DOE/EIA-0561(92)
Distribution Category UC-950

# Renewable Resources in the U.S. Electricity Supply

**February 1993**

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

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# Preface

Section 205(a)(2) of the Department of Energy Organization Act of 1977 (Public Law 95-91) requires the Administrator of the Energy Information Administration (EIA) to carry out a comprehensive program that will collect, evaluate, assemble, analyze, and disseminate data and information relevant to energy resources, reserves, production, demand, technology, and related economic and statistical information. To assist in meeting these responsibilities in the area of electric power and renewable energy resources, the EIA has prepared this report, *Renewable Resources in the U.S. Electricity Supply*. The report provides an introductory overview of current and long-term forecasted uses of renewable resources in the Nation's electricity market-place, the largest domestic application of renewable resources today. It is intended for a general audience, but it should be of particular interest to public utility analysts, policy and financial analysts, investment firms, trade associations, Federal and State regulators, and legislators. While it does not address major policy issues, it does provide important basic factual information on which useful discussion, analyses, and policies can be built.

The legislation that created the EIA vested the organization with an element of statutory independence. The EIA's responsibility is to provide timely, high-quality information and to perform objective, credible analyses in support of deliberations by both public and private decisionmakers. The EIA does not take positions on policy questions. Accordingly, this report does not purport to represent the policy positions of the U.S. Department of Energy or the Administration.

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# Executive Summary

Renewable resources (solar, wind, geothermal, hydroelectric, biomass, and waste) currently provide nearly 12 percent of the Nation's electricity supply. Almost 10 of this 12 percent is provided by hydroelectric resources alone. Biomass and municipal solid waste (MSW) together contribute more than 1 percent. All other renewable resources, including geothermal, wind, and solar, together provide less than 1 percent of the total.

Many renewable resources are relative newcomers to the electric power market. In particular, electricity generation using geothermal, wind, solar, and MSW resources have had their greatest expansion in the 1980's. This was a result of significant technological improvements, the implementation of favorable Federal and State policies, and the reaction to the increasing costs of using fossil and nuclear fuels. The use of renewable resources for electricity generation has also been encouraged as less environmentally damaging than fossil fuels. Because renewable energy is available domestically, renewable resources are viewed as more secure than imported fossil fuels.

This report, *Renewable Resources in the U.S. Electricity Supply*, presents descriptions of the history, current use, and forecasted future applications of renewable re-sources for electricity generation and of the factors that influence those applications.

Renewable resources account for more than 93 percent of total U.S. energy resources. Geothermal, solar, and wind resources are particularly plentiful, raising prospects for their expanded use in the future. However, today renewable resources are usually not economically accessible, and annually contribute only 7.4 percent of the Nation's marketed (bought or sold) energy consumption for all purposes, including for electricity.

Renewable resources are used for electricity supply today where natural resources, electricity demands, and public policies combine to make them competitive. For these reasons, the uses of geothermal, solar, and wind resources have been most frequently found in California.

Many different scenarios for the future of the U.S. economy, energy markets, and renewable resources can be envisioned. The Energy Information Administration's (EIA) long-term projections used in the *Annual Energy Outlook 1993* portray future conditions based upon what is currently known or reasonably likely to occur. From these forecasts, some general conclusions emerge.

First, as technologies and market experiences improve, renewable resources are likely to increase their contributions to the U.S. electricity supply (Table ES-1). Nationwide, electricity generation from renewable energy is projected to grow at a rate averaging 1.8 percent per year through 2010, expanding at a somewhat higher rate than total U.S. electricity generation. On a regional basis, renewable resources could make more significant contributions where they are available and the costs of alternatives are higher. Nevertheless, renewable resources are not likely to replace fossil fuels as the major contributors to electricity supply over the next two decades.

The use of renewable resources other than hydroelectricity should increase very rapidly. According to the EIA Reference Case projections, electricity generation using MSW, biomass, and geothermal resources is projected to increase significantly, from 56 billion kilowatthours in 1990 to 175 billion kilowatthours in 2010. Through 2010, electricity generation using geothermal resources will grow at a rate averaging over 7 percent annually, and the use of MSW is expected to grow at a rate of over 9 percent annually through 2010. Wind-powered electricity generation is projected to increase, growing more than 10 percent annually, from 2 billion kilowatthours in 1990 to 16 billion kilowatthours in 2010.

Second, conventional hydroelectric power, the mainstay of renewable resources in electric power today, is unlikely to enjoy rapid growth under current expectations, even if more favorable regulatory policies emerge. The lack of many additional large sites for hydroelectric facilities constrains major hydroelectric power growth. However, the rapid growth in the use of other renewable resources should offset the slow growth in hydropower, allowing renewable resources to slightly increase their current share of the electricity market during the forecast period.

**Table ES1. U.S. Electricity Net Generation Using Renewable Resources, 1990 and 2010**
(Billion Kilowatthours)

| | 1990 | Reference Case 2010 | Annual Percentage Rate of Growth 1990-2010[a] |
|---|---|---|---|
| Conventional Hydroelectric | 288 | 306 | 0.3 |
| Geothermal | 15 | 62 | 7.2 |
| Municipal Solid Waste | 10 | 54 | 8.5 |
| Biomass | 31 | 59 | 3.2 |
| Solar[b] | 1 | 4 | 9.2 |
| Wind | 2 | 16 | 10.4 |
| **Total, Renewable Resources** | **348** | **501** | **1.8** |
| Fossil/Storage/Other | 2,098 | 2,975 | 1.8 |
| Nuclear | 577 | 636 | 0.5 |
| **Total Generation** | **3,023** | **4,112** | **1.5** |

[a]Annual percentage rates of growth are calculated using unrounded values.
[b]Includes solar thermal and less than 0.02 billion kilowatthours grid-connected photovoltaic generation.
Notes: Totals may not equal sum of components due to independent rounding. Electric utility generation data exclude internal generating station use (net); nonutility data include internal use (gross).
Sources: Energy Information Administration. **1990 data:** For utilities, EIA-861 “Annual Electric Utility Report”; for nonutilities, EIA-867, “Annual Nonutility Power Producer Report.” **2010 projections:** *Annual Energy Outlook 1993*, DOE/EIA-0383(93), AEO 1993 Forecasting System run AEO93B.D0918921 (Washington, DC, January 1993).

If renewable resources are to provide a greater share of the Nation's electricity supply, the costs of using them will need to decline relative to alternatives. In some cases, such as wind and solar thermal generation, small improvements in generating costs may significantly increase their market penetration. In other cases, such as photovoltaic and most forms of geothermal power, large cost reductions are needed to spur greater market penetration. Of course, other events may also work to accelerate the use of renewable resources. Increases in fossil-fuel costs and additional environmental regulations on fossil-fueled plants could make the use of renewable resources economically more attractive. In addition, social policies, including favorable tax treatments or other forms of assistance, could promote interest in renewable resource use.

# 1. The Current Use of Renewable Resources in Electric Power

## Introduction

When considering U.S. energy supplies, national security, and environmental quality, discussion often turns to renewable energy resources such as solar, wind, hydroelectric, geothermal, and biomass. Renewable resources are characterized as secure domestic supplies of energy insulated from threats and interruptions by foreign suppliers. In addition, they are viewed as free of most of the harmful emissions (such as the carbon, sulfur, and nitrogen oxides) that are byproducts of burning coal and other fossil fuels. Renewable resources, therefore, are viewed as potential candidates for much more widespread use in meeting U.S. energy needs.

To help inform public discussion, this publication provides an overview of current and projected long-term uses of renewable resources in the U.S. electricity supply, the largest domestic use of renewable resources today. While the publication does not address major policy issues, it provides an important base of information on which useful discussion, analyses, and policies can be built.

The report has four parts. This chapter introduces basic concepts and discusses the history and current uses of renewable resources in U.S. electricity supply. Chapter 2 presents long-term projections for the use of renewable resources through 2010. Chapter 3 discusses factors likely to affect the projections over the next four decades. Finally, appendices to the report provide additional information on renewable resources, such as their locations and other physical characteristics (Appendix B), and on the technologies used in generating electricity (Appendix C).

