product applicability of photovoltaics.

The Energy Policy Act of 1992 (Public Law 102-486) contained several provisions that affect the infrastructure of the solar industry. Section 1916 extended indefinitely, retroactive to June 30, 1992, the 10-percent investment tax credit for solar equipment. At the end of 1993, 30 States had legislation providing financial incentives for investment in the use of solar devices. Many electric utilities joined the government action with low financing programs and rebates for investments in solar devices. The Rural Electrification Loan Restructuring Act of 1993 also contained provisions allowing rural electric cooperatives to make low-interest loans to assist their customers in the financing of on- and off-grid solar energy systems.

Current and Prospective Status

The current status of solar energy technologies varies among the different types of solar thermal and photovoltaic systems. Solar thermal parabolic trough systems, for instance, have been operating in California since 1985, whereas successful dish / engine systems are continuing to be developed and are anticipated to be ready within the next 5 years. Among the photovoltaic systems, hundreds of off-grid applications are currently cost-effective and in operation, while large-scale on-grid

Central receiver power plant at Sandia National Laboratory in Albuquerque, New Mexico. The plant consists of a large central tower, which houses the receiver, and a surrounding field of heliostats. The heliostats are large mirrors mounted on moveable frames that can track the sun and concentrate the sunlight onto a specific point, the receiver, on the tower. Inside the receiver, a pressurized fluid will be heated by the concentrated sunlight, become a gas, and drive a generator to produce electricity.

systems continue to be improved and may become available in the future. Small-scale solar collectors have been cost-effective and operational for decades, and they currently hold a large share of the pool and water heating markets in the United States.

The next phase of growth for large-scale, grid-connected solar electric technologies could be the federally sponsored Solar Enterprise Zone (SEZ) in southern Nevada. SEZ has proposals for 1,016 megawatts of projects, including 175 megawatts of photovoltaic and 841 megawatts of solar thermal-electric systems. Construction could begin in 1996, and the full target capacity could to be on line by 2003. Preliminary proposals submitted by the solar industry for inclusion in the SEZ program included an offer by the natural gas giant Enron Corporation of Houston, Texas. Enron surprised the solar industry by proposing to build a $150 million, 100-megawatt (peak) photovoltaic power plant at a per-kilowatthour cost well below the currently accepted industry cost. Enron believes it can lower electricity production costs with nonconcentrating thin-film photovoltaics to just 5.5 cents per kilowatthour over 15 years beginning in 1996, claiming that several recent breakthroughs in the thin-film photovoltaic technology make the future much brighter for large-scale photovoltaic developments.[128]

While the success of Enron's proposal is speculative at this time, it provides an example of the type of radical technological breakthroughs that have occurred in the solar and photovoltaic industries over the past several decades. The price of electricity from solar thermal trough technologies has fallen from more than 25 cents per kilowatthour in 1980 to less than 8 cents today. Costs must continue to fall, however, in order to bring the solar technologies closer to full cost-competitiveness with conventional energy technologies. The marginal cost of electricity from advanced combined-cycle gas-fired plants is around 2.5 cents per kilowatthour or less, and the total cost of power, including capital costs, is around 4 cents per kilowatthour. Grid-connected solar thermal-electric and photovoltaic plants are, therefore, not currently cost-competitive with new combined-cycle gas-fired plants. Advanced coal-fired power plants can also underprice solar power plants.

Nevertheless, as solar thermal and photovoltaic energy technologies continue to be developed, costs will continue to fall, and solar energy has the potential to become more competitive. In addition, if national concerns for the environment and quality of life continue to increase, new opportunities for solar energy will be presented. Solar energy could also gain a competitive advantage if the external benefits of the technology (e.g., no air emissions) and the external costs of other technologies (air and water pollution from fossil fuel emissions) were reflected in generating costs. The use of such "environmental externality adders" to change the relative prices of energy at the State level has, however, recently been rejected by the Federal Energy Regulatory Commission (FERC), which ruled that while a State could support renewables through broad tax or other mechanisms, it could not explicitly use environmental adders in the calculation of avoided-cost rates. (See the feature article in this report, "Renewable Resource Electricity in the Changing Regulatory Environment.")

The partnerships between the solar industry, electric utilities, and DOE are also hastening the development of cost-effective solar energy. The ability to further reduce the cost of solar energy will largely determine its future, but the treatment of these technologies in the regulatory and financial worlds will also have a major impact on the solar component of the future national energy composition.

[128]"Enron Identified as Source for SEZ Study's PV Prediction of 5.5 cents," *The Solar Letter*, Vol. 4, No. 26 (November 25, 1994).

Barriers to Commercialization and Market Niches

Solar technologies require either significant cost reductions or a combination of cost reductions and an increase in natural gas prices to become cost-competitive in most grid applications. Some obstacles slowing commercialization are technology-specific, while others are more general. The primary obstacle is that solar technologies cannot currently compete with conventional fossil-fueled technologies in grid-connected applications. On the other hand, some niche applications, such as photovoltaics for transmission and distribution support at the end of a fully loaded distribution line, have value above that of a new generating plant. Such applications may permit a technology to establish itself and benefit from economies of scale and learning effects.

Financial risk and uncertainty are also adversely affecting solar electric development. Because solar electric plants are highly capital intensive and have high absolute capital costs per kilowatt of capacity, they are riskier than most conventional power plants. The risks are partially offset by the modularity of the plants and their short construction leadtimes, but the overall risk-adjusted cost of capital for the plants is higher than that for conventional power plants.

An associated obstacle to solar development is the way in which electric utilities conduct their resource planning. Planning and avoided-cost methods usually do not consider nonmarket benefits and costs, understating the social benefits of solar energy. For instance, the environmental benefits of using the sun to produce electricity are not usually explicitly accounted for in the resource planning process. Because the environmental benefits of using cleaner technologies are dispersed and accrue to the general public, the decisionmaking utility has no direct incentive to take them into account. Therefore, even though solar energy technologies impose little or no pollution costs on society, that benefit is generally left out of the least-cost planning process.

While consideration of environmental and other nonmarket benefits of solar energy continues to be understated, some utilities have recently factored them into resource planning decisions on a more consistent basis. On the other hand, new regulatory trends are threatening the utilities' ability to do so, and the near-term future of solar electricity seems uncertain in light of the impending changes.

The South-facing roof of Georgetown University's intercultural center in Washington, DC, has an area of 35,000 square feet and supports a 300-kilowatt photovoltaic (PV) power system. The roof-mounted system consists of over 4,400 PV modules. Electricity generated by the center's roof is channeled into Georgetown's power grid, where it provides energy for university operations. Funding for the project came, in part, from the U.S. Department of Energy.

Despite these obstacles, solar thermal and photovoltaic energy technologies continue to enjoy success in certain market niches. Solar energy is a versatile power source, and solar technologies have some unique attributes that drive their use in situations where most conventional energy technologies, and even other renewables, are either not viable or not as cost-effective. For instance, because photovoltaic modules have no moving parts to wear or break down, they can be used for extended periods of time without maintenance or intervention; because solar systems are modular, they can be easily adapted to meet a variety of power requirement; and, in general, solar power systems have no "fuel" requirement other than the sun and can operate in almost any environment.

Solar Thermal Milestones

1974	The Solar Energy Industries Association (SEIA) formed	SEIA was formed in 1974. The association represents the interests of stakeholders in the solar industries and acts as a lobbying group in Washington, DC
1977	The Solar Energy Research Institute (SERI) formed	SERI—now the National Renewable Energy Laboratory (NREL)—was formed in 1977. NREL is a national laboratory that provides research and development support for solar and photovoltaic technologies.
1978	Public Utility Regulatory Policies Act (PURPA) enacted	PURPA mandated the purchase of electricity from qualifying facilities (QFs) meeting certain technical standards regarding energy source and efficiency. QFs were also exempted from both State and Federal regulation under the Federal Power Act and the Public Utility Holding Company Act.
1978	Energy tax credit	A 15-percent energy tax credit was added to an existing 10-percent investment tax credit, providing incentive for capital investment in solar thermal generation facilities for independent power producers.
1980-85	Oil price increases expected	During the early 1980s, the price of oil rose and was expected to increase at rates substantially above inflation. Because forecasts of energy prices were based on fossil fuel prices, the market for renewable energy projects was strong.
1981	California State energy tax credit	The State of California enacted a 25-percent tax credit for the capital costs of renewable energy systems.
1982	Solar One in operation	Solar One, a 10-megawatt central receiver demonstration project, was first operated in 1982 and established the feasibility of "power tower" systems. In 1988, the final year of operation, the system achieved an availability of 96 percent.
1983	California Standard Offer Contracts	California's Standard Offer Contract system for QFs provided renewable electric energy systems a relatively firm and stable market for their output. This allowed the financing of such capital-intensive technologies as solar thermal-electric.

1983	13.8-megawatt SEGS I plant installed	The first in a series of Solar Electric Generating Stations (SEGS) was installed in 1983, with output sold to Southern California Edison Company. SEGS I used solar trough technology to produce steam in a conventional steam turbine generator. Natural gas was used as a supplementary fuel for up to 25 percent of the heat input.
1984	25-kilowatt dish Stirling systems demonstrated	Advanco and McDonnel Douglas systems demonstrated the potential for high-efficiency dish Stirling systems.
1989	Size limit for qualifying facilities increased to 80 megawatts	In 1989, Federal regulations that govern the size of solar power plants were modified to increase maximum plant size to 80 megawatts from 30 megawatts. The larger size allowed SEGS VIII and IX to improve the economics of the power block, controls and auxiliary equipment, and to lower operating and maintenance costs.
1991	Luz International filing for bankruptcy	Luz went bankrupt while building its tenth SEGS plant. SEGS I through IX remain in operation today.
1992	7.5-kilowatt dish prototype operational	In 1992, a prototype system using an advanced stretched-membrane concentrator, through a joint venture of Sandia National Laboratories and Cummins Power Generation, became operational.
1992	Investment tax credits restored by the Energy Policy Act	The Act restored the 10-percent investment tax credit for independent power producers using solar technologies.
1994	Free-piston Stirling engine prototype tied to grid	The first solar dish generator using a free-piston Stirling engine was tied to a utility grid.
1994	Proposed solar enterprise zone in Nevada	The Corporation for Solar Technology and Renewable Resources, a public corporation, was established to facilitate solar developments at the Nevada Test Site. Proposals have been requested for the construction of 100 megawatts of solar electric capacity.
1994	Silvered film enters market	3M Company introduced a new silvered plastic film for solar applications.
1995	Federal Energy Regulatory Commission (FERC) prohibits qualifying facility contracts above avoided costs	In a ruling against the California Public Utilities Commission, FERC refused to allow a bidding procedure that would have the effect of allowing rates above avoided cost for power purchases from renewable QFs.

Photovoltaics Milestones

Early 1950s	First photovoltaics created	Photovoltaic technology was born in the United States with the invention of the solar silicon cell at Bell Labs in the early 1950s.
1958	Federal support linked to Vanguard satellite	Federal support for photovoltaic technology was initially tied to the space program, where its first significant use was to provide power for the Vanguard satellite in 1958.
1973	Interest in terrestrial applications created by oil shock	Spurred by the first world oil shock in 1973, interest in terrestrial applications of photovoltaics blossomed.
Late 1970s	Integrated Buildings Program established	By the late 1970s, a program for the development of distributed photovoltaics was established by the Department of Energy at Massachusetts Institute of Technology, focusing on design and demonstration issues for the buildings sector.
1978	Energy tax credit	The Energy Tax Act of 1978 established a 10-percent investment credit for photovoltaic applications.
1978	Solar Photovoltaic Energy, Research, Development and Demonstration Act	The Act committed $1.2 billion (current dollars) over 10 years to improve photovoltaic production levels, reduce costs, and stimulate private-sector purchases.
1978	Photovoltaic energy commercialization program	This program established a photovoltaic commercialization pathway, accelerating the installation of photovoltaic systems in Federal facilities.
1980	Carlisle House completed	The Carlisle house was completed in 1980, with participation from MIT, DOE, and Solar Design Associates. The residence featured the first building-integrated photovoltaic system, passive solar heating and cooling, superinsulation, internal thermal mass, earth-sheltering, daylighting, a roof-integrated solar thermal system, and a 7.5-peak-watt photovoltaic array of polycrystalline modules from Solarex.
1980	Crude Oil Profit Windfall Tax	In April 1980, the Crude Oil Windfall Profit Tax was enacted, raising the residential tax credit to 40 percent of the first $10,000 for photovoltaic applications, raising the business tax credit to 15 percent, and extending the credit to the end of 1985.

1981	More than 10 percent efficiency achieved by thin film cells	Boeing and Kodak fabricated the first thin-film photovoltaic cells with efficiencies greater than 10 percent.
1984	World price of photovoltaics below $10 per watt	The world price of photovoltaic modules fell below $10 per peak watt (1993 dollars) in 1984 (Worldwatch Institute).
1985	6-megawatt Carissa Plains plant completed	In 1985, the 6-megawatt Carissa Plains plant was added to Southern California Edison's system. The project was later dismantled.
1989	Renewable Energy and Energy Efficiency Technology Competitiveness Act	The Act sought to improve the operational reliability of photovoltaic modules, increase module efficiencies, decrease direct manufacturing costs, and improve electric power production costs.
1989	PVUSA formed	In 1989, PV for Utility Scale Applications (PVUSA), a national public-private partnership program, was created to assess and demonstrate the viability of utility-scale photovoltaic electric generating systems. PVUSA participants include Pacific Gas & Electric (PG&E), DOE, the Electric Power Research Institute, the California Energy Commission, and eight utilities and other agencies. The project was designed to provide utilities with the hands-on experience needed to evaluate and apply photovoltaic technologies, provide manufacturers with a test bed for their products, and generate communication between utilities and the photovoltaics industry.
1990	ARCO Solar bought by Siemens	In February 1990, Siemens A.G. of Munich, West Germany, acquired California-based ARCO Solar, the world's largest photovoltaic company. The sale, valued at $30 to $50 million, was a stock transaction, with Siemens buying all ARCO Solar stock and certain other assets related to its business.
1990	PVMaT formed	In early 1990, the PV Manufacturing Technology (PVMaT) project was begun. The activity is a government/industry research and development partnership between DOE and members of the U.S. photovoltaic industry. PVMaT is designed to improve manufacturing processes, accelerate manufacturing cost reductions for photovoltaic modules, improve commercial product performance, and lay the groundwork for a substantial scale-up of manufacturing capacity.

1992	15 percent efficiency achieved by thin-film cells	The University of South Florida fabricated a 15.89-percent efficient thin-film cell, breaking the 15-percent barrier for the first time.
1992	World price below $5 per watt	The world price of photovoltaic modules fell below $5 per peak watt (1993 dollars) in 1992 (Worldwatch Institute).
1993	First grid-supported system installed	In March 1993, as part of the PVUSA program, PG&E completed the installation of the first grid-supported photovoltaic system in Kerman, California. The 500-kilowatt system was the first effort aimed at “distributed power,” where a relatively small amount of power is carefully matched to a specific load and is produced near the point of consumption. The approach differs significantly from the traditional utility-supply model, where electricity is generated at a central point and distributed to outlying areas through high-voltage transmission lines.
1993	Record world efficiencies announced	New world-record efficiencies in polycrystalline thin film and single-crystal devices, approaching 16 percent and 30 percent, respectively, were achieved in 1993.
1995	Joint venture by Amoco and Enron	Two major energy companies announced their intention to use amorphous silicon modules for utility-scale photovoltaic applications.

Section III

International Renewable Energy: Current Status and Prospects

12. International Renewable Energy

Introduction

Renewable energy technologies are expected to play an increasingly significant role in the years ahead in many developing countries as well as most industrialized countries. In developing countries with strong economic growth, new electricity generation capacity will be needed to meet growing energy demand and to supply electricity to rural areas not served by grid-connected utilities. The absence of well-established grids in rural areas of many developing countries makes standalone and "village grid" renewable energy applications likely prospects for meeting energy service demands. Photovoltaic systems, hybrid systems (renewable systems with conventional backup systems), "mini-hydro" systems, wind systems, small solar thermal systems, and biomass systems may all be able to compete with conventional energy technologies, given appropriate resources and infrastructure. Where renewable energy sources are competitive with conventional sources, funding from private, government, and international organizations may be available to support their development.