The publication discusses seven categories of electric power generation using renewable resources: conventional hydroelectric power,[1] biomass, municipal solid waste (MSW), geothermal, solar thermal, solar photovoltaic, and wind power.

The report features two major qualifications. First, it is important to recognize that markets do not completely reflect all the economically useful contributions of renewable resources, because many (if not most) applications of renewable energy are not bought or sold in the marketplace.[2] Whereas, for example, most coal production in the United States is accounted for by marketplace statistics of firms buying or selling coal, most solar energy is neither bought nor sold. For example, the sun warms a house, reducing the need for electricity to warm it, yet no one pays for the use of the solar heat. In addition, solar energy sometimes is accounted for only indirectly in the prices of goods and services (as in the higher rents paid for sunlit buildings). Wind, water, solar and geothermal energy also make significant energy contributions outside the marketplace. Therefore, because of the incomplete representation of the value of renewable energy in marketplace data, information in this publication about renewable energy use may underestimate the value of renewable energy.

Second, although comparisons of fossil, nuclear, and renewable energy are made, in at least one respect renewable resources are intrinsically different from fossil and nuclear resources. Fossil and nuclear resources are, for all intents and purposes, fixed stocks, that is, measured at single points in time, such as on December 31 of each year. Moreover, whatever their absolute size, these resources are exhaustible. Once consumed they do not regenerate in any relevant time period. On the other hand, by definition, renewable resources are not fixed stocks; renewable resources are variable flows. "Flows" are products measured as a function of time, such as from January 1 through

[1]Pumped storage hydroelectric facilities, at which off-peak nuclear or coal-fired generation is used to pump water from lower to upper reservoirs for hydroelectric generation during peak periods, are excluded from this report as use of renewable resources, because these plants are typically fossil or nuclear energy storage devices.

[2]In addition to their nonmarket characteristics, both nonmarketed and marketed uses of renewable resources can be affected by externalities. For a discussion of the relationship of externalities to renewable energy use, see Chapter 3.

December 31 of each year. Renewable energy supplies regenerate over time. As a result, when comparisons of fossil, nuclear, and renewable energy resources are made, compromises are necessary; fixed fossil and nuclear stocks are compared with renewable energy flows for a selected time period. For this publication, 30-year accumulated flows of renewable energy are compared with fixed fossil energy stocks, to approximate long-term supplies for energy planning purposes.

## U.S. Energy Resources, Accessible Resources, and Reserves

Renewable resources are the most plentiful energy resources in the United States (Table 1). If they were economically exploitable, more than 93 percent of the Nation's energy resource supply would be renewable energy. Geothermal energy accounts for nearly 40 percent of the total, almost 1.5 million quads (quadrillion Btu);[3] well over half (54 percent) are solar (including biomass) and wind resources; only hydroelectric resources, accounting for less than 1 percent, are less plentiful than fossil or nuclear (uranium) resources. By contrast, fossil resources (shale oil, coal, petroleum, natural gas, and peat) represent less than 7 percent of domestic energy resources, and uranium far less than 1 percent.

However, both technology and cost drastically reduce the current opportunities for the efficient use of renewable resources and shift the economic balance in energy supply in favor of fossil fuels and uranium. Whereas some fossil and uranium resources can be

**Table 1. Total U.S. Energy Resources, Accessible Resources, and Reserves**
(Quadrillion Btu)

| | Resources | Accessible Resources[a] | Reserves[b] |
|---|---|---|---|
| Geothermal | 1,497,925 | 22,782 | 247 |
| Solar (including biomass)[c] | 1,034,940 | 586,687 | 352[c] |
| Wind | 1,026,078 | 5,046 | 5 |
| Shale Oil | 159,604 | 11,704 | 1 |
| Coal | 87,458 | 38,147 | 5,266 |
| Petroleum | 2,767 | 1,102 | 156 |
| Natural Gas | 1,705 | 887 | 231 |
| Peat | 1,415 | 354 | - |
| Uranium | 1,177 | 731 | 42 |
| Conventional Hydroelectric | 986 | 157 | 58 |
| **Total** | **3,814,057** | **667,597** | **6,358** |

[a]That part of resources able to be accessed with existing technologies regardless of cost. The term “accessible resources” is definitionally similar to the term “recoverable resources” for oil and gas resources.

[b]That part of accessible resources able to be cost effectively recovered today.

[c]Solar includes all biomass and the natural resource base for municipal solid waste energy. Although biomass is not estimated separately for resources or accessible resources, biomass is estimated to account for 334 quadrillion Btu (95 percent) of total solar reserves.

- = Less than 0.5 quadrillion Btu.

Notes: The resource values shown in Table 1 are broad estimates that result from estimation procedures highly dependent upon critical assumptions. They should be considered useful mainly for approximating the broad boundaries placed on future energy choices. For metric conversion, one British thermal unit equals 1,055 joules. For example, total reserves equal approximately $6.7 \times 10^{21}$ joules. Totals may not equal sum of components due to independent rounding.

Source: U.S. Department of Energy, Office of Conservation and Renewable Energy, *Characterization of U.S. Energy Resources and Reserves*, DOE/CE-0279 (Washington, DC, December 1989).

found in sufficiently high concentrations to afford cost-effective use, renewable resources are generally less accessible (for example, most geothermal resources are at depths below current drilling access); too scattered (for example, solar energy is very dispersed); or too costly to employ, given current technologies and costs. When technology is taken into consideration to estimate resources which are accessible, the availability of renewable resources is significantly reduced. Furthermore, when the costs of extraction and use are considered to determine reserves, the Nation's current energy reserve base becomes predominantly fossil rather than renewable resources.

In fact, most U.S. energy use today (except for unmeasured direct use of wind and solar energy) is from fossil fuels (Table 2). In 1990, more than 85 percent of all U.S. energy consumption for all purposes, including for electricity, transportation, and heat, was supplied by petroleum, natural gas, and coal. Renewable resources provided 7.4 percent of energy in the United States, with most of that from conventional hydroelectric power, biomass, and waste.

Despite difficulties in utilizing them today, the vast stores of renewable resources indicate possible oppor-tunities for the future. If technologies can be developed to access renewable resources economically, and if the electricity generating technologies using them can be made competitive, renewable resources have the potential to provide a larger share of the Nation's electricity consumption. Many decades from now, renewable resources could remain generally undiminished and available for use.

**Table 2. U.S. Energy Consumption, 1990**
(Quadrillion Btu)

| Energy Source | Consumption | Percent |
|---|---|---|
| Petroleum | 33.55 | 39.8 |
| Natural Gas | 19.30 | 22.9 |
| Coal | 19.12 | 22.7 |
| Nuclear | 6.16 | 7.3 |
| Renewable Resources | 6.26 | 7.4 |
| Conventional | | |
| Hydroelectric | 2.97 | 3.5 |
| Geothermal | 0.32 | 0.4 |
| Biomass | 2.90 | 3.4 |
| Solar | [a]0.04 | [b] |
| Wind | [a]0.02 | [b] |
| **Total** | **84.40** | **100.0** |

[a]Excludes unmeasured direct use.
[b]Less than 0.05 percent

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

Source: Energy Information Administration, *Annual Energy Review 1991*, DOE/EIA-0384(91) (Washington, DC, June 1992) Tables 3 and 107.

## History of the Use of Renewable Resources in Electricity Generation

The use of most technologies employing renewable resources for electricity generation has occurred within the last 20 years. However, two resources, hydropower and wood, have provided significant amounts of electricity since the early days of electricity generation.

### Before 1970

Conventional hydroelectric power has been a major contributor to the electricity industry and an important engine of U.S. economic development. Conventional hydroelectric power predates the electric utility industry. Michigan's Grand Rapids Electric Light and Power Company illuminated 16 lamps with hydroelectric power in 1880, 2 years before Thomas Edison's Pearl Street Station inaugurated the modern electric utility industry. The installation of huge hydroelectric generators at Niagara Falls by George Westinghouse in 1896 transformed the industry. The generators at Niagara Falls dwarfed earlier units, and the project's ability to transmit power for long distances over alter-nating current (AC) lines established the superiority of AC transmission and helped defeat Edison-backed reliance on direct current (DC) power. Over the following years, the use of hydroelectric power grew rapidly.

Federal interest in economic development further boosted the stature of hydroelectricity in the 1930's and beyond. The Mussel Shoals (Alabama) development during World

War I was the first large-scale Federal hydroelectric project. Massive hydroelectricity programs of the Tennessee Valley Authority, the Bureau of Reclamation of the U.S. Department of the Interior, and the U.S. Army Corps of Engineers aided economic development with water and low-cost power. Federal hydroelectric development was especially extensive in the Northwest, where unprecedented hydroelectric expansion began on the Columbia River in the 1930's including construction of the largest U.S. hydroelectric facility, Grand Coulee (6,500 megawatts). Hydroelectric dams generated electricity for production of defense goods during World War II and continued to assist agriculture and economic development afterwards. By 1940, hydroelectricity provided one-third of U.S. electric power.

The hydroelectricity share of the market has declined since that time. Major dam construction has continued, but at a slower rate. Most large productive hydroelectric sites either have been already developed or have been precluded from hydroelectric development to serve other demands. At the same time, Federal investments in hydroelectric power, both for economic development and for other purposes, have slowed. As a result, growth in hydroelectric capacity has given way to much faster growth in investments in fossil and nuclear powered electric generating capacity.

Wood has also been used extensively to generate electricity. Since early in the century, scrap wood and wastes have provided the wood, wood products, and pulp and paper industries with steam and heat for industrial processes and also with significant proportions of their electric power needs. The industries collect large volumes of scrap wood and waste, and face the challenge of disposing of a bulky and otherwise useless waste byproduct. As a result, electric power generation from these industry byproducts has offered both less expensive electric power and waste disposal advantages.

The overwhelming majority of wood-fired electric power generation facilities (184 of the total 190 plants in 1990) exist outside the electric utility sector. The same factors that make wood and wood wastes attractive to industries have made them generally unattractive to electric utilities. For electric utility plants, the costs of accumulating large fuel stocks with relatively low energy content almost always outweigh the benefits achieved by using these fuels.

Other than hydroelectric power and electricity generation from wood and wood wastes, no renewable resource provided any significant proportion of U.S. electric power before the 1970's. Until then, facilities powered by wind, solar thermal, photovoltaic, or geothermal resources, either remained small, isolated facilities disconnected from electric power networks, or took the form of experiments. The first geothermal site in the United States, The Geysers (north of San Francisco), was introduced in 1960, although its capacity did not exceed 100 megawatts until the 1970's.[4] By 1970, U.S. generating capacity using renewable resources totalled about 63 gigawatts (Table 3), almost 18 percent of total U.S. generating capacity. Over 61 gigawatts was conventional hydroelectric, about 1 gigawatt was capacity using wood and wood wastes, and the remainder was scattered among the other technologies.

**Table 3. U.S. Electricity Generating Capacity, 1970, 1980, 1990**
(Gigawatts)[a]

| | 1970 | 1980 | 1990 |
|---|---|---|---|
| Fossil[a] | 284.9 | 472.4 | 548.1 |
| Nuclear | 7.0 | 51.8 | 99.6 |
| Conventional Hydroelectric | 61.5 | 69.1 | 72.9 |
| Other Renewable | 1.4 | 2.8 | 12.3 |
| **Total** | **354.9** | **596.0** | **733.0** |

[a]Net summer capability. For nonutilities, nameplate capacity is used.

[b]Fossil includes coal, oil, natural gas, waste heat, and pumped storage hydroelectric.

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

Sources: Electric Utility Data: Energy Information Administration, *Annual Energy Review 1991*, DOE/EIA-0384(91) (Washington, DC, June 1992); Nonutility Data: for 1970 and 1980, Energy Information Administration, derived from Federal Energy Regulatory Commission, FPC-4, “Monthly Power Plant Report” and Science Applications International Corporation, “Technical Report Preparation, Final Report,” prepared for the Energy Information Administration, July, 1992; and for 1990, Energy Information Administration, EIA-867, “Annual Nonutility Power Producer Report.”

## The 1970's

The use of renewable resources did not increase rapidly in the 1970's. However, the decade did set the stage for later expansion. Few new generating technologies entered the marketplace, although the newly created U.S. Department of Energy, electric utilities, and other entities were actively involved in research and demonstration programs.

Although conventional hydroelectric and geothermal capacity grew substantially, the use of most categories of renewable resources for electricity generation did not grow significantly. No wind, solar thermal, or photovoltaic systems were providing electricity to the electric power network. Less than one-half gigawatt of generating capacity fueled by municipal solid waste (MSW) had been built. On the other hand, geothermal generating capacity grew to almost 0.7 gigawatt by 1980, and conventional hydroelectric generating capacity expanded from 62 gigawatts in 1970 to around 70 gigawatts by 1980. Nevertheless, because of the much greater expansion of fossil- and nuclear-fueled capacity, by the end of the decade renewable resources as a whole provided a smaller share of total U.S. electricity generating capacity than at the beginning. By 1980 renewable resources provided 15 percent of total capacity compared to 19 percent in 1970.

During the 1970's fossil fuel costs rose dramatically, spurring interest in renewable resource alternatives. Oil prices rose rapidly following the energy crises of 1973 and 1979, when actual or threatened restrictions in petroleum supplies from the Organization of Petroleum Exporting Countries (OPEC) sharply affected oil markets. Adjusted for inflation, crude oil prices more than tripled during the decade, and natural gas prices accelerated even more rapidly.[5] These increases in fossil fuel prices, coupled with concerns about national security and dependence upon foreign supplies, helped increase interest in renewable resources as alternative power supplies.

The increasing capital costs of electricity supply also raised interest in alternatives to traditional sources of electric power. Throughout the decade, ambitious capital building programs, plagued by high inflation and high interest rates, as well as with growing technical and regulatory requirements, endured rapid increases in capital costs. Large coal and nuclear-powered generating facilities, which had seemed economically inviting in earlier years, became less and less attractive as the decade wore on.

The rate of growth of electricity demand also slowed significantly during the 1970's. Partly in response to rapidly increasing prices, growth in electricity consumption, which average 7.3 percent a year in the 1960's, slipped to 4.2 percent through the 1970's.[6] As a result, utilities often found themselves with surplus generating capacity. Demands for new generating ca-pacity of all types declined dramatically, including for capacity using renewable resources.

At the same time, concerns about the environment and nuclear power safety continued to grow, and added to the public interest in renewable resources. Amendments to the Clean Air Act of 1970 (P.L. 91-604) in 1977 and 1979 added new restrictions on sulfur dioxide ($SO_2$) emissions from new fossil-fueled power plants, forcing the wider use of low-sulfur coal or installation of flue gas desulfurization (FGD) systems. Such actions increased the costs of generating electricity from coal and further spurred interest in less polluting sources of electric power, including renewable resources. Concerns about the safety of nuclear power were heightened in 1979 by an incident at the Three Mile Island number 2 reactor in Pennsylvania.

Possibly the single most important event in the 1970's creating a market for renewable resources in electric power was the passage of the Public Utility Regulatory Policies Act of 1978 (PURPA, P.L. 95-617). Before PURPA, electric utilities were reluctant to purchase electricity from nonutility firms. However, PURPA amended the Federal Power Act by requiring electric utilities to purchase electricity offered by “qualifying” nonutility producers, specifically including small facilities using renewable resources. PURPA exempted qualifying facilities (QFs) from some Federal and State regulations imposed on electric utilities. Finally, PURPA required electric utilities to pay QF “avoided cost” rates, i.e., rates equal to the additional costs the electric utilities would have incurred had they generated the power themselves or purchased it from other sources. Coupled with public expectations of generally rising electricity costs and other interests in renewable energy for security and environmental reasons, the PURPA requirements encouraged the more rapid entry of renewable resources into the electric power market. The addition of Federal and, occasionally, State tax credits for projects using renewable resources also set the stage for investments in new electric generating capacity.