Many industrialized countries also will be seeking new energy technologies that will enable them to meet their energy needs with minimal damage to the environment or without compromising the reliability or security of their energy supplies. In countries with well-developed electricity grids, efforts are being made to bring cost-effective renewable energy applications on line. Solar thermal, hydroelectric, geothermal, biomass, solar thermal/gas hybrid, and wind systems are likely to be the best renewable energy prospects.

In October 1995, the U.S. Department of Energy sponsored a Hemispheric Energy Symposium to discuss and refine shared goals of North and South American nations on policy and regulatory principles that will stimulate private-sector investment in sustainable energy technologies and energy cooperation. Other stated goals of the conference were to identify projects that will demonstrate innovative financial and technological approaches to meeting the energy service needs of the hemisphere; to identify strategies to mobilize private capital to finance projects and to support the transition of the energy sectors toward a market basis; and to establish work plans and mechanisms to address common issues and problems in implementing sustainable energy policies and projects.

In addition to international projects supported by the U.S. Government, several joint-party collaborative efforts currently under way are enhancing the prospects for the use of renewable energy resources. For example, the United Nations Educational, Scientific and Cultural Organization (UNESCO) launched an initiative in 1992, called the World Solar Summit Process (WSSP), to advance the prospects for renewables in the developing world.[129] The World Bank is also promoting renewable energy. The Bank's Solar Initiative is an effort to work with member countries, the energy industry, the research community, and nongovernmental organizations to hasten the commercialization of solar and other renewable energy technologies and to expand their applications in developing countries. The World Bank recently increased its support for renewable energy projects around the world and currently is working to identify and prepare projects suitable for financing by the Global Environmental Facility (see box on page 116).

Data on U.S. exports of solar thermal collectors and photovoltaic modules and cells in 1994 are presented in Tables 39, 40, and 41. Table 42 shows existing capacity and planned additions for geothermal electricity around the world.

Renewable Energy in Industrialized Countries

Europe

The European Community (EC) is currently stressing the importance of developing a sustainable energy supply.[130] The Energy Information Administration (EIA) projects that consumption of grid-connected

[129] Despite the word "solar" in its title, the WSSP's focus includes all renewable forms of energy.

[130] Unless otherwise noted, the source for information in this section is Electric Power Research Institute, *European Wind Technology*, EPRI-TR-101391 (Palo Alto, CA, March 1993), pp. 1-3.

International Renewable Energy Projects Supported by the World Bank

The Global Environmental Facility (GEF) is a financial mechanism created in 1991 that provides grant and concessional funds to recipient countries for projects and activities that aim to protect the global environment.[a] It is jointly implemented by the United Nations Development Program, the United Nations Environment Program, and the World Bank.

In March 1994, some 73 participating governments successfully concluded negotiations to restructure the GEF and replenish its Core Fund with $2 billion over a 3-year period.[b] A total of 147 projects have been funded at a total of about $870 million, allocated as follows: 46 percent for biodiversity, 14 percent for international waters,[c] 33 percent for climate change, 5 percent for ozone, and 2 percent for other projects. The following is an example of a GEF project:

- **Philippines:** Development of a geothermal energy field in the Eastern Visayas, Luzon, that will expand power plant capacity from 200 to 640 megawatts-electric and construction of related transmission systems that will interconnect most of the country. Institution-strengthening measures are included. In addition to support from the World Bank, cofinancing is expected from the Export-Import Bank of Japan, the Swedish Agency for International Technical and Economic Cooperation, and the GEF. The total cost of the project is estimated at $1.3 billion.

Outside the GEF, the World Bank's International Bank for Reconstruction and Development (IBRD) has approved the following projects for fiscal year (FY) 1994:[d]

- **China:** Construction of the 154-meter-high Xiaolangdi rockfill dam and a power station with an installed capacity of 1,800 megawatts (total cost $2.3 billion).
- **Indonesia:** Environmentally sustainable (renewable) expansion of electricity generation and transmission capacity, with cofinancing anticipated from Austria and Australia and from export credits (total cost $689 million).

Renewable energy also has begun to play a role in the energy projects funded by the International Financial Corporation (IFC), a member of the World Bank group. For FY 1994, the IFC approved $2.5 billion for new projects in 65 countries as part of $4.29 billion in total financing—of which energy accounted for $271 million—including syndications and underwriting on the projects, the total worth of which is $15.8 billion.[e] For FY 1995, the IFC approved a total of 183 projects totaling $2.9 billion.[f] IFC projects approved for FY 1994 include the following:[g]

- **China:** With support provided through its Technical Assistance Trust Funds Program, the IFC conducted a feasibility study to expand an existing joint venture for producing photovoltaic equipment.
- **Nepal:** Himal Power Ltd. will build and operate a 60-megawatt run-of-the-river hydroelectric project on a build-operate-transfer (BOT) basis on the Khimti Khola River in the Janakpur Zone of the country's central region. The $125.7 million project will receive $28 million in loans, $5 million in syndications, and $3 million in equity financing from the IFC.
- **Chile:** The IFC will provide $50 million in syndications for additional financing of a $500 million hydroelectric project of Empresa Eléctrica Pangue S.A. The project received $120 million of financing in fiscal year 1993.
- **Costa Rica:** Hidroeléctrica Aguas Zarcas S.A. will build, own, and operate an 11.1-megawatt, $15 million hydroelectric generation plant in San Carlos. The project will sell power directly to Instituto Costarricense de Electricidad, Costa Rica's main public electric utility. IFC assistance includes $3.3 million in loans, $6.1 million in syndications, $400,000 in initial currency or interest rate swap, and $700,000 in quasi-equity. In addition, through its Technical Assistance Trust Funds Program, the IFC has secured funding for a feasibility study for three small hydropower projects.

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[a]Unless otherwise noted, the source for information in this section is personal communication between Maria Subiza, GEF Secretariat, and Gabriel Sanchez, Science Applications International Corporation, on September 8, 1995.

[b]All funding and cost values are shown in year dollars in which funds were obligated.

[c]Projects on saltwater or freshwater resources that span more than one country.

[d]"Renewables Getting More Attention from World Bank, IFC, ESMAP," *Solar Letter* (September 20, 1994), pp. 240-241.

[e]International Financial Corporation, *Annual Report 1994.*

[f]International Financial Corporation, *Annual Report 1995.*

[g]"Renewables Getting More Attention from World Bank, IFC, ESMAP," *Solar Letter* (September 20, 1994), pp. 240-241.

Table 39. Distribution of U.S. Solar Thermal Collector Exports by Country, 1994

Country	Percent of U.S. Exports
Asia	
Japan	9.9
Taiwan	18.2
Other Asia	1.4
Total	**29.5**
Europe	
Austria	5.4
France	8.3
Spain	1.7
Switzerland	2.6
Other Europe	10.3
Total	**28.3**
The Americas	
Antigua	0.2
Bahamas	0.2
Bermuda	0.1
Canada	17.5
Costa Rica	0.5
Haiti	0.1
Jamaica	0.2
Mexico	2.6
Other Central America	0.8
Colombia	3.6
Total	**25.8**
Africa	
South Africa	2.9
Other Africa	2.8
Total	**5.7**
Australia	**9.3**
Total	**98.6**

Notes: Other represents shipments to countries not disaggregated by companies on Form CE-63A and may include shipments to enumerated countries. Totals may not equal sum of components due to independent rounding.

Source: Energy Information Administration, Form CE-63A, "Annual Solar Thermal Collector Manufacturer Survey."

renewable electricity in European member countries of the Organization for Economic Cooperation and Development (OECD) will grow from approximately 5.0 quadrillion Btu in 1992 to 6.2 quadrillion Btu by 2010.[131] The prospects for hydroelectric, wind, and cogeneration with biomass are favorable in the EC, particularly for the first two types of energy. The outlook for solar thermal and photovoltaic applications is favorable in some regions (such as Greece, Italy, and Southern Spain).

Most of the countries in the EC are actively pursuing the incorporation of wind power into their grid systems. Announced plans and reasonable projections indicate that more than 4,000 megawatts of wind power will be operational by 2000 (Table 43). The Electric Power Research Institute (EPRI) estimates that the new installed wind capacity could represent a $4 billion market between 1990 and 2000, or an average of $400 million annually (assuming $1,000 per kilowatt of installed capacity). Government energy policies are the driving force behind much of the increased consideration and use of wind. Underlying the policies is increased public concern about environmental degradation resulting from the combustion of fossil fuels, as well as uncertainty with regard to oil prices and mistrust of nuclear power.

Certain countries, such as Germany and Switzerland, have large solar energy budgets and have seen funding increase steadily for many years, while others, including Sweden and Norway, have seen budget reductions.[132] Other countries, such as Finland, France, Italy, and Spain, continue to have small but steady budgets for the various solar technologies. Support for photovoltaic projects has increased in all the EC countries except Denmark and Belgium. Many state, regional, provincial, and local governments also fund solar energy research and development activities.

In Eastern Europe, the prospects for development of renewable energy resources are generally poor, mainly because of a lack of financial resources and renewable technology expertise, as well as the lack of experience in environmental and renewable energy markets. Further development of hydroelectricity in the region seems unlikely. One of the few renewable energy projects in the region is an effort to develop wind power in Ukraine. A joint venture between a U.S. company and a Ukrainian utility seeks to build a 500-megawatt wind farm in the Crimea.[133]

Asia and Oceania

Information for three industrialized countries in the region—Japan, Australia, and New Zealand—is presented below.

- **Japan:** Japan has shown a strong interest in the development and introduction of new sources of energy that can serve as alternatives to oil. The Japanese government is strongly committed to improving the environment. The New Energy and

[131]Energy Information Administration, *International Energy Outlook 1995*, DOE/EIA-0484(95) (Washington, DC, June 1995).
[132]*Solar Update: Newsletter of the International Energy Agency Solar Heating and Cooling Program*, No. 23 (April 1994).
[133]Energy Information Administration, *International Energy Outlook 1995*, DOE/EIA-0484(95) (Washington, DC, June 1995).

Table 40. U.S. Export Shipments of Photovoltaic Modules and Cells by Type, 1994
(Peak Kilowatts)

Item	Type			
	Crystalline Silicon	Thin-Film Silicon	Concentrator Silicon	Total
Modules	11,104	265	5	**11,373**
Cells	6,301	40	0	**6,341**
Total	**17,404**	**305**	**5**	**17,714**

Note: Total may not equal sum of components due to independent rounding.
Source: Energy Information Administration, Form CE-63B, "Annual Photovoltaic Module/Cell Manufacturers Survey."

Table 41. Destination of U.S. Photovoltaic Cell and Module Export Shipments by Country, 1994

Destination	Peak Kilowatts	Percent of U.S. Exports	Destination	Peak Kilowatts	Percent of U.S. Exports
Africa			**Europe**		
Angola	1	*	Austria	72	0.4
Botswana	*	*	Belgium	3	0.4
Egypt	*	*	Cyprus	*	*
Kenya	31	0.2	England	19	0.1
Morocco	362	2.0	France	126	0.7
Nigeria	4	*	Germany	4,641	26.2
South Africa	791	4.5	Netherlands	151	0.9
Tanzania	*	*	Norway	287	1.6
Zaire	1	*	Spain	80	0.5
Total	**1,190**	**7.0**	Sweden	124	0.7
Asia			Switzerland	138	0.8
China	5	*	**Total**	**5,621**	**32.0**
Hong Kong	1,175	6.6	**North America**		
India	806	4.5	Belize	*	*
Indonesia	30	0.2	Canada	1,043	5.9
Israel	1	*	Caribbean[a]	180	1.0
Japan	2,857	16.1	Dominican Republic	14	0.1
Malaysia	*	*	Haiti	42	0.2
Pakistan	81	0.5	Mexico	2,058	11.6
Singapore	1,072	6.1	**Total**	**3,337**	**19.0**
Taiwan	111	0.6	**South America**		
Total	**6,138**	**35.0**	Argentina	538	3.0
Australia	**7**	*****	Bolivia	210	1.2
			Brazil	61	0.3
			Chile	110	0.6
			Columbia	367	2.1
			Ecuador	1	*
			Peru	105	0.6
			Venezuela	1	*
			Total	**1,393**	**8.0**
Total U.S. Exports				**17,714**	

[a]Includes all Caribbean countries except the Dominican Republic and Haiti.
* = Less than 500 peak watts or less than 0.05 percent.
Note: Totals may not equal sum of components due to independent rounding.
Source: Energy Information Administration, Form CE-63B, "Annual Photovoltaic Module/Cell Manufacturers Survey."

Table 42. Geothermal Electrical Plants: Country and World Total Capacity
(Megawatts)

Nation	Existing Plants	Existing Capacity	Planned Capacity
Argentina	1	0.6	
Australia	1	0.2	
China	11	23.4	
Costa Rica	2	57.0	107.0
El Salvador	5	105.0	60.0
France	1	4.0	
Greece	1	1.8	
Guatemala	1		240.0
Iceland	6	45.4	
Indonesia	6	307.3	1957.0
Italy	26	548.7	344.0
Japan	12	297.3	230.0
Kenya	1	45.0	
Mexico	28	731.6	260.9
New Zealand	4	283.0	141.0
Nicaragua	1	35.0	
Philippines	25	1076.7	1124.0
Portugal	2	6.4	
China	2	3.2	
Russia	1	11.0	110.0
Thailand	1	0.3	
Turkey	1	15.0	
United States	77	2849.9	512.0
World Total	**202**	**6314.0**	**5085.9**

Notes: Totals may not equal sum of components due to independent rounding. References do not specify whether capacity figures are gross or net. The small plant in Greece has been shut down since 1988. Much of the planned capacity is for the next 6 or 7 years. One notable exception is that planned capacity for Indonesia is through about 2015. Some countries did not provide dates for all planned capacity.

Source: Geothermal Energy Association, *International Geothermal Electric Power Plants* (Davis, CA, 1991); updated by M. McLarty, DynCorp EENSP, Inc. (Alexandria, VA, August 1995).

Industrial Technology Development Organization (NEDO) was established in 1980 as a central body to promote research and development for technologies related to new energy sources. Major emphasis has been placed on photovoltaic technologies, with research and development aimed at reducing the cost of photovoltaic modules, increasing the efficiency of single-crystal silicon solar cells and compound crystalline solar cells, and reducing the cost and improving the reliability of peripheral system components. Solar technologies for industrial process heat are also being investigated and developed. The renewable energy goals set in 1990 call for 6.2 percent of Japan's total primary energy supply to be provided by alternative energy sources by the year 2010 (1.4 percent in 1989). New energy sources include alcohol fuels, solar energy, black liquor, and charcoal fuel.[134]

- **Australia:** Australian researchers have produced a wide range of renewable energy innovations, but the record for commercialization of the technologies is uneven. Successfully taking renewable energy technologies from the laboratory to the marketplace remains a significant challenge. A number of federal and state government bodies are involved in research, development, and demonstration of applicable solar technologies. In the private sector, there are two photovoltaic module manufacturers, many photovoltaic system integrators and suppliers, and several major solar hot water heater manufacturers and specialty suppliers.

[134]*Solar Update: Newsletter of the International Energy Agency Solar Heating and Cooling Program*, No. 25 (June 1995).

Table 43. Estimates of Operational Wind Capacity in the European Community, 1989, 1991, 2000
(Megawatts)

Country	1989	1991	2000
Denmark	250	410	1,500
Netherlands	40	85	1,000
Germany	30	100	300
United Kingdom	7	12	300
Belgium	5	7	250
Italy	5	8	300
Spain	5	5	50
Greece	1	3	50
Ireland	1	6	150
Portugal	1	2	50
France	0	0	0
Luxembourg	0	0	0
Total	**345**	**638**	**3,950**

Source: Electric Power Research Institute, *European Wind Technology*, TR-101391 (Palo Alto, CA, March 1993), pp. 1-3.