## The 1980's

During the 1980's, new technologies using renewable resources began to appear in commercial markets. Although large quantities of generating capacity using renewable resources were not added during the 1980's, the decade was marked by significant technical progress, declines in costs, productive commercial experience, and greatly expanded contributions in specific segments of the electric power market.

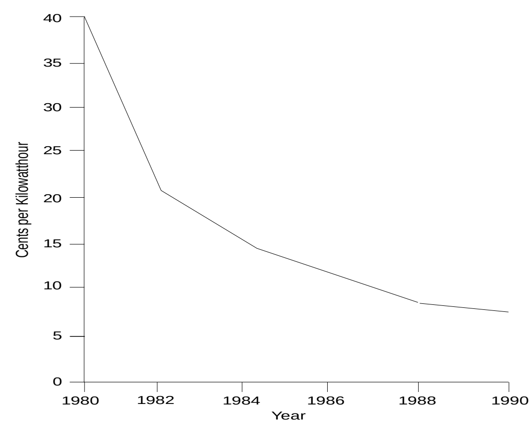
[5]Energy Information Administration, *Annual Energy Review 1991* DOE/EIA-0384 (91) (Washington, DC, June 1992).
[6]Energy Information Administration, *Annual Energy Review 1991*, DOE/EIA-0384(91) (Washington, DC, June 1992).

In general, each technology benefitted from public (usually Federal) and private investment during the 1980's, both for research, development and demonstration facilities, and for commercial projects. Operating experiences revealed opportunities for improvements in resource selection and site placement, materials and equipment selection, and manufacturing and operating efficiencies. More useful applications of technologies using renewable resources as part of the overall electricity supply mix were also found. (Appendix C, "Electricity Generating Technologies Using Renewable Resources," provides descriptions of generating technologies using renewable resources today. It also identifies specific applications appropriate to each technology.)

As a result, the total costs (capital plus operating costs) of producing electricity using renewable resources dropped significantly during the 1980's. Data assembled by the DOE and others reflect the progress in lowering costs. Figure 1 illustrates the progress for wind powered generation, with costs dropping from around 40 cents per kilowatthour in 1980 to below 10 cents in 1988.[7] Some of the most efficient units in California now produce electricity for less than 5 cents per kilowatthour.[8] Similarly, costs of electricity from solar thermal generating systems are estimated by the DOE to have fallen from about 60 cents per kilowatthour in 1980 to below 10 cents per kilowatthour by 1990 (Figure 2).[9] The costs of generating electricity using photovoltaics has fallen from above $19 dollars per kilowatthour in the early 1970's to about 30 cents today (in utility-grade applications).[10]

The costs of using geothermal energy, biomass, and MSW have also dropped. The least expensive geo-thermal plants in California are estimated to be producing power at 4.5 to 6.5 cents per kilowatthour, rates that may not be duplicated elsewhere, but which show that the technology can compete with fossil fuels.[11] Costs of generating power from wood are estimated to be competitive at about the 5-cent-per

**Figure 1. Cost of Electricity Using Wind Power Plants, 1980-1990**




Source: U.S. Department of Energy, *The Secretary's Annual Report to Congress 1990*, DOE/S-0010P(91) (Washington, DC, 1991).

kilowatthour-level, where wood fuel can be obtained for $2.00 per million Btu or less, usually within about a 50-mile radius. Because of the additional costs of trash handling, MSW facilities can only be competitive today when tipping fees (the per-ton fees paid to MSW facilities for accepting trash) become sufficiently high to offset the higher costs of producing electricity using MSW.[12] Finally, photovoltaic systems made substantial progress in the 1980's, despite remaining much more expensive than traditional sources of electricity for most purposes. Although the proportion of received sunlight converted to electricity (conversion efficiency) improved significantly over the decade (Figure 3), costs for utility scale (megawatt sized) photovoltaic systems today are still about 30 cents per kilowatthour, according to DOE estimates.[13]

[7]U.S. Department of Energy, *The Secretary's Annual Report to Congress 1990* DOE/S-0010P(91) (Washington, DC, 1991).

[8]California Energy Commission, "California Wind Project Performance: A Review of Wind Performance Results From 1985 to 1990," from Proceedings, Windpower 91).

[9]U.S. Department of Energy, *The Secretary's Annual Report to Congress 1990*, DOE/S-0010P(91) (Washington, DC, 1991).

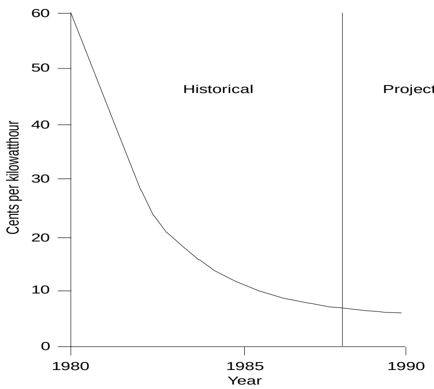
[10]U.S. Department of Energy, *Renewable Energy Technology Evolution Rationales*, Internal Working Draft, Geothermal Section, October 5, 1990.

[11]U.S. Department of Energy, Office of Policy, Planning and Analysis, *The Potential of Renewable Energy, An Interlaboratory White Paper*, SERI/TP-260-3674, (March 1990).

[12]U.S. Department of Energy, Office of Policy, Planning and Analysis, *The Potential of Renewable Energy, An Interlaboratory White Paper*, SERI/TP-260-3674, (March 1990).

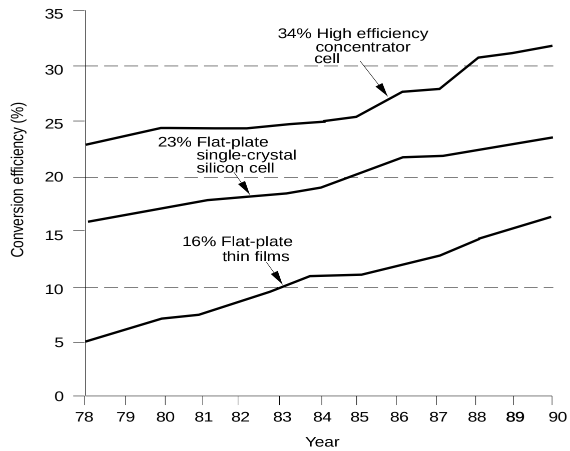
[13]U.S. Department of Energy, Office of Policy, Planning and Analysis, *The Potential of Renewable Energy, An Interlaboratory White Paper*, SERI/TP-260-3674, (March 1990).

**Figure 2. Cost of Electricity Using Solar Thermal Generating Plants, 1980-1990**




Source: U.S. Department of Energy, *The Secretary's Annual Report to Congress 1990*, DOE/S-0010P(91) (Washington, DC, 1991).

**Figure 3. Photovoltaic Cell Conversion Efficiencies, 1978-1990**




Note: Conversion efficiency is the proportion of received sunlight converted to electricity.

Source: U.S. Department of Energy, *The Secretary's Annual Report to Congress 1990*, DOE/S-0010P(91) (Washington, DC, 1991).

## Current Status

Renewable resources provided 348 billion kilowatthours of the more than 3 trillion kilowatthours of electricity generated in the United States in 1990 (Table 4); that is nearly 12 percent of total electricity generation. Almost 10 of this 12 percent (288 billion kilowatthours) was provided by hydroelectric resources alone. Biomass and MSW contributed more than 1 percent. All other renewable resources, including geothermal, wind, and solar, together provided less than 1 percent of the total. Conversely, fossil resources, primarily coal, provided 69 percent of the Nation's electricity, and nuclear power provided 19 percent.

**Table 4. U.S. Electricity Generating Capacity and Net Generation, 1990, By Fuel Type**

| Fuel | Net Summer Capability[a] (Gigawatts) | Net Generation[b] (Billion Kilowatthours) |
|---|---|---|
| Fossil[c] | 528.7 | 2,100 |
| Storage | 19.5 | -2 |
| Nuclear | 99.6 | 577 |
| Renewable | 85.2 | 348 |
| Conventional Hydroelectric | 72.9 | 288 |
| Geothermal | 2.6 | 15 |
| Municipal Solid Waste | 2.0 | 10 |
| Biomass | 6.0 | 31 |
| Solar[d] | 0.4 | 1 |
| Wind | 1.4 | 2 |
| **Total** | **733.0** | **3,023** |

[a]For nonutilities, nameplate capacity is used.

[b]For nonutilities, gross generation including internal station use is shown.

[c]Fossil includes coal, oil, natural gas, petroleum coke, waste gases, and waste heat.

[d]Includes both solar thermal and less than 0.02 billion kilowatthours grid-connected photovoltaic generation.

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

Source: Energy Information Administration. 1990 data: For utilities, EIA-861 “Annual Electric Utility Report”; for nonutilities, EIA-867, “Annual Nonutility Power Producer Report.”

Electric utilities (investor-owned, Federal, municipal, rural electric cooperative, and other publicly owned) own most of the generating capacity using renewable resources (Table 5). In addition to owning most hydro-electric facilities, electric utilities also own most of the geothermal capacity. However, most of the generating capacity using other renewable resources (MSW, biomass, solar, and wind) has been provided by the nonutility sector, particularly in recent years. Of the 9,746 megawatts of generating capacity using biomass, MSW, wind, and solar, 95 percent is nonutility-owned.

The dominance of nonutilities in the use of these renewable resources for electricity supply can be traced to three factors. First, nonutility electricity generation is often a byproduct of other industrial activities. Biomass-fueled electricity is generally a byproduct of the forest, wood, and paper industries, which use biomass waste to generate steam and electricity for their own use. MSW-powered generation is a byproduct of the trash disposal industry. Second, renewable resources are encouraged in nonutility markets by PURPA, which exempts renewable-fueled power plants built by non-utilities from being regulated as electric utilities, while at the same time requiring utilities to purchase the output from them at full avoided cost. Finally, during the 1980's, electric utilities slowed capacity expansion and increasingly turned to the nonutility sector to meet all forms of new generating capacity needs. California, in particular, has experienced all three factors, plus strong public preferences for and policies promoting the use of renewable resources. Also, electric utilities in California have made a concerted effort to research and invest in renewable resource-fueled projects.

The use of renewable resources for electricity generation is highly concentrated regionally (Tables 6 and 7), with most renewable resources being used for power in either the easternmost or westernmost States. Often the use follows the concentrations of the natural resource bases (Appendix B). But other factors also play an important part. These factors include the overall rate of growth of demand for new generating capacity and the rate of growth of costs in an associated activity (such as waste disposal). Over three-fourths of all renewable generating capacity can be found in three regions: the Northwest, West, and South Atlantic (Table 6). Of the total 85 gigawatts of electric generating capacity fueled by renewable resources, almost 39 percent is located in the Northwest alone.

The predominance of renewable resources in these three regions occurs both for conventional hydroelectric capacity and for all other renewable resources taken together. Hydroelectric resources are concentrated in the Northwest, West, and South Atlantic regions, and reflect the natural distribution of favorable hydroelectric sites in the country.

**Table 5. U.S. Generating Capacity Using Renewable Resources, 1990**
(Net Summer Capability, Megawatts, by Ownership Group)

| Source | Electric Utility[a] | Nonutility[b] | Total[b] |
|---|---|---|---|
| Conventional Hydroelectric | 71,423 | 1,476 | 72,899 |
| Geothermal | 1,614 | 961 | 2,575 |
| Municipal Solid Waste | 244 | 1,765 | 2,009 |
| Biomass | 221 | 5,750 | 5,971 |
| Solar[a] | 3 | 360 | 363 |
| Wind | [d] | 1,403 | 1,403 |
| **Total** | **73,505** | **11,715** | **85,220** |

[a]Electric utilities include investor-owned, federal, rural electric cooperative, municipal and other publicly owned electric utilities.
[b]For nonutilities, nameplate capacity is used.
[c]Includes solar thermal and grid-connected photovoltaics.
[d]Less than 0.5 megawatts.
Note: Totals may not equal sum of components due to independent rounding.
Source: Energy Information Administration. For utilities, EIA-861 *"Annual Electric Utility Report";* for nonutilities, EIA-867, *"Annual Nonutility Power Producer Report."*

**Table 6. U.S. Generating Capacity Using Renewable Resources, 1990, by Federal Region**
(Net Summer Capability, Megawatts)[a]

| Federal Region[b] | Conventional Hydroelectric | Other Renewable | Total Renewable | Total Capacity, All Sources |
|---|---|---|---|---|
| New England | 1,875 | 1,268 | 3,143 | 26,655 |
| New York/New Jersey | 1,802 | 347 | 2,149 | 46,836 |
| Mid-Atlantic | 2,172 | 681 | 2,853 | 78,087 |
| South Atlantic | 10,900 | 2,654 | 13,554 | 152,750 |
| Midwest | 1,217 | 762 | 1,979 | 127,452 |
| Southwest | 2,702 | 830 | 3,532 | 118,001 |
| Central | 838 | [c] | 838 | 38,488 |
| North Central | 5,931 | 53 | 5,984 | 29,870 |
| West | 13,120 | 5,196 | 18,316 | 74,730 |
| Northwest | 32,343 | 529 | 32,872 | 40,141 |
| **United States** | **72,899** | **12,321** | **85,220** | **733,009** |

[a]For nonutilities, nameplate capacity is used.
[b]For a list identifying the States in each Federal region, see Appendix D.
[c]Less than 0.5 megawatts.
Note: Totals may not equal sum of components due to independent rounding.
Source: Energy Information Administration. For utilities, EIA-861 *"Annual Electric Utility Report";* for nonutilities, EIA-867, *"Annual Nonutility Power Producer Report."*

**Table 7. U.S. Net Generation Using Renewable Resources, 1990, by Federal Region**
(Billion Kilowatthours)[a]

| Federal Region[b] | Conventional Hydroelectric | Other Renewable | Total Renewable | Total Capacity, All Sources |
|---|---|---|---|---|
| New England | 8.6 | 7.4 | 16.0 | 108.5 |
| New York/New Jersey | 27.5 | 2.0 | 29.5 | 174.0 |
| Mid-Atlantic | 7.7 | 3.2 | 10.9 | 347.0 |
| South Atlantic | 38.0 | 13.0 | 50.9 | 642.5 |
| Midwest | 5.0 | 3.8 | 8.8 | 549.4 |
| Southwest | 8.1 | 5.1 | 13.2 | 472.0 |
| Central | 4.2 | [c] | 4.2 | 144.8 |
| North Central | 18.7 | 0.3 | 19.0 | 164.0 |
| West | 31.9 | 23.2 | 55.1 | 254.7 |
| Northwest | 138.4 | 2.3 | 140.7 | 166.4 |
| **United States** | **288.1** | **60.3** | **348.3** | **3,023.3** |

[a]For nonutilities, gross generation including internal station use is shown.
[b]For a list identifying the States in each Federal region, see Appendix D.
[c]Less than 0.05 billion kilowatthours.
Note: Totals may not equal sum of components due to independent rounding.
Source: Energy Information Administration. For utilities, EIA-861 *"Annual Electric Utility Report";* for nonutilities, EIA-867, *"Annual Nonutility Power Producer Report."*

Other regions, particularly the more arid regions or regions lacking large vertical drops, are unlikely ever to have significant hydroelectric capacities. After the Northwest and West, the South Atlantic region features the greatest absolute use of renewable resources to generate electricity, reflecting the region's abundant hydroelectric capacity and extensive use of wood and wood waste in electricity generation. Similarly, New England's use of renewable resources is predominantly in hydroelectric and wood / wood waste-fired generation.

The use of nonhydroelectric renewable resources is also regionally concentrated. The West (especially California) employs policies that encourage the development of renewable resources. Laws, regulations, and electric utility choices in California reflect a preference for renewable fuels there. Of a total of 12.3 gigawatts of other generating capacity powered by renewable resources, 5.2 gigawatts, 42 percent, is located in the West, overwhelmingly in California. In fact, nonhydroelectric renewable resources provide nearly 7 percent of all generating capacity in the West, a substantially higher proportion than for most other regions. Geo-thermal resources are concentrated in the West, along with useful wind and solar conditions.