- **New Zealand:** The government of New Zealand is committed to the development of renewable energy through a number of legislative and funding measures. Government policy seeks the creation of a market in which renewables are placed on an equal footing with conventional fuels. There are 8 manufacturers of solar water heaters in New Zealand, operating in a market roughly estimated to be between 100 and 200 domestic installations annually. The market for photovoltaics remains small and involves mainly small systems for remote area lighting and low-current applications. A grid-connected photovoltaic system is planned for two industrial projects in the near future. Other renewable technologies are also used, such as landfill gas generating plants, small hydroelectric projects, and remote area wind energy power systems. There are plans to have several geothermal stations in the near future, including a 14-megawatt plant by 1995.

Renewable Energy in Developing and Emerging Countries

In the developing regions of the world, several countries are aggressively pursuing electrification programs and will likely be the examples that other countries follow as they develop and implement electrification programs in the future. If countries like India, China, Brazil, and South Africa are successful in their efforts to meet significant portions of their energy needs through renewable energy technologies, the prospect that other countries will follow a similar path will increase substantially.

Africa

As democratization and economic liberalization efforts move forward, many African nations are attempting to improve their energy supply resources and expand their power systems to rural areas populated by millions of poor people without access to electricity. The long-term prospects for renewable power systems in these areas are optimistic, as efforts are being made to reverse the urban migration trend by installing sustainable power sources that are essential to the economic health of the rural areas.

- **South Africa:** Distribution remains the major challenge to providing all of South Africa with electricity. To address this problem, the National Electrification Forum (NEF) has devised a strategy to accelerate grid extensions and provide electricity through cost-effective standalone power sources. Some forms of renewable energy are cost-effective when developed with backup diesel power in the remote areas of the country.

  The prospects for solar thermal and photovoltaic applications in South Africa are particularly favorable, because the country is well endowed with solar resources. For example, the annual 24-hour global solar radiation average is about 220 watts per square meter in South Africa, compared with only 150 watts per square meter in parts of the United States. In cases where the application is more than 5 kilometers from the grid, the cost of photovoltaic installations is competitive with grid extension costs. South Africa imports both solar thermal collectors and photovoltaic cell and module systems manufactured in the United States. In 1993, it accounted for about 85 percent of the solar thermal collectors exported by U.S. firms to Africa.

  Recently, in a joint venture with a U.S. company, South Africa has begun producing photovoltaic energy systems. The prospects for wind energy projects in South Africa are also favorable because it has good wind resources in certain regions of the country, especially along its extensive coastline. Although wind energy systems are still not cost-effective as compared with coal-fired electricity on large-scale projects, small-scale applications—especially, hybrid configurations of wind near photovoltaic or diesel generation sites—may be more cost-effective. Unlike Latin America and parts of Asia, South Africa does not have a large hydroelectric potential because of its semi-arid climate and periodic droughts.

In addition to South Africa, the following African countries are importers of photovoltaic cell and module systems manufactured in the United States: Angola, Botswana, Burkina Faso, Egypt, Ethiopia, Ghana, Kenya, Lesotho, Nigeria, Senegal, South Africa, Swaziland, Tanzania, Uganda, Zaire, Zambia, Zimbabwe.[135]

Asia

Most of the fastest-growing emerging economies are located in Asia. In those countries with strong economic growth, there will be an increasing effort to install new electricity generation capacity to meet the energy demands accompanying strong growth and to supply electricity to rural areas now off the grid. The absence of well-established grids in most of the vast rural areas of Asia makes standalone renewable energy applications and "village-grid" renewable applications the best prospects for electrification. EIA's forecasts estimate a 3-percent annual increase in renewable energy consumption between 1990 and 2010 for Asia excluding China.[136]

The two major emerging markets for renewable energy in Asia are China and India. Near-term developments in those countries will likely influence the use of renewables in the rest of Asia. Indonesia also has a significant number of installed photovoltaic systems in remote areas, and cells and modules manufactured in the United States have been imported by India, China, Indonesia, Hong Kong, Malaysia, Nepal, Pakistan, the Philippines, Singapore, South Korea, and Taiwan.[137]

China: China is rich in hydropower, wind, solar, geothermal, and biomass resources.[138] At the end of 1993, the Chinese government estimated that it had approximately 77 megawatts of installed renewable capacity, with wind and geothermal accounting for the largest portions. China's General Development Plan expects this total to increase to 9,830 megawatts by the year 2020, with wind power accounting for 86 percent of the installed nonhydroelectric renewable energy capacity (Table 44). EIA's renewable energy consumption forecast for China estimates a 6-percent annual increase between 1990 and 2010.[139] In 1995, the U.S. Department of Energy and China's Ministry of Agriculture signed a 5-year agreement on renewable energy cooperation.

- **Wind:** China currently has 30 megawatts of installed wind capacity, with small household wind turbines accounting for 17 megawatts, and 14 wind farms with 95 wind turbines accounting for 13 megawatts. The introduction of foreign investment for project development will be encouraged through joint ventures, leading to a projected average annual growth rate of 130 to 150 megawatts of wind capacity. China also expects to manufacture wind turbines by 2000.
- **Photovoltaics:** Photovoltaic technology has been widely used in remote standalone electricity applications (e.g., for telecommunication) and is also being used to supply electricity to households in remote locations. At the end of 1993, 3.3 megawatts of solar cells were in use in China. In the years ahead, China plans to use photovoltaics mainly in remote mountainous districts and islands along the coasts, where electricity for households is not available. China forecasts that, by the year 2000, photovoltaics will supply electricity to approximately 6 million of the 120 million rural residents currently without electricity.

Table 44. China's General Development Plan for New Renewable Generation Capacity by Type, 1993-2010
(Megawatts)

Year	Wind	Solar	Ocean	Geothermal	Biomass	Total
1993	30	3	6	30	7	**77**
2000	1,040	70	40	106	20	**1,276**
2010	3,170	200	200	200	45	**3,815**

Note: Totals may not equal sum of components due to independent rounding.
Source: National Renewable Energy Laboratory, Analytic Studies Division, "International Renewable Energy: Prospects, Initiatives, and Projects," unpublished final report prepared for the Energy Information Administration (Golden, CO, August 1995).

[135]Energy Information Administration, *Solar Collector Manufacturing Activity 1993*, DOE/EIA-0174(93) (Washington, DC, August 1994).
[136]Energy Information Administration, *International Energy Outlook 1995*, DOE/EIA-0484(95) (Washington, DC, June 1995).
[137]Energy Information Administration, *Solar Collector Manufacturing Activity 1993*, DOE/EIA-0174(93) (Washington, DC, August 1994).
[138]Unless otherwise indicated, the source for information in this section is Yin Liem, *Renewable Energy Programs and Projects* (Beijing, Peoples Republic of China: Ministry of Electric Power, December 1994).
[139]Energy Information Administration, *International Energy Outlook 1995*, DOE/EIA-0484(95) (Washington, DC, June 1995).

- **Ocean:** As of 1993, China had 10 small tidal power stations totaling 6 megawatts of generating capacity. In the near term, China feels that tidal energy should be developed only on a relatively large scale.

- **Geothermal:** China's first low-temperature geothermal power plant was built in the Fengshun Guangdong province in 1979. At the end of 1993, approximately 30 megawatts of installed geothermal capacity existed in China.

- **Hydropower:** China has a large hydroelectric potential and an ambitious expansion program underway.[140] Currently, there are more than 150 hydroelectric projects under construction in China. The most significant is the Three Gorges dam along the Yangtze River, which would be the world's largest, with an estimated cost of $20 billion and an installed capacity of 18 gigawatts.

India: Although India is experiencing strong economic growth and rising energy demand, its electricity supply is plagued by low plant load factors and inadequate plant availability.[141] In order to meet its growing energy needs, India has adopted a blend of thermal, hydroelectric, and nuclear sources for power generation, as well as such alternative energy sources as solar, wind, and tidal energy, which will total approximately 35,000 megawatts of installed capacity by the year 2000.[142] The Ministry of Non-Conventional Energy Sources (MNES) has laid out a series of financial incentives to attract investors.

- **Wind:** Wind energy is one of the new technologies most strongly supported by the Indian government, which has developed a comprehensive strategy and program for harnessing wind energy, including the creation of a wind resource data base, indigenous technology development and field testing, demonstration projects, incentives for commercialization, and technical training. Over the past decade, the MNES has constructed a wind map of India and has identified 69 locations where wind velocities are high and constant enough to ensure profitable electricity generation. The total power generation capacity in those locations is estimated to exceed 20,000 megawatts.[143]

- **Solar:** Second to wind power generation, solar power has a high potential in India. U.S. manufacturers of solar thermal collectors and photovoltaic cells and modules count India as an important export market.

- **Hydropower:** Small hydroelectric projects also have a strong potential in India. Studies indicate that these projects are almost as profitable as wind energy power generation. The potential for small hydroelectric power generation is estimated to be over 20,000 megawatts. Under various programs, 142 projects, totaling 105 megawatts of capacity, have been implemented, and another 155 projects with 196 megawatts total capacity are in progress.[144]

Indonesia: With over 6,000 islands having remote villages that are not connected to the electricity grid, Indonesia's geography is ideally suited for standalone renewable applications, particularly photovoltaic systems. Some 25,000 photovoltaic systems have been installed with government funds or assistance from foreign organizations and through hire-purchase by the users themselves.[145]

The Americas

Total electric capacity additions in Latin America[146] from 1990 to 2000 are expected to be 41.6 gigawatts

[140]Energy Information Administration, *International Energy Outlook 1995*, DOE/EIA-0484(95) (Washington, DC, June 1995), and *Country Analysis Briefs 1994*, DOE/EIA-0595 (Washington, DC, May 1995).

[141]J.J. Thakkar, *The Electric Power Transmission and Energy Demand Management Market in India* (Bombay, India: American Consulate General, July 1993). Available from U.S. Department of Commerce, International Trade Administration, National Trade Data Bank, file number ISA9307.

[142]*India: Renewable Energy Market Overview*, derived from a telegraphic report dated 12 April 1994, prepared at the American Consulate, Bombay, India. Available from U.S. Department of Commerce, International Trade Administration, National Trade Data Bank, file number IMI940412.

[143]*India: Renewable Energy Market Overview*, derived from a telegraphic report dated 12 April 1994, prepared at the American Consulate, Bombay, India. Available from U.S. Department of Commerce, International Trade Administration, National Trade Data Bank, file number IMI940412.

[144]*India: Renewable Energy Market Overview*, derived from a telegraphic report dated 12 April 1994, prepared at the American Consulate, Bombay, India. Available from U.S. Department of Commerce, International Trade Administration, National Trade Data Bank, file number IMI940412.

[145]"Sinar Surya: Solar Energy in Indonesia," *Renewable Energy* (August 23, 1995). On-line information from the Solstice database.

[146]Latin America is defined here to include all primarily Romance language (Spanish, French, and Portuguese) speaking countries in North, Central, and South America.

(Table 45), of which 85 percent is expected to be hydroelectric.[147] Most of the capacity additions will be concentrated in Argentina, Brazil, Chile, Columbia, Mexico, and Venezuela. EIA's renewable energy consumption forecasts estimate 3-percent annual growth for Canada and Mexico between 1990 and 2010.[148]

Financing is a major concern as Latin America attempts to increase its electric power capacity. This has driven Latin American governments, many of which maintain strong control of the energy sector, toward forming partnerships with private capital and separating the regulatory role of the government from the operational role of energy companies.[149] Along with regulatory reform, the increased "market access" resulting from the North American Free Trade Agreement (NAFTA) should make capital more accessible for renewable projects planned in Latin America.[150]

Environmental concerns are also driving Latin America's electricity generation agenda. The environmental benefits of many renewable energy technologies, along with their decreasing costs and appropriateness to many of Latin America's rural areas, ensure that the prospects for renewable energy projects will remain favorable in the years ahead. Prospects for renewable energy for some specific countries in the Americas, including Canada, are summarized below.

- **Brazil:** Brazil provides some of the best prospects for renewable energy projects in Latin America. The combination of economic growth and regulatory reform in the energy sector is providing a fertile environment for renewables. Hydropower currently provides 95 percent of Brazil's total energy, and its potential is believed to be 261 gigawatts.[151] Before the year 2000, Brazil expects to complete the expansion of two major hydroelectric plants with a combined capacity of 20 gigawatts.[152] Brazil's large biomass resources, especially sugar cane residues, also make the prospects favorable for thermal electric projects in the years ahead. The potential for solar and wind energy is also good in Brazil, where about 20 million people live without electricity. Joint projects, such as the U.S.-Brazilian Renewable Energy Electrification Project (REEP), are now bringing electricity to rural homes.

- **Canada:** Canada has pursued extensive development of hydroelectric power resources since the 1970s.[153] Beyond hydroelectricity, only modest development of renewable resources has taken place. For example, in 1992 Canada consumed less than 30 million kilowatthours of nonhydroelectric renewable resources. Government funding for renewable energy is much lower today than it was a decade ago due to fiscal restraint polices. However, significant research and development programs remain in the areas of solar and photovoltaics. Government support for renewable energy is carried out through the funding and research and development programs of the Efficiency and Alternative Energy Technology Branch (EAETB) of the Canada Centre for Mineral and Energy Technology (CANMET).

  In the private sector, there are about 15 small and medium-sized Canadian companies that manufacture solar products. Sales in 1991 and 1992 reached an estimated $2 million (U.S. dollars). The market for passive solar technologies, such as high-performance windows, was estimated at about 1.2 million square meters in 1991. Total photovoltaic sales estimates for 1993 are $12 million, but most of

Table 45. Installed Generating Capacity in Latin America and the Caribbean by Type, 1990 and 2000
(Gigawatts)

Year	Hydroelectric	Thermal Steam	Gas-Fired	Oil-Fired	Geothermal	Nuclear	Total
1990	92.8	51.1	7.2	3.9	0.9	2.8	**158.7**
2000	128.2	53.0	10.5	3.5	2.0	3.1	**200.3**

Source: National Renewable Energy Laboratory, Analytic Studies Division, "International Renewable Energy: Prospects, Initiatives, and Projects," unpublished final report prepared for the Energy Information Administration (Golden, CO, August 1995).

[147]F. Gutierrez, "Region in Transition," *Independent Energy* (January 1995), pp. 33-37.
[148]Energy Information Administration, *International Energy Outlook 1995*, DOE/EIA-0484(95) (Washington, DC, June 1995).
[149]F. Gutierrez, "Region in Transition," *Independent Energy* (January 1995), pp. 33-37.
[150]NAFTA currently includes Mexico, Canada, and the United States; Chile is likely to be added in the near future.
[151]"GWe in Brazil; Small-Scale in Indonesia," *Solar Letter* (May 13, 1994), p. 109.
[152]Energy Information Administration, *International Energy Outlook 1995*, DOE/EIA-0484(95) (Washington, DC, June 1995).
[153]Energy Information Administration, *International Energy Outlook 1995*, DOE/EIA-0484(95) (Washington, DC, June 1995).

the activity is in distribution rather than manufacturing. The most common application is standalone systems for remote areas. Total installed photovoltaic capacity in Canada is about 800 kilowatts.

- **Mexico:** The government of Mexico places great importance on the development of renewable energy. Through the Comisión Federal de Electricidad (CFE), Mexico's only utility, the government has developed geothermal and hydroelectric resources. By 1989, these two renewable resources had shares of 3 and 32 percent of Mexico's total installed generating capacity, respectively.[154] In addition, standalone photovoltaic systems have been installed in more than 60,000 locations. Although there was a marked decrease in imports of photovoltaic system in 1995 due to the ongoing financial crisis, Mexico's prospects for near-term recovery, close links to U.S. exporters, abundance of renewable resources, and government and private sector commitment to renewable technologies are likely to translate into continued growth of renewable resource use in the near future.