Clearly, most regions of the United States feature little use of renewable resources other than hydroelectricity for electricity supply. Five regions—New York / New Jersey, the Midwest, Southwest, North Central, and Central regions—each rely on nonhydroelectric renewable resources for less than 1 percent of their total electricity supply. Four of these regions—the Midwest, Southwest, North Central, and Central—have adequate electric generating capacity and low fossil-energy prices, relatively meager wood supplies, and low land- fill costs, making continued use of fossil-fueled capacity likely. On the other hand, the Midwest and Southwest have extensive solar and wind resources available to them.

Use of each individual renewable resource is highly concentrated. Almost all geothermal capacity is located in the West, with the remainder in the Northwest. Similarly, the vast majorities of solar and wind-powered systems are located in the West. Because most biomass-fueled generating capacity is forest-products based, biomass-fired capacity is concentrated in the Southeast, West, New England, and Mid-Atlantic regions, where forests are most abundant. MSW facilities are most heavily concentrated in regions with high trash-volume, especially in urban areas that face

## California, Home to Renewable Energy

California stands out as a premier area for the use of renewable resources in electric power generation. About 90 percent of the Nation's geothermal capacity is in California, including the oldest and largest geothermal field, The Geysers (1,866 megawatts) in northern California; three other major sites, Coso Hot Springs, East Mesa, and the Salton Sea project, are in southern California. California hosts over 95 percent of the Nation's solar thermal capacity, including facilities in the Harper Lake and Kramer Junction areas of the Mojave desert, north of Los Angeles (Figure 4). The Nation's largest central station photovoltaic facility, PVUSA (1 megawatt) is located in California. Finally, almost all the major wind systems in the United States are located in California. The largest, Altamont, east of San Francisco, operates more than 7,000 wind turbines serving Pacific Gas and Electric Company. The second and third, Tehachapi and San Gorgonio, near Los Angeles, serve Southern California Edison.

California's prominence in using renewable resources results from a number of factors, including natural resource endowments, continuing demand growth, support from business, government, and the public; and favorable tax and regulatory treatment. Certainly the existence of favorable wind, solar, and geothermal resources situated near demand centers plays a part. California has also responded to a strong public preference for renewable resources. Favorable attitudes and actions by citizens, electric utilities, and State regulatory agencies provided the interest and business conditions under which capacity that used renewable resources could be built. Concerns about the environmental consequences (as well as the cost) of coal-fired generation precluded siting coal-fired generators in the State, opening the way for alternative sources. Public encouragement and other factors aided California in offering favorable prices and conditions to renewable resources during the decade; favorable treatment of renewable resources under PURPA, and state tax incentives also spurred uses of renewable alternatives.

**Figure 4. Solar Thermal Generating Facility, Kramer Junction, California**

Source: U.S. Department of Energy, Sandia National Laboratories.

high and growing landfill costs, generally along the Eastern seaboard and in the Midwest.

The absence of extensive generating capacity using renewable resources in the Nation's heartland is more easily explained by market conditions than by the lack of renewable resources. Many areas have abundant excellent solar and wind resources (Appendix B). Certainly many areas appear to be better endowed than California. However, many renewable resources are located far from demand centers; the costs of transmitting the electricity may raise its delivered cost above the cost of generating electricity closer to the demand. North Dakota's winds, for example, can only serve major demands if the power is transmitted many hundreds of miles. Also, in many areas, demand for electricity has not grown rapidly enough to induce significant capacity growth of any sort, which reduces opportunities for exploitation of renewable resources. Finally, many areas of the country have less expensive fossil resources, especially coal and natural gas. Where additional electric generating capacity has been built, coal and natural gas have often been competitive, providing consumers with less expensive power. For these regions, the increased use of renewable resources in electric power generation will likely have to await higher electricity demand growth rates, lower costs of technologies using renewable resources, and additional access to electricity transmission.

# 2. Projections of Renewable Resources in the U.S. Electricity Supply

## Introduction

To assist the energy industry and to provide policymakers with information about the energy supply and demand in the United States, the EIA has prepared long-term projections, including for renewable resources, in the *Annual Energy Outlook 1993* (AEO93).[14] These projections consider renewable resource supplies within the context of overall energy demands and supplies. This chapter presents and discusses these projections to draw conclusions relevant to the use of renewable resources.

## Energy Information Administration (EIA) Projections

The AEO93 offers a baseline case, called the Reference Case, and three pairs of other cases that give high and low projections based on various assumptions. The Reference Case is used to facilitate comparisons among the other six cases and with forecasts prepared by other organizations. However, the Reference Case should not be viewed as a most likely scenario. Four of the six other cases illustrate the effects of changes in factors known to be important to renewable energy markets. The High Economic Growth Case and the Low Economic Growth Case show the long term effects of different rates of U.S. economic growth. The High World Oil Price Case and the Low World Oil Price Case show the effects of different fossil fuel prices. The final two cases demonstrate the effects of the uncertainties inherent in recoverable oil and natural gas resource estimates. These two cases are not considered relevant for the renewable energy projections and are not discussed here.

### Assumptions

The Reference Case combines the assumption of an economic growth rate (Gross Domestic Product, GDP) of 2.0 percent per year with a mid-level path for the world oil price (Table 8). The High Economic Growth Case assumes the same mid-level world oil prices, but combines them with an assumption of higher macroeconomic growth, 2.4 percent per year; the Low Economic Growth Case also assumes a mid-level world oil price path, but combines it with a lower macroeconomic growth rate of 1.6 percent a year.

World oil prices are defined as the average refiner acquisition cost of imported crude oil in the United States. The High World Oil Price Case combines the Reference Case economic growth trend with a higher world oil price path, starting at $19 per barrel in 1991 and rising gradually to $38 in 2010 (using real 1991 dollars). Because the world oil price is higher than that assumed for the Reference Case, the effective rate of

**Table 8. World Oil Price and Economic Growth Assumptions for the *Annual Energy Outlook 1993***

| Assumptions | Reference Case | Low Economic Growth Case | High Economic Growth Case | Low Oil Price Case | High Oil Price Case |
|---|---|---|---|---|---|
| Oil Price in 2010 ($1991 per barrel) . . . . . . . . . | $29.30 | $29.30 | $29.30 | $18.10 | $38.10 |
| Economic Growth (GDP) Rate (1990-2010) . . | 2.0 | 1.6 | 2.4 | 2.1 | 2.0 |

Source: Energy Information Administration, *Assumptions for the Annual Energy Outlook 1993*, DOE/EIA-0527(93) (Washington, DC, January 1993).

[14]Energy Information Administration, *Annual Energy Outlook 1993*, DOE/EIA-0383(93) (Washington, DC, January 1993).

economic growth and the level of GDP in 2010 in this case are slightly lower than in the Reference Case, yielding a slightly lower overall demand for energy. The Low World Oil Price Case combines Reference Case economic growth with an assumption that world oil prices will fall to about $18 per barrel by 2010. Once again, the world oil price results in macroeconomic feedback resulting in a slightly higher overall demand for energy than in the Reference Case.

Although the major source of renewable energy for electricity generation is hydroelectric power, projections for conventional hydroelectricity are assumed not to vary across the cases. Overlapping regulatory processes, conflicting requirements for licenses and permits, disagreements over environmental issues, as well as a lack of available sites, have constrained the develop-ment of hydroelectric power plants. Additions to hydroelectric generating capability have been small during the 1980's and are not likely to increase significantly in the foreseeable future.

The costs of electricity generating technologies using renewable resources are implicitly considered in the projections by assumptions that the relative costs and efficiencies of technologies using them will not fall significantly in comparison with traditional fossil-fueled technologies. Further, the EIA projections do not pre-sume any legal or regulatory actions, such as additional taxes or subsidies, beyond those occurring under existing legislation, that might affect the relative prices of energy choices.

The AEO93 also assumes the provisions of the Energy Policy Act of 1992 (see Box). The resulting projections for renewable resources include the net effects of the production tax credits for wind and biomass, and the 10 percent investment tax credit for solar and geothermal projects. The effects of the Act on renewable energy are assessed in the overall context of U.S. energy markets.

A fuller explanation of the assumptions and references for the AEO93, including the effects of the Energy Policy Act, can be found in *Assumptions for the Annual Energy Outlook 1993*.[15] The Electricity Market Module (EMM) of the "Intermediate Future Forecasting System" (IFFS) is used to develop the projections for the electricity markets. However, in general, projections for renewable resources in electricity generation are pro-vided exogenously using a combination of utility- and nonutility-declared plans, separate models, macroeconomic and world oil price assumptions and demand growth forecasts from the AEO, and expert judgment. For a summary description of specific assumptions for renewable energy markets, see Appendix A of this report.

## EIA Reference Case Results

In the Reference Case, U.S. electricity generation is projected to grow moderately through 2010, at an average rate of 1.5 percent a year. During the 1990-2010 forecast period, all U.S. electricity generating capacity is expected to increase slowly, growing at an average annual rate of about 0.9 percent (Table 9). The EIA expects most of the growth in electric generating capacity to continue to be provided by fossil fuels—coal, natural gas and oil.

According to the EIA Reference Case, through 2010 electricity generation using renewable resources is projected to increase more rapidly than overall U.S. generation. Generation using renewable resources is forecast to increase at an average annual rate of growth of 1.8 percent. Net generation that relies on renewable resources increases from 348 billion kilowatthours in 1990 to 501 billion kilowatthours in 2010.

As a result, the renewable resource share of the electricity marketplace should grow slightly over the next 20 years. By 2010, renewable resources are projected to capture 12.2 percent of the U.S. electricity generation. Of course, on a regional basis, where they are available and costs of alternatives are high, renewable resources, particularly MSW, biomass, geothermal, and wind, could make increasingly significant contributions.

The mix of renewable resources in electricity supply is expected to change noticeably over the forecast period. Hydroelectric capacity is expected to grow little, losing some of its relative share, while electricity generation using other renewable resources, particularly MSW and geothermal, is expected to grow more rapidly than overall demand.

From 1990 through 2010, total U.S. conventional hydroelectric capacity is expected to grow by only 4 gigawatts; its growth rate will average 0.3 percent a year. Little additional conventional hydroelectric capacity expansion is expected after 1995. The EIA Reference Case projections indicate that the increased use of other renewable resources will offset the lower rate of growth for hydroelectric power. Electricity

## The Energy Policy Act of 1992

The Energy Policy Act of 1992 (P.L. 102-485), signed into law by President Bush on October 24, 1992, affects virtually every part of U.S. energy markets. As a result, the Act is likely to have both direct and indirect effects on the Nation's use of renewable resources for electric power supply.

Some parts of the law are explicitly designed to directly increase the use of renewable resources. The law establishes a permanent 10 percent investment tax credit for solar and geothermal projects. It also establishes a 1.5 cent per kilowatthour production tax credit or payment for electricity produced from the use of wind or biomass (from crops dedicated to energy use) in plants brought on line before July 1, 1999. A facility may earn the credit or payment for 10 years. The Act also authorizes the Department of Energy to assist demonstration and commercialization projects using renewable resources, and authorizes a range of actions to encourage growth in exports of technologies using renewable resources. The net effect of these provisions should be to encourage expanded use of these resources.

Other parts of the legislation, while designed to improve the efficiency of energy markets overall, may or may not result in increased use of renewable energy resources. The law sets higher energy efficiency standards for some classes of buildings, motors, lights, and commercial and industrial equipment. These standards will reduce the growth in energy demands, including from renewable resources. The law also encourages alternatives to renewable energy. It reforms the nuclear power plant licensing process and promotes the development of advanced nuclear power plants. It encourages environmentally sound uses of coal, streamlines the regulation of oil pipelines, and promotes the use of natural gas. These features will act to increase the competitiveness of fossil and nuclear energy sources. Other features have less clear effects on renewable energy. For example, the Act exempts some classes of electricity generating firms from regulation as public utilities and increases access to electricity transmission networks by electricity producers other than electric utilities. These exemptions are generally viewed as favorable to renewable energy sources, but as favorable to their fossil fuel competitors as well.

generation from other renewable energy sources is expected to grow at an average annual rate of 6.2 percent. Collectively, geothermal, MSW, biomass, wind, and solar-powered capacity are projected to grow from 12.3 gigawatts in 1990 to 36.2 gigawatts by 2010. Over the 20-year period, the average annual rate of growth in generating capacity for this group is 5.5 percent—over six times the average rate of growth of total capacity (from all sources).

The greatest expansion in renewable energy for electricity supply over the 20-year forecast period is expected to occur in the use of MSW. Electric generating capacity using MSW is expected to expand from 2.0 gigawatts in 1990 to 11.4 gigawatts by 2010, increasing at an average rate of 9.1 percent resulting from population and economic growth and the reduced availability of landfill space. Of the total projected non-hydroelectric capacity growth of 23.9 gigawatts, 39 percent will be provided by additional MSW plants.

Geothermal-based electric generating capacity is also projected to expand rapidly, from about 2.6 gigawatts in 1990 to 8.5 gigawatts by 2010. Electricity generation using geothermal resources is expected to grow at an average rate of 7.2 percent, helped by the provisions of the Energy Policy Act. Given that hydrothermal and hot dry rock resources are concentrated in the West, it is not surprising that almost all of the expansion is expected to occur in the Western region, especially in California. No geothermal generating capacity growth is anticipated in any States east of the North Central region.

In the Reference Case, the EIA projects wind-powered capacity to increase from 1.4 gigawatts in 1990 to over 6.3 gigawatts by 2010, increasing at a rate almost 9 times the projected overall rate of total U.S. electric generating capacity expansion. Nevertheless, with wind accounting for less than 0.2 percent of U.S. electric generating capacity in 1990, by 2010 wind still will provide only about 0.7 percent of the U.S. total. Some expansion in solar thermal electricity generation is expected over the period. The projections do not include forecasts for photovoltaic systems disconnected from the utility transmission network (dispersed

**Table 9. U.S. Electric Generating Capacity and Net Generation Projections for 2010**

| Technology | 1990[a] | 2010 Reference | 2010 High Economic Growth | 2010 Low Economic Growth | 2010 High World Oil Price | 2010 Low World Oil Price |
|---|---|---|---|---|---|---|
| **Net Summer Capability (Gigawatts)** | | | | | | |
| Conventional Hydropower | 72.9 | 76.9 | 76.9 | 76.9 | 76.9 | 76.9 |
| Geothermal | 2.6 | 8.5 | 8.5 | 8.5 | 9.7 | 7.3 |
| Municipal Solid Waste | 2.0 | 11.4 | 13.9 | 10.9 | 11.4 | 11.4 |
| Biomass/Other Waste[b] | 6.0 | 8.1 | 8.3 | 7.2 | 8.1 | 8.1 |
| Solar[c] | 0.4 | 1.9 | 1.9 | 1.9 | 2.2 | 1.7 |
| Wind | 1.4 | 6.3 | 6.3 | 6.3 | 7.3 | 5.3 |
| **Total Capacity, Renewable** | **85.2** | **113.1** | **115.9** | **111.7** | **115.5** | **110.7** |
| Fossil/Nuclear/Other[d] | 647.8 | 767.0 | 814.2 | 722.1 | 759.4 | 780.6 |
| **Total Generating Capacity** | **733.0** | **880.1** | **930.1** | **833.8** | **874.9** | **891.3** |
| **Percent Renewable** | **11.6** | **12.9** | **12.5** | **13.4** | **13.2** | **12.4** |
| **Net Generation** (Billion Kilowatthours) | | | | | | |
| Conventional Hydropower | 288 | 306 | 306 | 306 | 306 | 306 |
| Geothermal | 15 | 62 | 62 | 62 | 72 | 53 |
| Municipal Solid Waste | 10 | 54 | 70 | 50 | 54 | 54 |
| Biomass/Other Waste[b] | 31 | 59 | 60 | 54 | 59 | 59 |
| Solar[c e] | 1 | 4 | 4 | 4 | 4 | 3 |
| Wind | 2 | 16 | 16 | 16 | 19 | 14 |
| **Total Renewable** | **348** | **501** | **519** | **492** | **513** | **488** |
| Fossil/Nuclear/Other[d] | 2,675 | 3,611 | 3,816 | 3,393 | 3,576 | 3,679 |
| **Total Net Generation** | **3,023** | **4,112** | **4,335** | **3,885** | **4,089** | **4,167** |
| **Percent Renewable** | **11.5** | **12.2** | **12.0** | **12.7** | **12.5** | **11.7** |

[a]The 1990 data shown in the table are actual EIA published values (preliminary data), while the 1990 values published in the *Annual Energy Outlook 1993* are estimates.
[b]Includes wood, wood waste, and other biomass.
[c]Includes both solar thermal and grid-connected photovoltaic capacity. Solar does not include dispersed photovoltaics.
[d]Includes pumped storage hydroelectric.
[e]Includes solar thermal and less than 0.02 billion kilowatthours grid-connected photovoltaic generation.