In the Americas, the following countries are importers of solar thermal collectors manufactured in the United States: Antigua, Bahamas, Bermuda, Canada, Chile, Columbia, Costa Rica, Haiti, Jamaica, Mexico, and Trinidad. The following countries are importers of photovoltaic cell and module systems manufactured in the United States: Argentina, Belize, Bolivia, Brazil, Canada, Columbia, Costa Rica, Dominican Republic, Ecuador, Haiti, Caribbean countries, Mexico, Panama, Peru, and Venezuela.[155]

Conclusions

The prospects for international renewable energy developments are perceived by many to be stronger than for domestic markets. A variety of factors account for this perception:

- Many developing countries are experiencing strong economic growth and need to improve their energy systems for growth to continue.
- A variety of efforts are underway to bring electricity to the estimated 2 billion people currently living without it. A significant share of the population resides far away from the nearest power grid, increasing the potential need for standalone renewable systems.
- Renewables can be cost-effective in off-grid applications, providing electricity for lighting, communications, and water pumping to relatively isolated areas.
- The need for international capital to help finance the expansion of energy systems is motivating the governments of many developing countries to enact policies designed to reduce state control of the energy industry, foster joint public-private programs, and remove barriers to the inflow of foreign capital.
- International organizations, such as the World Bank and the United Nations, are giving renewables increased attention relative to pre-1970 levels. These and other multilateral organizations will continue to offer a number of funding opportunities for renewable energy projects.
- Many foreign governments have enacted policies to encourage the development and implementation of renewable energy programs.

[154] Energy Information Administration, *International Energy Outlook 1995*, DOE/EIA-0484(95) (Washington, DC, June 1995).
[155] Energy Information Administration, *Solar Collector Manufacturing Activity 1993*, DOE/EIA-0174(93) (Washington, DC, August 1994).

Appendices

Appendix A
EIA Renewable Energy Data Sources

The Energy Information Administration (EIA) develops renewable energy information from a wide variety of sources, cutting across different parts of the organization. This appendix provides a list of all sources which the EIA uses to obtain renewable energy information. While most data come from EIA data collection forms, some are derived from secondary sources. For EIA data collections, additional information is available in the EIA publication *Directory of Energy Data Collection Forms*, DOE/EIA-0249(94), December 1994. Instructions on obtaining this publication are contained in the report Preface.

CE-63A/B, "Annual Solar Thermal Collector Manufacturers Survey" and "Annual Photovoltaic Module/Cell Manufacturers Survey"

Energy Sources: Solar energy.
Energy Functions: Disposition.
Frequency of Collection: Annually.
Respondent Categories: Photovoltaic module/cell manufacturers and/or importers; solar thermal collector manufacturers and/or importers.
Description: Forms CE-63A/B are designed to gather for publication data on shipments of solar thermal collectors and photovoltaic modules. Data are collected by end use and market sector. Collector types include low-temperature, medium-temperature air, medium- temperature liquid, thermosiphon, flat plate, concentrator, integral collector storage, and evacuated tube and concentrators. Respondents are manufacturers, importers, and exporters of solar thermal collectors and photovoltaic modules.

EIA-176, "Annual Report of Natural and Supplemental Gas Supply and Disposition"

Energy Sources: Natural gas; synthetic fuels.
Energy Functions: Consumption; costs and/or prices; disposition; supply; transportation.
Frequency of Collection: Annually.
Respondent Categories: Natural gas distributors (including importers/exporters); natural gas pipelines; natural gas processors; natural gas producers.
Reporting Requirement: Mandatory.
Description: Form EIA-176 is designed to provide data on the consumption of natural gas by major end-use category, demand, and prices by State for various analyses and publications. Data collected include the origin of natural gas supplies and the disposition of natural gas on a State basis. Respondents include natural and synthetic gas producers, processors, distributors, storage operators, and pipeline operators.

EIA-457A/H, "Residential Energy Consumption Survey"

Energy Sources: Coal and coal products; electricity; natural gas; petroleum and petroleum products; wood.
Energy Functions: Consumption costs and/or prices.
Frequency of Collection: Triennially.
Respondent Categories: Electric utilities; natural gas distributors (including importers/exporters); petroleum and petroleum product distributors; institutions (nonprofit); individuals/households.
Reporting Requirement: Voluntary and mandatory.
Description: Forms EIA-457A through G are used to collect comprehensive national and regional data on both the consumption of and expenditures for energy in the residential sector of the economy. Data are used for analyzing and forecasting residential energy consumption. Housing, appliance, and demographic characteristics data are collected via personal interviews with households, and consumption and expenditure billing data are collected from the energy suppliers. End-use intensities are produced for space heating, water heating, air conditioning, refrigerators, and appliances. Rental agents are contacted by telephone to check on fuels used in rented apartments. Surveys were conducted in 1978, 1979, 1980, 1981, 1982, 1984, 1987, 1990, and 1993. Form EIA-457H is used to collect detailed lighting usage information for a subsample.

EIA-846(A,B,C), "Manufacturing Energy Consumption Survey"

Energy Sources: Coal and coal products; electricity; natural gas; petroleum and petroleum products; wood.
Energy Functions: Consumption; disposition; financial; and/or management; production; research and development; other energy functions.
Frequency of Collection: Triennially.
Respondent Categories: Manufacturing.
Reporting Requirement: Mandatory.
Description: Forms EIA-846A through D are used to collect information on energy consumption, energy usage patterns, and fuel-switching capabilities of the manufacturing sector of the U.S. economy. The information from this survey is used to publish aggregate statistics on the consumption of energy for fuel and nonfuel purposes; fuel-switching capabilities; and certain energy-related issues; such as energy prices, on-site electricity generation, and purchases of electricity from nonutilities. Since 1991, the survey has also collected information on end users of energy, participation in energy management programs, and penetration of new technology. Respondents are a sample of manufacturing establishments in Standard Industrial Classification categories 20 through 39.

EIA-860, "Annual Electric Generator Report"

Energy Sources: Electricity.
Energy Functions: Financial and/or management; production.
Frequency of Collection: Annually.
Respondent Categories: Electric utilities.
Reporting Requirement: Mandatory.
Description: Form EIA-860 is used to collect data on the status of electric generating plants and associated equipment in operation and those scheduled to be in operation in the United States within 10 years of filing of the report. These data are used to maintain and update EIA's electric power plant frame data base. Data are collected on power plant sites, and the design data of electric generators. Respondents include each electric utility that operates, or plans to operate, a power plant in the United States within 10 years of the report.

EIA-861, "Annual Electric Utility Report"

Energy Sources: Electricity.
Energy Functions: Disposition; financial and/or management; production.
Frequency of Collection: Annually.
Respondent Categories: Electric utilities.
Reporting Requirement: Mandatory.
Description: Form EIA-861 is a mandatory collection of data, filed annually by each electric utility in the United States, its territories, and Puerto Rico. The survey collects data on generation, wholesale purchases, and sales and revenue by class of consumer and State. These data are used to maintain and update the EIA's electric utility frame data base. This data base provides information to answer questions from the Executive Branch, Congress, other public agencies, and the general public. Respondents include each electric utility that is a corporation, person, agency, authority, or other legal entity or instrumentality that owns or operates facilities within the United States, its territories, or Puerto Rico for the generation, transmission, distribution, or sale of electric energy primarily for use by the public.

EIA-867, "Annual Nonutility Power Producer Report"

Energy Sources: Electricity.
Energy Functions: Production.
Frequency of Collection: Annually.
Respondent Categories: Nonutility power producers.
Reporting Requirement: Mandatory.
Description: Form EIA-867 is used to collect data annually from nonutility power producers who own or plan on installing electric generation equipment with a total capacity of one megawatt or more at an existing or proposed site. Electricity generation, installed capacity, and energy consumption data are collected. These data will be used to augment existing electric utility data and for electric power forecasts and analyses.

EIA-871A/F, "Commercial Buildings Energy Consumption Survey"

Energy Sources: Electricity; natural gas; natural gas products; petroleum and petroleum products; wood; other energy sources.
Energy Functions: Consumption; costs and/or prices.
Frequency of Collection: Triennially.
Respondent Categories: Commercial buildings; electric utilities; natural gas distributors (including importers/exporters); petroleum and petroleum product distributors; other (industry); Federal government institutions (nonprofit).
Reporting Requirement: Voluntary and mandatory.
Description: Forms EIA-871A through F are used to collect information for the Commercial Buildings Energy Consumption Survey (CBECS). The survey provides comprehensive national and regional information on the consumption of, and expenditures for, energy in the commercial sector of the economy.

Data are used in EIA models and published in statistical and analytical reports. Physical characteristics information for commercial buildings is collected by personal interviews with building owners and managers using Form EIA-871A. Billing and consumption data for the buildings are collected by mail from individual energy suppliers by using Forms EIA-871C through F (depending upon the energy source). Supplemental information on construction improvements, maintenance, and repairs is collected for the Bureau of the Census by using Form EIA-871G. This survey was renamed the CBECS in 1989. Previously it was conducted under the name of Nonresidential Buildings Energy Consumption Survey.

EIA-886, “Alternative Fuel Vehicles Suppliers’ Annual Report”

Energy Sources: Alternative motor fuels.
Energy Functions: Production; supply.
Frequency of Collection: Annually.
Respondent Categories: Other (industry); Federal government; State government; local government Institutions (nonprofit); individuals/households.
Reporting Requirement: Mandatory.
Description: Form EIA-886 is an annual survey of the number of alternative fuel vehicles (AFVs) made available on a calendar year basis. The data will be used to track the AFV supply situation for the Federal Government, State Governments, and fuel providers to acquire AFVs. Respondents are AFV manufacturers, importers, and conversion companies.

Appendix B
Renewable Data Limitations

This appendix provides information about the quality of renewable energy consumption data presented in Section I of this report. Information pertinent to renewable energy source data quality, in general, is presented, followed by fuel-specific information.

Obtaining complete information on renewable energy projects poses special challenges due to their nature. One challenge is the dispersed nature of many renewable energy forms, such as a photovoltaic (PV) system for generating electricity that may operate in a "stand-alone" fashion in a remote location. If the facility is not connected to an electricity grid, there is no Federal regulatory requirement to report its operating information. Tracking down hundreds or thousands of such facilities, each with a small power output, can be extremely challenging.

Another challenge involves tracking renewable energy supplies. Conventional energy supplies, such as petroleum, are easily tracked because the distribution networks (usually pipelines) are limited and well-defined. This permits one to make reasonable assumptions about fuel consumption, assuming stocks can be reasonably estimated.[156] The same cannot be said for many renewable energy supplies. Often, a large number of energy consumers must be surveyed in order to make reasonable inferences about renewable energy consumption. Wood, for example, is gathered by tens of thousands of entities for fuel uses not reportable for regulatory purposes. Thus, obtaining accurate data on wood energy consumption would entail conducting large consumption surveys.

Finally, some renewable energy sources are byproducts (such as pulping liquor) of non-energy processes. To track such uses, information must be solicited from respondents not generally considered to be in the energy supply chain.

Electricity[157]

As noted in Chapter 1, 63 percent of renewable energy consumption measured by EIA is used to produce electric power. It is therefore important to examine the coverage quality of EIA renewable electricity data. EIA renewable electricity generation is derived from two principal sources: Form EIA-759, "Monthly Power Plant Report" and Form EIA-867, "Annual Nonutility Power Producer Report." Form EIA-759 is sent to all utilities, while the EIA-867 is required of all other facilities exceeding 1 megawatt capacity. (This includes facilities which meet Federal Energy Regulatory Commission [FERC] standards as a "qualifying facility" [QF], as well as independent power producers [IPPs]). Therefore, off-grid electric applications are not captured here (although they may be covered in EIA's Manufacturing Energy Consumption Survey[158]).

Because electric utilities are easily identified, seldom change business status, and have mandatory regulatory reporting requirements, complete coverage of utility-generated electricity is virtually assured. In contrast, nonutilities (i.e., QFs and IPPs) are required only to file regulatory reports at the time of their intention to become a grid electricity-producing facility. Over time, QF ownerships and locations change frequently. These factors, combined with the large number of QF applications, make tracking these facilities difficult. Accordingly, EIA has developed a threshold below which nonutility units are not surveyed. Prior to 1991, there was no threshold; all units discovered were surveyed. For 1991 and 1992, EIA surveyed only nonutility generating units greater than 5 megawatts. In 1993, EIA modified the threshold to 1 megawatt. Data shown in Section I are statistically adjusted to place data for 1990-1994 on a 1 megawatt threshold basis. This has the effect of making the data prior to 1993 slightly less accurate.

[156] Even if stock data are only approximate, conventional energy stocks are normally a small percentage of production.

[157] Information in this section is based on the report, "Renewable Energy Frame Review Updated Report: Survey Sampling Frame and Electricity Discrepancy Estimates," by Decision Analysis Corporation of Virginia (Vienna, Virginia, August 1993).

[158] Because the MECS is based on the Bureau of the Census' Annual Survey of Manufacturers, EIA does not know the identity of MECS respondents.

Form EIA-867 coverage is particularly weak for facilities producing electricity from municipal solid waste (MSW). Accordingly, EIA uses information provided by Governmental Advisory Associates (GAA) reports, namely, the "Resource Recovery Yearbook" and "Methane Recovery Yearbook," to develop its waste-generated electricity estimates.

An analysis of the Form EIA-867 universe indicates that the survey's capacity undercoverage varies between 3 and 10 percent, depending on the fuel source (Table B1). Capacity and unit coverage are the most difficult for wind, where numerous small units exist. EIA has analyzed the differences between capacities reported for identical renewable units on Form EIA-867 and alternative sources. Capacity discrepancies were found to result from four factors:

- Obsolete information.
- Facility versus generator reporting: A non-EIA source may cite capacity figures for an entire facility, not taking into account individual generators that use conventional fuels or a mixture of conventional and renewable fuels.
- Capacity definition differences: Form EIA-867 requests respondents to report nameplate electric capacity. However, alternative capacity measures are being reported on non-EIA data sources.
- Numerical rounding practices: This has the greatest effect on small units.

In a followup study of capacity discrepancies, the EIA-867 was over four times more likely to have the correct value than the alternative source, which covered units of all sizes.

EIA has attempted to compare GAA data on MSW with information used by the U.S. Environmental Protection Agency (EPA). However, definitional differences make data quality evaluation difficult.

Non-Electric Renewable Energy Consumption

Overview

The primary application for renewable energy other than making electricity is creating heat, for industrial processes, buildings, or water. Most non-electric consumption data are gathered on two EIA consumption surveys: the Manufacturing Energy Consumption Survey (MECS), and the Residential Energy Consumption Survey (RECS). MECS is based on the U.S. Bureau of the Census' Census of Manufacturing. As far as renewable energy is concerned, MECS provides consumption estimates of total industrial energy and various categories of biomass, including wood. RECS is based on an area probability sample of households selected by EIA. For renewable energy, it provides estimates of residential wood energy consumption.

Table B1. Evaluation of EIA's Undercoverage of Nonutility Electricity Data

Fuel	Source	Number of Facilities[a]	Capacity
Biomass	EIA-867[b] (≥ 1 MW)	471	14,090
	"Electricity Discrepancy Estimates"[c]	759	15,037
Geothermal	EIA-867	48	1,551
	"Electricity Discrepancy Estimates"	57	1,590
Wind	EIA-867	82	1,803
	"Electricity Discrepancy Estimates"	739	1,992
Solar	EIA-867	11	365
	"Electricity Discrepancy Estimates"	152	374

Source: Energy Information Administration, Form EIA-867, "Annual Nonutility Power Producer Report."

[a]Excludes some EIA-867 facilities that could not be matched with facilities contained in non-EIA data sources.

[b]Based upon the 1991 survey year. Excludes *some* EIA-867 facilities that could not be matched with facilities contained in non-EIA data sources. The 1991 EIA-867 survey did not indicate what nonutility facilities under 5 megawatts are renewable.

[c]"Renewable Energy Frame Review Updated Report: Survey Sampling Frame and Electricity Discrepancy Estimates," by Decision Analysis Corporation of Virginia, August 2, 1993.

There are two other non-electric applications for renewable energy: solar heating and alcohol transportation fuels. Solar energy for non-electric applications is derived from the EIA Solar Collector Manufacturing Survey, Form CE-63A/B. The survey does not collect energy "consumption," but rather production statistics on various types of solar and photovoltaic energy units. EIA applies additional assumptions regarding their application to estimate the amount of heat energy derived from solar/PV panels installed. (See Chapter 5 for further discussion.) Alcohol fuel consumption information is provided by the Form EIA-819M, "Monthly Oxygenate Telephone Report."

Biomass

Wood is the principal component of biomass energy. Information on non-electric wood energy consumption is derived from the MECS and RECS surveys.

Although some questions about MECS coverage have been raised, no formal analysis of current data exists to support this concern. According to 1983 U.S. Forest Service statistics on wood harvested for fuelwood, the Pulp and Paper Industry subgroup of the Forest Products Industry group consumed only 42 percent of total sector wood energy, not including black liquor (a byproduct fuel). MECS surveys the smaller-populated Pulp and Paper Industry intensively but only randomly samples the larger-populated remainder of the Forest Products Industry. For a variety of reasons, it is difficult to trace wood energy supply to wood consumed for energy. RECS covers wood consumption only for the primary residence of those surveyed; thus, wood consumption by second homes is omitted. This causes residential wood energy consumption to be understated by about 5 percent.

Cross-checks of Form EIA-819M information on alcohol fuels with data from the Bureau of Alcohol, Tobacco, and Firearms and the U.S. Department of Transportation have not revealed any major deficiencies in the Form EIA-819M data.

Geothermal

EIA does not collect data on non-electric applications of geothermal energy such as crop drying and groundwater heat pumps. A study prepared for the DOE Office of Energy Efficiency and Renewable Energy, Geothermal Division, indicates that direct uses of geothermal energy, expressed in electric equivalents, amounted to nearly 4.2 gigawatthours in 1993 (Table B2). Sixty percent of this energy was provided by geothermal heat pumps.

Wind, Solar and Photovoltaic

EIA does not collect information on direct energy uses of wind (e.g., water-pumping). No comprehensive source of such information is known.

The data collected on Forms CE-63A and CE-63B are subject to various limitations: (1) coverage (the list of respondents may not be complete or, on the other hand, there may be double counting); (2) nonresponse

Table B2. Geothermal Energy Supplied for Major Direct Use Applications, 1993

Application	Number of Projects	States[a]	Temperature Range (C)	Capacity (MW)	Annual Energy (GWh/yr)
Space & District Heating[b]	123	6	26 to 166	169	386
Geothermal Heat Pumps	[c]168,000	50	6 to 39	1,733	2,403
Greenhouses	38	8	37 to 110	81	197
Aquaculture	27	9	16 to 93	104	574
Resorts & Spas	190	14	24 to 93	71	446
Industrial	12	6	86 to 154	43	176
Total				**2,242**	**4,181**

Source: P.J. Lienau, J.W. Lund, K. Rafferty, and G. Culver, *Reference Book on Geothermal Direct Use*, (August 1994), p. 4.
[a]Number of States where projects are located.
[b]Differs from 1990 inventory (Lund, 1990) because Mammoth Lakes and Bridgeport geothermal district heating systems were not built; therefore, they are not included in the inventory.
[c]Number of equivalent 3-ton geothermal heat pump units.

(some of those surveyed may not respond, or they may not provide all the information requested); and (3) adjustments (errors may be made in estimating values for missing data).

The universe of respondents is a census of those U.S.-based companies involved in manufacturing and/or importing solar collectors and photovoltaic cells and modules. Care has been taken to establish the survey frames accurately. The frames of potential respondents are compiled from previous surveys and from information in the public domain. However, because the solar collector and photovoltaic cell and module industries are subject to sporadic entry and exit of manufacturers and importers, the frame may exclude some small companies that have recently entered or reentered the industry.

From 1991 through 1994, EIA received reports from all known potential respondents. During the 1990 Form CE-63B survey period, however, one photovoltaic manufacturer that was known to have shipped photovoltaic cells and modules during the first half of the year went out of business during the second half, and no data were acquired. For that company, 1990 shipments were estimated at one-half of the shipments reported for 1989.

During 1986, the solar thermal collector manufacturing industry experienced a substantial slowdown in shipments as a result of lower conventional energy prices and the expiration of the solar tax credit at the end of 1985. Reported shipments declined from 16.4 million square feet in 1984 to 4.9 million square feet in 1986. Many of the 1986 shipments probably occurred during the first quarter, as customers took delivery of materials purchased in late 1985, when solar tax credits were still available. Although reported shipments in 1985 were only 68 percent of those reported in 1984, it is likely that actual shipments were higher in 1985, which was believed to be a banner year because of the impending expiration of the energy tax credit. The number of companies reporting 1985 shipments and, therefore, the reported shipments may have been low because many of the companies had gone out of business by the time the survey was conducted (in early 1987) and could not be located.

Appendix C
Procedures for Estimating Biomass Consumption Levels

Procedure for Industrial Sector Woodfuel Consumption

Industrial wood consumption data for 1990 were derived using the 1988 Manufacturing Energy Consumption Survey (MECS) conducted by EIA. Estimates for 1990 were developed by multiplying the 1988 MECS wood energy consumption value by the ratio of total industrial energy consumption in 1990 to total industrial energy consumption in 1988.

For 1991, consumption estimates from the 1991 MECS survey were used.

For 1992 through 1994, estimates were based on the 1991 MECS survey, combined with an assumed growth rate of just under 2 percent annually. This reflects historical growth in the pulp and paper industry, the largest industrial consumer of wood energy.

MECS data used include selected wood inputs of energy for heat, power, and electricity generation consumed in the following fuel categories:

- Waste materials
- Pulping liquor
- Roundwood
- Wood chips, etc.

Regional and sectoral woodfuel consumption values from 1991 through 1994 were derived by applying the 1990 sectoral and regional distributions presented in *Estimates of U.S. Biofuels Consumption 1990*. This procedure was used because significant portions of the 1991 MECS wood consumption data by industrial sector and by region were withheld due to disclosure requirements and/or estimated standard errors that were greater than 50 percent.

Procedure for Residential Sector Woodfuel Consumption

Residential woodfuel consumption estimates for 1990 through 1994 could not be obtained from EIA surveys. The most recent data reported in EIA's Residential Energy Consumption Survey (RECS) were for 1990 (582 trillion Btu total). The procedure used for estimating residential fuelwood consumption these years consisted of applying the ratios of population-weighted *regional* heating degree days to each regional RECS value, respectively. Use of this procedure was based on the assumption that the residential sector consumed the same amount of wood per heating degree-day.

For 1990, survey estimates from the 1990 RECS were used. For 1991, consumption was estimated as follows:

$$C = C' (a/b)$$

where:

C = 1991 estimated consumption
C' = 1990 RECS consumption
= 582 trillion Btu
a = heating degree-days for 1991.
b = heating degree-days for 1990.

The same approach was used to estimate 1992 through 1994 residential woodfuel consumption.

Procedure for Electric Utility Sector Woodfuel Consumption

The 1990 through 1994 electric utility woodfuel consumption data were obtained by contacting each electric utility that reported woodfuel use on Form EIA-759, "Monthly Power Plant Report," to determine the number of short tons burned by each facility in each year. For plants that reported consumption in short tons of green wood (tons of wood containing 50 percent or more water by weight), consumption data were converted into oven-dried short tons using the following formula:

$$ODST = GT \times CF$$

where:

$ODST$ = oven-dried short ton.
GT = green tons consumed
CF = (8,000,000 Btu per green ton) / (17,200,000 Btu per oven-dried short ton)
= 0.465 oven-dried short tons per green ton.

Procedure for MSW and Landfill Gas Estimates

Municipal solid waste (MSW) and landfill gas estimates for 1992 were derived from data contained in Governmental Advisory Associates (GAA), *Resource Recovery Yearbook*[159] and *Methane Recovery Yearbook.*[160] The following specific steps were taken to calculate both MSW and landfill gas consumption estimates for 1992.

Municipal Solid Waste

Steam Plants. For steam-only plants, the following equation was used:

> *Thermal output (trillion Btu) = [Steam output (pounds per hour) × Btu per pound of steam × days operating per year × 24 hours per day]* / 10^{12}.

Electricity Plants. For electricity-only plants, the following equation was used:

> *Thermal output (trillion Btu) = [MSW throughput (tons per day) × 2,000 pounds per ton × days operating per year × Btu per pound of MSW]* / 10^{12}.

Electricity and Steam Plants. For electricity-and-steam plants, the equation for electricity-only plants was used.

Landfill Gas (Methane)

The following equation was used to derive estimates of consumption for 1990:

> *Thermal output (trillion Btu) = [Cubic feet of methane produced per day × Btu per cubic foot of methane × (365 days - days shut down)]* / 10^{12}.

For plants producing pipeline-quality gas, the Btu per cubic foot value for treated gas was used. Data for 1992 are not yet available; however, GAA estimates that by the beginning of 1994, landfill gas energy consumption had increased by 25 percent from 1990 levels. The estimates for 1990 were increased by 25 percent to obtain 1992 consumption.

Procedure for Manufacturing Waste Estimates

The 1991 and 1992 manufacturing waste estimates were derived by applying the 1991 / 1990 and 1992 / 1990 total industrial energy consumption ratios to the estimated 1990 values, respectively.

Procedure for Fuel Ethanol Consumption Estimates

The 1992 through 1994 ethanol consumption estimates were derived from EIA's (Petroleum Supply Division) ethanol production data, change in stocks, and net imports as reported on Form EIA-819M. Specifically, consumption was derived as:

> *Consumption = Production - Stock Changes.*[161]

Fuel ethanol consumption estimates for 1990 and 1991 were compiled from fuel alcohol production and import data collected by the Bureau of Alcohol Tobacco and Firearms (BATF) and fuel ethanol export data collected by the Foreign Trade Office, Bureau of the Census. BATF production data were collected from two statistical releases, "Alcohol Fuel Production" and "Distilled Spirits." The Bureau of the Census fuel ethanol export data were obtained from Schedule B, Commodity Number 2207.20.0000, "Ethyl Alcohol, Denatured of Any Strength (for Nonbeverage Use)."

Fuel ethanol consumption was derived from the two BATF statistical releases and Bureau of the Census export data as follows:

> *Fuel Alcohol Production + Imports for Fuel Use - Exports of Ethyl Alcohol.*[162]

BATF alcohol fuel production and import data are reported in proof gallons and have been converted to wine gallons. (Two proof gallons are approximately equal to one wine gallon). Census export data were reported in wine gallons prior to 1989 and in liters thereafter. Export data reported in liters have been converted to wine gallons. (One liter is equal to 0.264 gallons). A heating value of 76,400 Btu per gallon was used to convert gallons to Btu.

Regional distributions for all years were based on gasohol sales data published by the U.S. Department of Transportation, Federal Highway Administration.[163]

[159]Governmental Advisory Associates, Inc., *Resource Recovery Yearbook* (New York, NY, 1993).

[160]Governmental Advisory Associates, Inc., *1993-94 Methane Recovery from Landfill Yearbook* (New York, NY, 1994).

[161]Imports and exports of ethanol were assumed to be equal.

[162]Data on fuel alcohol stocks are not available. Consequently, fuel alcohol consumption data presented in this report are based on the assumption that change in fuel alcohol stocks is zero in each year.

[163]U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics* (various issues), Table MF-33GLA, "Monthly Gasohol Reported by States."

Appendix D
Renewable Electric Plant Information System (REPIS) Data Base

The National Renewable Energy Laboratory (NREL), under contract with the Energy Information Administration (EIA), has updated the Renewable Electric Project Information System (REPiS), a cost and performance database of existing renewable electric generating facilities, originally developed in 1987. The REPIS database represents an attempt to characterize and document the current status of renewable electric project development in the United States, using publicly available data.

Table D1. Installed Operating Capacity, by Technology, as of December 31, 1994
(Kilowatts)

Fuel Resource Type	Technology					
	Bioenergy	Geothermal	Hydro	Photovoltaic	Solar Thermal	Wind
Agricultural Residues (Waste)	556,325	--	--	--	--	--
Biogas	839,463	--	--	--	--	--
Geothermal Steam	--	2,904,858	--	--	--	--
Municipal Solid Waste	2,801,268	--	--	--	--	--
Solar	--	--	--	8,778	367,748	--
Timber Residues	4,354,927	--	--	--	--	--
Water	--	--	92,671,697	--	--	--
Wind	--	--	--	--	--	2,131,323

Notes: Bioenergy capacity includes all bioenergy fuels (agricultural residues, biogas, municipal solid waste, and timber residues). Some units which use bioenergy fuels may also use fossil fuels. In these cases only the bioenergy fuel portion is included in the capacity figure.

Source: National Renewable Energy Laboratory, Renewable Electric Plant Information System (REPIS) database, beta version.

Table D2. Installed Operating Capacity, by FERC Region, by Technology, as of December 31, 1994
(Kilowatts)

FERC Region[a]	Technology					
	Bioenergy	Geothermal	Hydro	Photovoltaic	Solar Thermal	Wind
1	1,440,666	--	3,383,832	266	--	81,904
2	470,163	--	5,735,842	90	--	2,031
3	844,698	--	5,765,001	412	--	3,661
4	2,465,677	--	15,320,054	153	--	45
5	944,160	--	3,378,564	58	--	28,229
6	23,900	--	3,027,468	1,218	--	3,668
7	16,603	--	1,416,225	4	--	2,684
8	59,355	39,100	6,326,594	28	--	755
9	1,733,106	2,865,758	16,677,122	6,532	367,748	2,006,852
10	553,655	--	31,640,995	17	--	1,495

[a]FERC Region includes: **Region 1–New England** = Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont; **Region 2** = New Jersey and New York; **Region 3–Mid-Atlantic** = Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, and West Virginia; **Region 4–South Atlantic** = Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee; **Region 5–Midwest** = Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin; **Region 6–Southwest** = Arkansas, Louisiana, New Mexico, Oklahoma, and Texas; **Region 7–Central** = Iowa, Kansas, Missouri, and Nebraska; **Region 8–North Central** = Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming; **Region 9–West** = Arizona, California, Hawaii, and Nevada; **Region 10–Northwest** = Alaska, Idaho, Oregon, and Washington.

Notes: Bioenergy capacity includes all bioenergy fuels (agricultural residues, biogas, municipal solid waste, and timber residues). Some units which use bioenergy fuels may also use fossil fuels. In these cases only the bioenergy fuel portion is included in the capacity figure.

Source: National Renewable Energy Laboratory, Renewable Electric Plant Information System (REPIS) database, beta version.

Table D3. Installed Operating Capacity by Owner Company Type, by Technology, as of December 31, 1994
(Kilowatts)

Owner Type	Technology					
	Bioenergy	Geothermal	Hydro	Photovoltaic	Solar Thermal	Wind
Canadian	--	--	3,900	--	--	--
Cooperatives	48,400	--	308,183	104	--	44
Investor-Owned Utilities	639,310	1,354,350	30,607,924	1,536	--	13,239
Nonutilities	7,288,994	1,186,238	1,673,242	2,333	367,748	2,116,893
Publicly Owned	566,129	364,270	60,078,448	4,805	--	1,147

Notes: Bioenergy capacity includes all bioenergy fuels (agricultural residues, biogas, municipal solid waste, and timber residues). Some units which use bioenergy fuels may also use fossil fuels. In those cases only the bioenergy fuel portion is included in the capacity figure. Some units are owned by more than one type of owner. In those cases, the capacity figure has been factored in respect to their ownership type.

Source: National Renewable Energy Laboratory, Renewable Electric Plant Information System (REPIS) database, beta version.

Table D4. Planned Capacity by Technologies and by Fuel/Resource Types Which Have a High Probability of Success, as of June 1995
(Kilowatts)

Fuel/Resource Type	Technology					
	Bioenergy	Geothermal	Hydro	Photovoltaic	Solar Thermal	Wind
BioGas	62,500	--	--	--	--	--
Geothermal Steam	--	76,000	--	--	--	--
Municipal Solid Waste[a]	189,900	--	--	--	--	--
Solar	--	--	--	5	10,000	--
Timber Residues[b]	73,100	--	--	--	--	--
Water	--	--	450,250	--	--	--
Wind	--	--	--	--	--	488,755

[a]Includes industrial and medical wastes.
[b]Includes milling and logging residues.

Notes: A high probability of success is defined as either meeting one of the four EIA-867 criteria for reporting or is currently under construction. Reporting is required if the facility has obtained one or more of the following: all environmental and regulatory approvals, a signed contract for the electric energy, financial disclosure for the facility, or facility equipment has been ordered. Bioenergy capacity includes all bioenergy fuels (agricultural residues, biogas, municipal solid waste, and timber residues). Some units which use bioenergy fuels may also use fossil fuels. In these cases only the bioenergy fuel portion is included in the capacity figure.

Source: 1993 Form EIA-867, p. i.

Table D5. Additions to Operating Renewable Capacity, by Technology, 1980-1994
(Kilowatts)

Online Year	Technology					
	Bioenergy	Geothermal	Hydro	Photovoltaic	Solar Thermal	Wind
1980	159,040	258,000	1,510,534	6	10,000	167
1981	241,611	3,000	230,656	285	--	183,856
1982	347,638	119,000	769,854	1,517	400	175,638
1983	807,444	307,000	1084,287	5,227	--	156,749
1984	351,609	150,868	2259,896	1,076	18,950	469,967
1985	417,351	487,100	3229,184	332	30,025	233,030
1986	439,258	141,200	649,707	1,352	65,536	171,002
1987	648,048	74,400	429,015	339	32,804	126,838
1988	631,962	435,540	570,735	87	65,608	87,924
1989	871,760	347,730	264,341	96	160,000	110,105
1990	304,290	48,000	71,940	326	--	21,950
1991	478,075	--	1,213,850	21	--	155,130
1992	179,100	53,000	216,352	498	--	5,587
1993	56,275	73,000	51,495	1,519	--	93,715
1994	122,010	--	44,955	944	--	179,033

Notes: Bioenergy capacity includes all bioenergy fuels (Agricultural residues, biogas, municipal solid waste, and timber residues). Some units which use bioenergy fuels may also use fossil fuels. In those cases only the bioenergy fuel portion is included in the capacity figure.

Source: National Renewable Energy Laboratory, Renewable Electric Plant Information System (REPIS) database, beta version.

Appendix E
Wood Data Tables

Table E1. Ownership of Timberland in the United States, 1991
(Thousand Acres)

Region	National Forest	Other Public	Forest Industry	Non-Industry Private	Total
Northeast	2,179	6,489	11,858	58,914	79,449
North Central	7,366	14,263	4,340	52,380	78,349
Southeast	4,847	4,309	16,252	59,387	84,975
South Central	6,707	4,639	22,774	80,395	114,515
Rocky Mountains	943	198	24	2,363	3,528
Intermountain	35,459	5,789	2,894	14,959	59,101
Pacific Northwest and Alaska	18,790	10,383	9,034	14,712	52,919
Pacific Southwest	8,370	754	3,280	4,497	16,901
U.S. Total	84,661	46,824	70,455	287,606	489,555
Proportion of Total (Percent)	17.3	9.6	14.4	58.7	100

Source: USDA Forest Service, *Forest Resources of the United States, 1992*, General Technical Report RM-234, September 1993, pp. 36-42.

Table E2. Roundwood Products, Logging Residues, and Other Removals from Growing Stock and Other Sources, 1991
(Thousand Cubic Feet)

Region	Region Total	Softwood	Hardwoods
Northeast	2,835,209	887,559	1,947,650
North Central	2,475,053	310,885	2,164,168
Southeast	5,081,712	3,033,993	2,047,719
South Central	6,264,117	3,432,702	2,831,415
Great Plains	110,259	37,374	72,885
Intermountain	910,333	881,480	28,853
Pacific Northwest and Alaska	3,959,564	3,750,342	209,222
Pacific Southwest and Hawaii	1,226,142	1,124,347	101,795
U.S. Total	**22,862,389**	**13,458,682**	**9,403,707**

Note: In addition to roundwood, this table reports logging residues and other wood sources which are sound enough to chip, such as material from cultural and clearing operations, sound dead and cull trees, trees smaller than 5 inches in diameter at breast height, tops above the 4-inch diameter growing stock top, and sound downed trees (excluding stumps and limbs).

Source: USDA Forest Service, *Forest Resources of the United States, 1992*, General Technical Report RM-234, September 1993, pp. 114-116.

Table E3. Standard Industrial Classification (SIC) Codes of Major Wood Processing Operations Using Wood and Bark Residues

Industry	SIC Code
Sawmills	
Hardwood lumber, rough	24211
Softwood lumber, rough	24212
Planing mills	
Hardwood lumber, dressed	24213
Softwood lumber, dressed	24214
Wood chips grinders	24215
Millwork Operations	24310
Cabinet Manufacturers	24340
Wood preservers	24910
Particleboard Manufacturers	24920
Operations not otherwise classified (picture frames, hardboard, etc.)	24990
Gum and wood chemical mfrs.	28610
Manufacturers of boot and shoe cut stock and findings (wood heels, etc.)	31310
Farm machinery and equipment manufacturers	35230
Textile machinery mfrs. (bobbins, picker sticks, etc.)	35520
Industrial patterns makers	35650
Railroad equipment	37430
Musical instruments	39310
Lead pencils, crayons, and artist materials	39250
Brooms and brushes	39910
Signs and advertising displays	39930
Burial caskets	39950
Other miscellaneous fabricated wood products	39990
Dimension and flooring	
Softwood cut stock	24217
Softwood siding	24218
Hardwood flooring	24261
Hardwood dimension and furniture parts 24262	24626
Handle blanks	24263
Wood frames in household furniture	24266
Special product sawmills (i.e., staves and heading)	24290
Wooden pallet and container mills	
Boxes and shockets[1]	24410
Pallets and skids	24480
Containers, not elsewhere classified	24490
Wirebound box	24491
Veneer and plywood container mills	24493
Cooperage manufacturers	24495

See source note at end of table.

Table E3. Standard Industrial Classification (SIC) Codes of Major Wood Processing Operations Using Wood and Bark Residues (Continued)

Industry	SIC Code
Prefabricated building and mobile home mfrs.	
Structural components not elsewhere classified	24390
Mobile homes	24510
Prefabricated wood buildings and components	24520
Log homes	24525
Travel trailer and camper manufacturers	37920
Mfrs. of transportation equipment not elsewhere classified	37990
Plywood and veneer mills	
Hardwood veneer and plywood	24350
Hardwood plywood type products	24353
Softwood veneer and plywood	24360
Furniture manufacturers	
Wood household furniture except upholstered	25110
Wood household furniture, upholstered	25120
Box springs	25153
Wood television, radio, phonograph, and sewing machine cabinets	25170
Wood office furniture	25210
Public building and related furniture	25310
Partitions and fixtures	25410
Drapery hardware and wooden blinds	25910
Mfrs. of furniture and fixtures not elsewhere classified	25990
Pulp, paper, and paperboard mills	
Pulp mills	26110
Paper mills, except building board mills	26210
Paperboard mills	26310
Building paper and building board mills	26610
Boat, sporting goods, and game manufacturers	
Boat building and repairing	37320
Games, toys, and children's vehicles, except dolls and bicycles	39440
Mfrs. of sporting and athletic goods not elsewhere classified	39490

Source: Tennessee Valley Authority, *Production and Use of Industrial Wood and Bark Residues in the Tennessee Valley Region, 1984,* Technical Note B61, August 1986, pp. B1-B3.

Appendix F
Highlights of IRS Proposed Rule on Ethanol and ETBE

On October 19, 1994 the Internal Revenue Service (IRS) made public its intention to revise excise tax regulations related to ethanol.[164] This action would implement changes legislated by the Energy Policy Act of 1992 (EPACT) and the Omnibus Budget Reconciliation Act of 1993.

Gasohol. The Federal excise tax rate for gasoline is 18.4 cents per gallon. Before January 1, 1993, Section 48.4081(c) of the Internal Revenue Code authorized a reduction of the tax rate on gasoline blends containing "at least" 10 percent ethanol by volume ("gasohol"). U.S. Environmental Protection Agency (EPA) rules do not authorize blends in excess of 10 percent ethanol, however. Problems arose because blenders could not always blend precise 10 percent mixtures, due to the operating characteristics of pumping and metering equipment. Any mixture in excess of 10 percent was taxed at the regular rate on the entire volume.

Effective January 1, 1993 a special rule, promulgated in section 48.4081-6(b)(2) of the Internal Revenue Code, made allowance for these limitations by qualifying mixtures of at least 9.8 percent but less than 10 percent. Known as the "tolerance rule," this regulation also permitted mixtures in this range to be considered to contain 10 percent ethanol, thereby qualifying them for the 5.4 cents per blend-gallon tax reduction, where the total volume of the blend is interpreted as 10 times the actual quantity of ethanol contained in the blend.

Effective January 1, 1993, section 1920 of EPACT amended Section 48.4081(c) of the Internal Revenue Code to extend the tax rate reduction to 5.7 percent and 7.7 percent gasoline/ethanol blends.[165] The 5.4 cents per blend-gallon rate is prorated to apply to these two proportions. The current IRS proposed ruling would continue the tolerance rule for 10 percent blends but would not extend it to the new proportions (because there is no EPA penalty for slightly exceeding the 5.7 percent or 7.7 percent proportions). It should be noted in all cases, however, that the applicable tax reduction is based on the actual quantity of ethanol used in the blend.

Blender Credit. Under Subsection 40.6427(f) of the code, if a blender is registered by the IRS and produces a gasoline/ethanol blend with gasoline that has already been taxed at the full 18.4 cent rate, the blender can receive a tax credit or payment on a basis of equivalence with the 5.4 cents per blend-gallon tax reduction for 10 percent gasohol previously described. Provisions for specific cases are discussed in the proposed rule.

Ethyl Tertiary Butyl Ether (ETBE). The proposed IRS rule would continue to treat ETBE in the same way for tax purposes that it has been treated previously. The effect of the IRS interpretation is that ETBE "contains" that proportion of ethanol that was used to make it and the tax rate reduction applies to the ethanol "portion" of the ETBE when the ETBE is mixed with gasoline. The following example was cited:

> ". . . a gasoline/ETBE mixture would qualify as 5.7 percent gasohol if the mixture contains 12.7 percent ETBE and each gallon of ETBE is made from .45 gallon of alcohol" (0.45 x 12.7 percent = 5.7 percent).

[164]*Federal Register*, Vol. 59, No. 201, Department of the Treasury, Internal Revenue Service, 26 CFR Parts 40 and 48; Notice of Proposed Rulemaking: Gasoline and Diesel Fuel Excise Tax; Rules Relating to Gasohol; Tax on Compressed Natural Gas (59 FR 52735).

[165]These proportions are not arbitrary. A neat ethanol blend of 10 percent by volume produces a mixture of 3.7 percent oxygen content by weight. EPA regulations governing oxygen content in gasoline are expressed in terms of percentage oxygen weight relative to the weight of the resultant blend in any given volume. Minimum oxygen weight requirements for winter time gasolines used in areas prone to carbon monoxide pollution are stated at 2 percent and 2.7 percent, depending on the area. A 5.7 percent ethanol/gasoline blend results in results in a fuel containing just over 2 percent oxygen by weight and a 7.7 percent ethanol/gasoline blend yields a fuel containing just over 2.7 percent oxygen by weight.

Appendix G
Geological Processes and Geothermal Energy

The genesis of geothermal resources lies in the geological transport of anomalous amounts of heat close enough to the surface for access. Thus, the distribution of geothermal areas is not random but is governed by geological processes of global, regional and local scale. This fact is important in exploration for geothermal resources.

Geothermal resources commonly have three components: (1) an anomalous concentration of heat (i.e., a *heat source*); (2) *fluid* to transport the heat from the rock to the surface; and (3) *permeability* in the rock sufficient to form a plumbing system through which the water can circulate.

Heat Sources

The two most common sources of geothermal heat are: (1) intrusion of molten rock (magma) from great depth to high levels in the earth's crust; and (2) ascent of groundwater that has circulated to depths of 1 to 3 miles (1.6 to 5 km) and has been heated in the normal or enhanced geothermal gradient without occurrence of a nearby intrusion.

One geological process that generates shallow magmatic crustal intrusions in several different ways is known as plate tectonics.[166] As the laterally moving oceanic plates press against neighboring plates, some of which contain the imbedded continental land masses, the oceanic plates are thrust beneath the continental plates. These zones of under-thrusting, where crust is consumed, are called *subduction zones*.[167]

The subducted plate descends into the mantle and is heated by the surrounding warmer material and by friction. Temperatures become high enough to cause partial melting. Since molten or partially molten rock bodies (magmas) are lighter than solid rock, the magmas ascend buoyantly through the crust. Volcanos result if some of the molten material escapes at the surface, but the majority of the magma usually cools and consolidates underground. Crustal intrusion and volcanos occur on the landward side of oceanic trenches 30 to 150 miles (50 to 250 km) inland. The volcanos of the Cascade Range of California, Oregon, and Washington, for example, overlay the subducting Juan de Fuca plate and owe their origin to the process just described. The Pacific Ring of Fire, which extends around the margins of the Pacific basin, is composed of volcanos in the Aleutians, Japan, the Philippines, Indonesia, New Zealand, South America, and Central America, all of which are due to subduction.

Another important source of volcanic rocks are point sources of heat in the mantle. The mantle contains local areas of upwelling, hot material called *plumes*,[168] which have persisted for millions of years. As crustal plates move over these hot spots, a linear or arcuate chain of volcanos results, with young volcanic rocks at one end of the chain and older ones at the other end. The Hawaiian Island chain is an example. The thermal features of Yellowstone National Park are believed to be the result of an underlying mantle plume.

Fluid

Geothermal resources require a *fluid transport medium*.[169] In the earth that medium is groundwater that circulates near or through the heat source. The groundwater can originate as connate water that was trapped in voids during the formation of the rock. But quite often the water is meteoric in origin, meaning that it percolated from the surface along pathways determined by geological structures such as faults and formation boundaries. The density and viscosity of water both

[166]*Plate tectonics* is a theory of global-scale dynamics involving the movement of many rigid plates of the earth's crust. Considerable tectonic activity occurs along the margins of the plates, where buckling and grinding occur as the plates are propelled by the forces of deep-seated mantle convection currents. This has resulted in continental drift and changes in the shape and size of oceanic basins and continents.

[167]Subduction zones are elongate regions along which a crustal block descends relative to another crustal block.

[168]A *plume* is a body of magma that upwells in localized areas.

[169]A *fluid transport medium* is a liquid that transports energy, dissolved solids, or dissolved gases from their origin to their destination.

decrease as temperature increases. Water heated at depth is lighter than cold water in surrounding rocks, and is therefore subject to buoyant forces that tend to push it upward. If heating is great enough for buoyancy to overcome the resistance to flow in the rock, heated water will rise toward the earth's surface. As it rises, cooler water moves in to replace it. In this way, natural convection is set up in the groundwater around and above a heat source such as an intrusion. Convection can bring large quantities of heat within reach of wells drilled form the surface.

Because of their varied origin and the reactivity inherent to heated water, geothermal waters exhibit a wide range of chemical compositions. Salinities can range from a few parts per million up to 30 percent; dissolved gases such as carbon dioxide and hydrogen sulfide are common. As a result, geothermal waters play an important role in crustal processes, not only in transporting heat, but also in altering the physico-chemical properties of rock. Such fluids have produced many ore deposits of copper, lead, zinc, and other metals in proximity to heat sources.

Permeability

Permeability is a measure of a rock's *capacity to transmit fluid*. The flow takes place in pores between mineral grains and in open spaces created by fractures and faults. *Porosity* is the term given to the *amount of void space* in a volume of rock. Interconnected porosity provides flow paths for the fluids, and creates permeability. The porosity of the reservoir rocks determines the total amount of fluid available, whereas the permeability determines the rate at which fluid can be produced. One must *not* envisage a large bathtub of hot water that can be tapped at any handy location. Both porosity and permeability vary over wide ranges at different points in the reservoir. Open fault zones, fractures and fracture intersections, contacts between different rock types and shattered zones produced by hydraulic fracturing, and mineral growth areas in rocks all lead to varying degrees of permeability.

Most geothermal systems are structurally controlled, i.e., the magmatic heat source has been emplaced along zones of structural weakness in the crust. Permeability may be increased around the intrusion from fracturing and faulting in response to stresses involved in the intrusion process itself and in response to regional stresses.

Hydrothermal Resources

A conceptual model of a hydrothermal system where steam is the pressure-controlling phase is a so-called *vapor-dominated geothermal system*.[170] The Geysers geothermal area in California, about 80 miles north of San Francisco, is a vapor-dominated resource. Steam is produced from depths of 3,000 to 10,000 feet (1 km to 3 km) and is used to run turbine engines which turn electrical generators. The Geysers is still the largest geothermal electric producing area in the world despite the continued drop in production and lack of adequate recharging of the required fluids. Other producing vapor-dominated resources occur at Larderello and Monte Amiata, Italy, and at Matsukawa, Japan.

In a high-temperature, *liquid-dominated geothermal system*[171,172,173,174] groundwater circulates downward in open fractures and removes heat from deep, hot rocks as it rises buoyantly and is replaced by cool recharge water moving in from the sides. Rapid convection produces uniform temperatures over large volumes of the reservoir. There is typically an upflow zone at the center of each convection cell, an outflow zone or plume of heated water moving laterally away from the center of the system, and a downflow zone where recharge water is actively moving downward. Escape of hot fluids is often minimized by a near-surface sealed zone or caprock formed by precipitation of minerals in fractures and pore spaces.

[170]D.E. White, L.J.P. Muffler, and A.H. Truesdell, "Vapor-Dominated Hydrothermal Systems Compared with Hot-Water Systems," *Economic Geology*, Vol. 66 (1971), pp. 75-97.
[171]D.E. White and D.L. Williams, eds., *Assessment of Geothermal Resources of the United States—1975,* U.S. Geological Survey Circular 726 (1975), 155 pp.
[172]W.A.J. Mahon, L.E. Klyen, and M. Rhode, "Neutral Sodium/Bicarbonate/Sulfate Hot Waters in Geothermal Systems," *Chinetsu* (Journal of the Japan Geothermal Energy Association), Vol. 17 (1980), pp. 11-24.
[173]R.W. Henley and A.J. Ellis, "Geothermal Systems Ancient and Modern, a Geochemical Review," *Earth Science Review*, Vol. 19 (1983), pp. 1-50.
[174]D.L. Norton, "Theory of Hydrothermal Systems," *Annual Review of Earth and Planetary Science*, Vol. 12 (1983), pp. 155-177.

Appendix H
Additional Solar and Photovoltaic Data Tables

Table H1. Solar-Related Sales as a Percentage of Total Sales, 1993 and 1994

Solar-Related Sales as a Percent of Total Sales	1993	1994
90-100	25	24
50-89	9	9
10-49	5	5
Less than 10	2	3
Total	**41**	**41**

Source: Energy Information Administration, Form CE-63A, "Annual Solar Thermal Collector Manufacturers Survey."

Table H2. Distribution of Solar Thermal Collector Shipments, 1993 and 1994

	Shipments (thousand square feet)	
Recipient	1993	1994
Wholesale Distributors	3,710	5,504
Retail Distributors	2,410	1,406
Exporters	343	385
Installers	313	185
End Users and Other[a]	191	146
Total	**6,968**	**7,627**

[a]Other includes minimal shipments not explained on Form CE-63A.

Note: Totals may not equal sum of components due to independent rounding.

Source: Energy Information Administration, Form CE-63A, "Annual Solar Thermal Collector Manufacturers Survey."

Table H3. Shipments of Solar Thermal Collectors by Destination, 1993 and 1994
(Square Feet)

Destination	1993	1994	Destination	1993	1994
Alabama	1,682	19,619	Nebraska	1,682	18,109
Alaska	0	105	***Nevada***	13,009	116,146
Arizona	285,506	254,342	***New Hampshire***	1,725	5,302
Arkansas	1,682	1,619	***New Jersey***	60,926	167,974
California	1,540,145	1,352,493	New Mexico	10,240	38,615
Colorado	23,611	69,123	***New York***	73,757	199,893
Connecticut	13,908	182,313	***North Carolina***	5,840	4,864
Delaware	0	224	***North Dakota***	0	0
District of Columbia	0	0	**Ohio**	13,908	8,732
Florida	3,701,116	3,612,368	***Oklahoma***	0	217
Georgia	34,505	36,215	***Oregon***	122,534	172,180
Hawaii	196,507	204,542	**Pennsylvania**	17,620	82,136
Idaho	222	271	Puerto Rico	253,379	156,006
Illinois	27,709	53,338	***Rhode Island***	0	112
Indiana	12,579	14,805	South Carolina	2,620	638
Iowa	256	559	***South Dakota***	0	0
Kansas	2,036	1,907	Tennessee	1,794	1,694
Kentucky	0	0	***Texas***	40,254	106,788
Louisiana	1,682	7,827	***Utah***	354	38,324
Maine	23,909	43,837	Vermont	1,832	18,132
Maryland	14,236	8,203	Virgin Islands (U.S.)	2,923	3,112
Massachusetts	12,494	51,116	**Virginia**	2,097	15,297
Michigan	3,382	105,081	**Washington**	12,859	8,019
Minnesota	1,059	8,971	West Virginia	165	0
Mississippi	0	18,000	***Wisconsin***	15,300	10,078
Missouri	3,374	1,866	Wyoming	0	30
Montana	111	240			
Shipments to United States/Territories				**6,556,529**	**7,221,382**
Exports				**411,475**	**405,321**
Total Shipments				**6,968,004**	**7,626,703**

Note: Italicized States sponsored incentives for solar thermal collector purchases during 1993 (Solar Energy Industries Association, *Solar Industry Journal*, First Quarter 1993, pp. 16-21). States in bold face type sponsored incentives during 1994. (Steve Kalland, Solar Energy Industries Association, personal communication to James Holihan, Energy Information Administration, Washington, DC, June 1, 1994).

Source: Energy Information Administration, Form CE-63A, “Annual Solar Thermal Collector Manufacturers Survey.”

Table H4. Shipments of Complete Solar Thermal Collector Systems, 1993 and 1994

Shipments	1993	1994
Complete Collector Systems Shipped[a]	18,809	17,892
System Shipments (thousand square feet)	2,989	3,262
System Shipments (percent of total shipments)	43	43
Number of Companies	31	32
Value of Systems (thousand dollars)	20,631	18,433

[a]A complete system is a unit with a collector and all the necessary functional components, except for installation materials.

Source: Energy Information Administration, Form CE-63A, "Annual Solar Thermal Collector Manufacturers Survey."

Table H5. Distribution of Photovoltaic Cells and Modules, 1993 and 1994

Recipient	Shipments (peak kilowatts) 1993	1994
Wholesale Distributors	10,354	13,248
Retail Distributors	862	1,230
Exporters	151	17
Installers	1,278	2,443
End Users	2,295	1,892
Module Manufacturers	5,256	6,174
Other[a]	754	1,073
Total	**20,951**	**26,077**

[a]Other includes categories not identified by reporting companies.

Note: Totals may not equal sum of components due to independent rounding.

Source: Energy Information Administration, Form CE-63B, "Annual Photovoltaic Module/Cell Manufacturers Survey."

Table H6. Shipments of Complete Photovoltaic Module Systems, 1992-1994

Category	1992	1993	1994
Complete Photovoltaic Systems Shipped (units)	232	447	2,350
Modules in Complete Systems (peak kilowatts)	781	1,395	1,015
Modules in Systems as Percent of Total Module Shipments	6	9	12
Values of Complete Systems (thousand dollars)	7,409	14,123	10,096

Source: Energy Information Administration, Form CE-63B, "Annual Photovoltaic Module/Cell Manufacturers Survey."

Table H7. Percent of Solar Collector Shipments by the 10 Largest Companies, 1986-1994

Year	Company Rank	Shipments (Thousand Square Feet)	Percent of Total Shipments
1986	1-5	7,771	83
	6-10	785	8
1987	1-5	6,371	88
	6-10	499	7
1988	1-5	7,585	93
	6-10	335	4
1989	1-5	9,748	85
	6-10	1,321	12
1990	1-5	9,955	87
	6-10	1,029	9
1991	1-5	5,429	83
	6-10	829	13
1992	1-5	6,110	86
	6-10	609	9
1993	1-5	6,135	88
	6-10	551	8
1994	1-5	6,401	84
	6-10	861	12

Note: Totals may not equal sum of components due to independent rounding.

Sources: Energy Information Administration: Form CE-63A, "Annual Solar Thermal Collector Manufacturers Survey."

Table H8. Companies Involved in Solar-Thermal Activities by Type, 1993 and 1994

Type of Activity	1993	1994
Collector or System Design	31	30
Prototype Collector Development	18	16
Prototype System Development	16	16
Wholesale Distribution	25	28
Retail Distribution	22	22
Installation	21	17
Noncollector System Component Manufacture	18	14

Source: Energy Information Administration, Form CE-63A, "Annual Solar Thermal Collector Manufacturers Survey."

Glossary

Abatement: Reducing the degree or intensity of, or eliminating, pollution.

Acid Rain: Also called "acid precipitation" or "acid deposition," acid rain is precipitation containing harmful amounts of nitric and sulfuric acids formed primarily by nitrogen oxides and sulfur oxides released into the atmosphere when fossil fuels are burned. It can be wet precipitation (rain, snow, or fog) or dry precipitation (absorbed gaseous and particulate matter, aerosol particles, or dust). Acid rain has a pH below 5.6. Normal rain has a pH of about 5.6, which is slightly acidic. (The pH value is a measure of acidity or alkalinity, ranging from 0 to 14. A pH measurement of 7 is regarded as neutral. Measurements below 7 indicate increased acidity, and those above 7 indicate increased alkalinity.)

Adders: Environmental adders are estimates of the monetary value of damage imposed upon society by each additional ton of a particular pollutant. In theory, when these values are added to the direct cost of resources under planning consideration, resources with the lowest marginal social cost can be identified.

Air Collector: A medium-temperature collector used predominately in space-heating, utilizing pumped air as the heat-transfer medium.

Allowance: An authorization for the holder to emit a specified amount of a pollutant into the atmosphere as set forth in the Clean Air Act Amendments of 1990; for example, one sulfur dioxide allowance permits one ton of SO_2 emissions.

Alternating Current: An electric current that reverses its direction at regularly recurring intervals, usually 50 or 60 times per second.

Amorphous Silicon: An alloy of silica and hydrogen, with a disordered, noncrystalline internal atomic arrangement, that can be deposited in thin-layers (a few micrometers in thickness) by a number of deposition methods to produce thin-film photovoltaic cells on glass, metal, or plastic substrates.

Annualized Growth Rates: Calculated as follows:

$$(x_n / x_1)^{1/n} \quad ,$$

where x is the value under consideration and n is the number of periods.

Aquifer: A subsurface rock unit from which water can be produced.

Availability Factor: A percentage representing the number of hours a generating unit is available to produce power (regardless of the amount of power) in a given period, compared to the number of hours in the period.

Avoided Costs: The incremental costs of energy and / or capacity, except for the purchase from a qualifying facility, a utility would incur itself in the generation of the energy or its purchase from another source.

Baghouse: A woven or felted fabric bag-like device that lets gas through but removes suspended particles.

Biomass: Organic nonfossil material of biological origin constituting a renewable energy source.

Black Liquor: A byproduct of the paper production process that can be used as a source of energy.

Brine: A highly saline solution. A solution containing appreciable amounts of sodium chloride and other salts.

Busbar Cost: The cost per kilowatthour to produce electricity, including the cost of capital, debt service, operation and maintenance, and fuel. The power plant "bus" or "busbar" is that point beyond the generator but prior to the voltage transformation point in the plant switchyard.

Capacity Factor: The ratio of the electrical energy produced by a generating unit for the period of time considered to the electrical energy that could have been produced at continuous full-power operation during the same period.

Capacity, Gross: The full-load continuous rating of a generator, prime mover, or other electric equipment under specified conditions as designated by the manufacturer. It is usually indicated on a nameplate attached to the equipment.

Capital Cost: The cost of field development and plant construction and the equipment required for the generation of electricity.

Cast Silicon: Crystalline silicon obtained by pouring pure molten silicon into a vertical mold and adjusting the temperature gradient along the mold volume during cooling to obtain slow, vertically-advancing crystallization of the silicon. The polycrystalline ingot thus formed is composed of large, relatively parallel, interlocking crystals. The cast ingots are sawed into wafers for further fabrication into photovoltaic cells. Cast-silicon wafers and ribbon-silicon sheets fabricated into cells are usually referred to as polycrystalline photovoltaic cells.

Climate Change (Greenhouse Effect): The increasing mean global surface temperature of the Earth caused by gases in the atmosphere (including carbon dioxide, methane, nitrous oxide, ozone, and chlorofluorocarbons). The greenhouse effect allows solar radiation to penetrate the Earth's atmosphere but absorbs the infrared radiation returning to space.

Cogeneration: The production of electrical energy and another form of useful energy (such as heat or steam) through the sequential use of energy.

Combined Cycle: An electric generating technology in which electricity is produced from otherwise lost waste heat exiting from one or more gas (combustion) turbines. The exiting heat is routed to a conventional boiler or to a heat recovery steam generator for utilization by a steam turbine in the production of electricity. Such designs increase the efficiency of the electric generating unit.

Concentrator: A reflective or refractive device that focuses incident insolation onto an area smaller than the reflective or refractive surface, resulting in increased insolation at the point of focus.

Convection: Motion in a fluid or plastic material due to some parts being buoyant because of their higher temperature. Convection is a means of transferring heat through mass flow rather than through simple thermal conduction.

Cull Wood: Wood logs, chips, or wood products that are burned.

Direct Current: An electric current that flows in a constant direction. The magnitude of the current does not vary or has a slight variation.

Electric Utility Restructuring: With some notable exceptions, the electric power industry historically has been composed primarily of investor-owned utilities. These utilities have been predominantly vertically integrated monopolies (combining electricity generation, transmission, and distribution), whose prices have been regulated by State and Federal government agencies. Restructuring the industry entails the introduction of competition into at least the generation phase of electricity production, with a corresponding decrease in regulatory control. Restructuring may also modify or eliminate other traditional aspects of investor-owned utilities, including their exclusive franchise to serve a given geographical area, assured rates of return, and vertical integration of the production process.

Electrostatic Precipitator: A number of vertical, parallel metal plates utilizing the mutual attraction of opposite electric charges to remove dust or ash particles or liquid droplets suspended in a gas.

Emission: The release or discharge of a substance into the environment; generally refers to the release of gases or particulates into the air.

Emissions Trading: With an emissions trading system, a regulatory agency specifies an overall level of pollution that will be tolerated (a cap) and then uses allowances to develop a market to allocate the pollution among sources of pollution under the cap. Emissions permits or allowances become the currency of the market, as pollution sources are free to buy, sell, or otherwise trade permits based on their own marginal costs of control and the price of the permits. In no case can total emissions exceed the cap.

Ethyl Tertiary Butyl Ether (ETBE): A colorless, flammable, oxygenated hydrocarbon ($(CH_3)_3COC_2H_5$) blend stock formed by the catalytic etherification of isobutylene with ethanol.

Evacuated Tube: In a solar thermal collector, an absorber tube, which is contained in an evacuated glass cylinder, through which collector fluids flows.

Exempt Wholesale Generator (EWG): A nonutility electricity generator that is not a qualifying facility under the Public Utility Regulatory Policies Act of 1978.

Externalities: Benefits or costs, generated as a byproduct of an economic activity, that do not accrue to the parties involved in the activity. Environmental externalities are benefits or costs that manifest themselves through changes in the physical or biological environment.

Flat Plate Pumped: A medium-temperature solar thermal collector that typically consists of a metal frame, glazing, absorbers (usually metal), and insulation and that uses a pump liquid as the heat-transfer medium: predominant use is in water heating applications.

Flow Control: The laws, regulations, and economic incentives or disincentives used by waste managers to direct waste generated in a specific geographic area to a designated landfill, recycling, or waste-to-energy facility.

Fuel Cells: One or more cells capable of generating an electrical current by converting the chemical energy of a fuel directly into electrical energy. Fuel cells differ from conventional electrical cells in that the active materials such as fuel and oxygen are not contained within the cell but are supplied from outside.

Fuelwood: Wood and wood products, possibly including coppices, scrubs, branches, etc., bought or gathered, and used by direct combustion.

Fumarole: A vent from which steam or gases issue; a geyser or spring that emits gases.

Generation (Electricity): The process of producing electric energy from other forms of energy; also, the amount of electric energy produced, expressed in watthours (Wh).

Geopressured: A type of geothermal resource occurring in deep basins in which the fluid is under very high pressure.

Geothermal Energy: As used at electric utilities, hot water or steam extracted from geothermal reservoirs in the Earth's crust that is supplied to steam turbines at electric utilities that drive generators to produce electricity.

Geothermal Plant: A plant in which the primary equipment is a turbine and generator. The turbine is driven either from hot water or by natural steam that derives its energy from heat found in rocks or fluids at various depths beneath the surface of the earth. The fluids are extracted by drilling and/or pumping.

Geyser: A special type of thermal spring that periodically ejects water with great force (See Thermal Spring).

Giga: One billion.

Green Pricing: In the case of renewable electricity, green pricing represents a market solution to the various problems associated with regulatory valuation of the nonmarket benefits of renewables. Green pricing programs allow electricity customers to express their willingness to pay for renewable energy development through direct payments on their monthly utility bills.

Greenhouse Effect: The increasing mean global surface temperature of the Earth caused by gases in the atmosphere (including carbon dioxide, methane, nitrous oxide, ozone, and chlorofluorocarbon). The greenhouse effect allows solar radiation to penetrate, but absorbs the infrared radiation returning to space.

Grid: The layout of an electrical distribution system.

Groundwater: Water occurring in the subsurface zone where all spaces are filled with water under pressure greater than that of the atmosphere.

High-Temperature Collector: A solar thermal collector designed to operate at a temperature of 180 degrees Fahrenheit or higher.

Hot Dry Rock: Heat energy residing in impermeable, crystalline rock. Hydraulic fracturing may be used to create permeability to enable circulation of water and removal of the heat.

Hub Heights: In a horizontal-axis wind turbine, the distance from the turbine platform to the rotor shaft.

Hydraulic Fracturing: Fracturing of rock at depth with fluid pressure. Hydraulic fracturing at depth may be accomplished by pumping water into a well at very high pressures. Under natural conditions, vapor pressure may rise high enough to cause fracturing in a process known as hydrothermal brecciation.

Independent Power Producer (IPP): A wholesale electricity producer (other than a qualifying facility under the Public Utility Regulatory Policies Act of 1978), that is unaffiliated with franchised utilities in the area in which the IPP is selling power and that lacks significant marketing power. Unlike traditional utilities, IPPs do not possess transmission facilities that are essential to their customers and do not sell power in any retail service territory where they have a franchise.

Integrated Resource Planning (IRP): In the case of an electric utility, a planning and selection process for new energy resources that evaluates the full range of alternatives, including new generating capacity, power purchases, energy conservation and efficiency, cogeneration, district heating and cooling applications, and renewable energy resources, in order to provide adequate and reliable service to electrical customers at the lowest system cost. Often used interchangeably with least-cost planning.

Internal Collector Storage (ICS): A solar thermal collector in which incident solar radiation is absorbed by the storage medium.

Internalizing Externalities: This expression means to create social conditions where the damages (or benefits) from production and consumption are taken into account by those who produce the effects. Such social conditions can be created by government regulation, a tort system, bargaining between private parties, or other policy and institutional arrangements. Benefits and damages can exist even when all externalities have been internalized.

Kilo: One thousand.

Kilowatt (kW): One thousand watts of electricity (See Watt).

Kilowatthour (kWh): One thousand watthours.

Levelized Cost: The present value of the total cost of building and operating a generating plant over its economic life, converted to equal annual payments. Costs are levelized in real dollars (i.e., adjusted to remove the impact of inflation).

Liquid Collector: A medium-temperature solar thermal collector, employed predominantly in water heating, which uses pumped liquid as the heat-transfer medium.

Low-Temperature Collectors: Metallic or nonmetallic collectors that generally operate at temperatures below 110 degrees Fahrenheit and use pumped liquid or air as the heat transfer medium. They usually contain no glazing and no insulation,and they are often made of plastic or rubber, although some are made of metal.

Magma: Naturally occurring molten rock, generated within the earth and capable of intrusion and extrusion, from which igneous rocks are thought to have been derived through solidification and related processes. It may or may not contain suspended solids (such as crystals and rock fragments) and / or gas phases.

Marginal Cost: The change in cost associated with a unit change in quantity supplied or produced.

Mass Burner: A relatively large one-chamber combustion system used to incinerate municipal solid waste under conditions of excess air; it is built on site and consumes fuel without prior processing or sorting.

Medium-Temperature Collectors: A collector designed to operate in the temperature range of 140 degrees to 180 degrees Fahrenheit, but that can also operate at a temperature as low as 110 degrees Fahrenheit. The collector typically consists of a metal frame, metal absorption panels with integral flow channels (attached tubing for liquid collectors or integral ducting for air collectors), and glazing and insulation on the sides and back.

Mega: One million.

Megawatt (MW): One million watts of electricity (See Watt).

Merchant Facilities: High-risk, high-profit facilities that operate, at least partially, at the whims of the market, as opposed to those facilities that are constructed with close cooperation of municipalities and have significant amounts of waste supply guaranteed.

Methane: The most common gas formed in coal mines; a major component of natural gas.

Methyl Tertiary Butyl Ether (MTBE): A colorless, flammable, liquid oxygenated hydrocarbon $((CH_3)_3COCH_3)$ that contains 18.15 percent oxygen and has a boiling point of 55.2 degrees Celsius. It is a fuel oxygenate produced by reacting methanol with isobutylene.

Modular Burner: A relatively small two-chamber combustion system used to incinerate municipal solid waste without prior processing or sorting; usually fabricated at a factory and delivered to the incineration site.

National Ambient Air Quality Standards (NAAQS): Maximum air pollutant standards that the U.S. Environmental Protection Agency set under the Clean Air Act for attainment by each State. The standards were to be achieved by 1975, along with State implementation plans to control industrial sources in each State.

Net Photovoltaic Cell Shipment: The difference between photovoltaic cell shipments and photovoltaic cell purchases.

Net Photovoltaic Module Shipment: The difference between photovoltaic module shipments and photovoltaic module purchases.

Nonattainment: Refers to areas of the United States that have not met air standards for human health by deadlines set in the Clean Air Act.

Nonuniformly Mixed Pollutants: Pollutants whose effects vary depending on their geographic point of origin, prevailing wind patterns, and current environmental conditions in receptor areas.

Nonutility Generation: Electric generation by end-users, independent power producers, or small power producers under the Public Utility Regulatory Policies Act, to supply electric power for industrial, commercial, and military operations, or sales to electric utilities.

Operating and Maintenance (O&M) Cost: Operating expenses are associated with operating a facility (i.e., supervising and engineering expenses). Maintenance expenses are that portion of expenses consisting of labor, materials, and other direct and indirect expenses incurred for preserving the operating efficiency or physical condition of utility plants that are used for power production, transmission, and distribution of energy.

Ozone: Three-atom oxygen compound (O_3) found in two layers of the Earth's atmosphere. One layer of beneficial ozone occurs at 7 to 18 miles above the surface and shields the Earth from ultraviolet light. Several holes in this protective layer have been documented by scientists. Ozone also concentrates at the surface as a result of reactions between byproducts of fossil fuel combustion and sunlight, having harmful health effects.

Parabolic Dish: A high-temperature (above 180 degrees Fahrenheit) solar thermal concentrator, generally bowl-shaped, with two-axis tracking.

Parabolic Trough: A high-temperature (above 180 degrees Fahrenheit) solar thermal concentrator with the capacity for tracking the sun using one axis of rotation.

Particulates: Visible air pollutants consisting of particles appearing in smoke or mist.

Passive Solar: A system in which solar energy alone is used for the transfer of thermal energy. Pumps, blowers, or other heat transfer devices that use energy other than solar are not used.

Peak Watt: A manufacturer's unit indicting the amount of power a photovoltaic cell or module will produce at standard test conditions (normally 1,000 watts per square meter and 25 degrees Celsius).

Photovoltaic Cell: An electronic device consisting of layers of semiconductor materials fabricated to form a junction (adjacent layers of materials with different electronic characteristics) and electrical contacts and being capable of converting incident light directly into electricity (direct current).

Photovoltaic Module: An integrated assembly of interconnected photovoltaic cells designed to deliver a selected level of working voltage and current at its output terminals, packaged for protection against environment degradation, and suited for incorporation in photovoltaic power systems.

Pollution: Any substances in water, soil, or air that degrade the natural quality of the environment, offend the senses of sight, taste, and smell, and/or cause a health hazard. The usefulness of a natural resource is usually impaired by the presence of pollutants and contaminants.

Private Activity Bond (PAB): A bond in which more than 10 percent of the proceeds are secured by the interest in the property of a private business or used in a nonpublic business. A PAB can still be tax-exempt if used (at least 95 percent) for qualified investments, such as waste-to-energy facilities, and provided that State allocation caps are not exceeded.

Public Utility Regulatory Policies Act of 1978 (PURPA): One part of the National Energy Act, PURPA contains measures designed to encourage the conservation of energy, more efficient use of resources, and equitable rates. Principal among these were suggested retail rate reforms and new incentives for production of electricity by cogenerators and users of renewable resources.

Pulpwood: Roundwood, whole-tree chips, or wood residues.

Pyrolysis: The thermal decomposition of biomass at high temperature in the absence of oxygen.

Quadrillion Btu: Equivalent to 10 to the 15th power Btu.

Qualifying Facility (QF): A cogeneration or small power production facility that meets certain ownership, operating, and efficiency criteria established by the Federal Energy Regulatory Commission (FERC) pursuant to the Public Utility Regulatory Policies Act of 1978 (PURPA). (See the Code of Federal Regulations, Title 18, Part 292.)

Rankine Cycle Technology: A repeated succession of operations or cycling representing the idealization of the processes in certain heat engines in which the working fluid is a liquid and its vapor. Vapor or condensing turbines operate on an approximate Rankine cycle. Vapor-compression refrigerators, air conditioners, and heat pumps use the Rankine cycle in reverse.

Reformulated Gasoline (RFG): Gasoline whose composition has been changed (from that of gasolines sold in 1990) to (1) include oxygenates, (2) reduce the content of olefins, aromatics, and volatile components, and (3) reduce the content of heavy hydrocarbons to meet performance specifications for ozone-forming tendency and for release of toxic substances (benzene, formaldehyde, acetaldehyde, 1,3-butadiene, and polycyclic organic matter) into the air from both evaporation and tailpipe emissions.

Refuse-Derived Fuel (RDF): Fuel processed from municipal solid waste that can be in shredded, fluff, or densified pellet forms.

Renewable Energy Source: An energy source that is regenerative or virtually inexhaustible. Typical examples are wind, geothermal, and water power.

Reserve: That portion of the demonstrated reserve base that is estimated to be recoverable at the time of determination. The reserve is derived by applying a recovery factor to that component of the identified coal resource designated as the demonstrated reserve base.

Retail Wheeling: An arrangement in which a utility transmits electricity from outside its service territory to a retail customer within its customer service territory.

Ribbon Silicon: Single-crystal silicon derived by means of fabricating processes that produce sheets or ribbons of single-crystal silicon. These processes include edge-defined film-fed growth, dendritic web growth, and ribbon-to-ribbon growth.

Roundwood: Logs, bolts, and other round timber generated from the harvesting of trees.

Scrubber: An emission control device that adds alkaline reagents to react with and neutralize acid gases.

Silicon: A semiconductor material made from silica, purified for photovoltaic applications.

Single Crystal Silicon (Czochralski): An extremely pure form of crystalline silicon produced by the Czochralski method of dipping a single crystal seed into a pool of molten silicon under high vacuum conditions and slowly withdrawing a solidifying single crystal boule rod of silicon. The boule is sawed into thin wafers and fabricated into single-crystal photovoltaic cells.

Smog: Air pollution associated with oxidants.

Solar Energy: The radiant energy of the sun, which can be converted into other forms of energy, such as heat or electricity.

Solar Thermal Collector: A device designed to receive solar radiation and convert it into thermal energy. Normally, a solar thermal collector includes a frame, glazing, and an absorber, together with the appropriate insulation. The heat collected by the solar thermal collector may be used immediately or stored for later use.

Solar Thermal Collector, Special: An evacuated tube collector or a concentrating (focusing) collector. Special collectors operate in the temperature (low concentration for pool heating) to several hundred degrees Fahrenheit (high concentration for air conditioning and specialized industrial processes).

Stoker Boiler: A boiler in which fuel is burned on a grate with the fuel supplied and the ash removed continuously. Most of the steam is used for process heat, with the remainder being used for electricity if desired.

Stranded Investment: Refers to the financial impairment—not necessarily plant closure in the physical sense—when the price of plant output falls to a level at which the owner can no longer earn a sufficient return on investment.

Superconducting Magnetic Energy Storage (SMES): SMES rings are devices being developed that will store electricity without loss by circulating the electricity through a ring of superconducting magnets. This application would allow utilities to generate electricity during periods of low demand for use during peak periods.

Thermosiphon System: A solar collector system for water heating in which circulation of the collection fluid through the storage loop is provided solely by the temperature and density difference between the hot and cold fluids.

Tipping Fee: Price charged to deliver municipal solid waste to a landfill, waste-to-energy facility, or recycling facility.

Transmission System (Electric): An interconnected group of electric transmission lines and associated equipment for moving or transferring electric energy in bulk between points of supply and points at which it is transformed for delivery over the distribution system lines to consumers, or is delivered to other electric systems.

Turbine: A machine for generating rotary mechanical power from the energy of a stream of fluid (such as water, steam, or hot gas). Turbines convert the kinetic energy of fluids to mechanical energy through the principles of impulse and reaction, or a mixture of the two.

Uncertainty: The state of not being definitely ascertainable or fixed as in time of occurrence, number, quality, or some other characteristic.

Uniformly Mixed Pollutants: Pollutants that have the same effect on the environment regardless of their geographic point of origin.

Vapor-Dominated Geothermal System: A conceptual model of a hydrothermal system where steam pervades the rock and is the pressure-controlling fluid phase.

Watt (Electric): The electrical unit of power. The rate of energy transfer equivalent to 1 ampere of electric current flowing under a pressure of 1 volt at unity power factor.

Watt (Thermal): A unit of power in the metric system, expressed in terms of energy per second, equal to the work done at a rate of 1 joule per second.

Watthour (Wh): The electrical energy unit of measure equal to 1 watt of power supplied to, or taken from, an electric circuit steadily for 1 hour.

Wheeling: The use of the transmission facilities of one system to transmit power and energy by agreement of, and for, another system with a corresponding wheeling charge, e.g., the transmission of electricity for compensation over a system that is received from one system and delivered to another system).