Notes: Forecasts of renewable electric generating capacity for the High and Low Oil and Gas Recovery Cases are the same as for the Reference Case. Totals may not equal sum of components due to independent rounding.

Sources: Energy Information Administration, **1990 data**: For utilities, EIA-861 *Annual Electric Utility Report*; for nonutilities, EIA-867, *Annual Nonutility Power Producer Report*. **Projections for 2000 and 2010**: *Annual Energy Outlook 1993*, DOE/EIA-0383(93).

photovoltaics). However, applications of very small but high-value photovoltaic devices, such as for powering monitoring devices, lights, pumps, remote building electricity supply, and other uses for which connection to transmission lines is too costly, are expected to proliferate over the forecast period.

Nonutilities, including independent power producers, and also cogenerators and small facilities qualifying under PURPA, will build about four-fifths of the 28 gigawatts of new electricity generating capacity using renewable resources. Much of the new capacity, such as that fueled by MSW and biomass, will be provided by municipalities and industries. Also, PURPA benefits for electricity production from renewable resources apply to nonutility producers and not to electric utilities. Finally, in some instances (for example, wind and solar thermal), investment in the technologies should continue to occur outside the electric utility sector.

## Alternative EIA Case Results

In the four alternative EIA projection cases, long-term renewable energy projections for electric power are developed under economic growth and world oil price assumptions different from the Reference Case. The alternative cases suggest that both higher rates of economic growth and higher world oil prices (of the magnitudes assumed in the cases) could result in increased use of renewable resources over the forecast period.

Changes in the assumed rate of economic growth through 2010 directly affect electricity supply using renewable energy resources. High economic growth (2.4 percent per year) yields over 4 gigawatts more generating capacity using renewable resources than low economic growth (1.6 percent per year) (Table 9). The higher economic growth causes additional waste generation and expansion in electricity generation from MSW; similarly, high economic growth causes the use of more biomass (wood) for electricity in the paper and lumber industries. By the same token, low economic growth results in lower rates of growth in MSW and biomass available for use in electric power generation.

Changes in world oil prices also have a direct affect on the growth of electricity supply from renewable resources. Because Reference Case assumptions for economic growth are retained, results for MSW and biomass are unchanged for these cases. In the High World Oil Price Case, with resulting higher natural gas prices, a total of nearly 5 gigawatts more geothermal, solar, and wind-powered generating capacity is built by 2010 than under low world oil price assumptions. This occurs despite a drop of 78 billion kilowatthours in overall electricity generation—geothermal, solar, and wind resources become more competitive relative to fossil fuels. All three resources are responsive to the increases in natural gas prices, particularly in the West.

## Comparison With Other Forecasts

To put the EIA forecast into perspective, this section compares the EIA Reference Case projections with non-EIA forecasts. Several differences among the forecasts make comparisons difficult. First, the EIA projections incorporate the provisions of the Energy Policy Act of 1992, whereas the non-EIA projections were completed before enactment of this law. Second, details concerning

## Solar Two

The U.S. Department of Energy and a consortium of 12 electric utilities and others is retrofitting the Solar One solar thermal central receiver pilot plant (Appendix C) for operation beginning in 1995.

The original 10-megawatt Solar One facility, located near Barstow, California, demonstrated that the central receiver concept can operate reliably. Solar One, however, used oil as the energy storage medium, a medium inefficient for more than brief energy storage. As a result, the Solar One facility acted as a peaking unit during times of maximum sunlight.

Solar Two will reuse much of the original facility, including the 300-foot tower, the turbine, the generator, and its field of dual-axis (horizontal and vertical) mirrors called heliostats. However, the newer facility will introduce a molten-salt heat transfer medium to collect and store heat energy, replacing the earlier oil system. "Cold" (550 degrees Fahrenheit) molten salt, a mixture of sodium and potassium nitrate, will be pumped from a cold storage tank to the receiver at the top of the tower. Concentrated sunlight from the heliostat field will heat the molten salt to 1,050 degrees Fahrenheit, either for direct use (via a heat exchanger) or for storage and later use in generating electricity.

The molten-salt receiver system is expected to permit the power from Solar Two to be dispatchable (available when needed rather than only when the sun shines), and, in later large-scale commercial applications, to operate at capacity factors up to 60 percent, allowing electricity production even at night or during bad weather, and to produce electricity with zero emissions, all at a cost (when the system is fully commercial) no greater than from alternatives.

Solar Two is expected to cost $39 million. The cost will be shared equally by the DOE and the consortium.

different assumptions and definitions used in the non-EIA forecasts are often not readily available. Third, the various forecasts typically do not use directly comparable fuel categories for measurement.

Fourth, some of the forecasts use nameplate capability, rather than net summer capability. Nameplate capability represents the manufacturer's reported capacity for each turbine generator, while net summer capability represents the actual tested capacity of the unit at peak summer demand. Nameplate capability is generally 5 to 10 percent greater than net summer capability.

And finally, some of the projections are limited to electric utility forecasts, and either omit nonutilities altogether or lump together all fuels for nonutilities, eliminating the possibility of completely comparable resource comparisons for the total electricity market.

Four major alternative projections are compared with the EIA Reference Case for U.S. renewable energy markets in 2010: the WEFA Group (WEFA), the DRI/McGraw-Hill (DRI), the Gas Research Institute (GRI), and finally, the projections provided by the Union of Concerned Scientists (UCS).[16] Generally, the macroeconomic assumptions (Table 10) used by the EIA and the other organizations are similar for the 1990-2010 forecast period. Most of them fall between the EIA's Low Economic Growth (averaging 1.6 percent a year) and High Economic Growth case assumptions (2.4 percent a year), although the UCS projections assumed a 2.7 percent annual real growth rate.

## Results

Despite major differences in underlying assumptions and presentation, some common conclusions emerge from a comparison of the EIA projections for renewable energy with other forecasts through 2010 (Table 11).

In all the projections, renewable energy is expected to increase its contribution to U.S. electricity supply. The alternative projections (DRI and GRI) for electric utilities only (i.e., excluding nonutilities) forecast a total of between 76 and 82 gigawatts of generating capacity using renewable resources in 2010. These projections are similar to the EIA forecast of 81 gigawatts in 2010. The WEFA projections, including both electric utilities and nonutilities, forecast a total of 107 gigawatts of generating capacity using renewable resources in 2010. The UCS Reference Case projects the most expansion, to 135 gigawatts of renewable capacity in 2010, a result of assumed higher economic growth (and consequent electricity demand expansion) and greater competitiveness of renewable resources in the electric power marketplace.

**Table 10. Comparison of Macroeconomic Forecasts**
(Average Annual Percentage Change, 1990-2010)

| | EIA *AEO93* | | | Other Forecasts | | | |
|---|---|---|---|---|---|---|---|
| Projection | Reference | High Economic Growth | Low Economic Growth | WEFA | DRI | GRI | UCS |
| Real Gross Domestic Product (GDP)[a] | 2.0 | 2.4 | 1.6 | 2.4 | [c]2.2 | 2.0 | 2.7 |
| Inflation[b] | 3.9 | 3.3 | 5.3 | 3.6 | [d]3.7 | 4.1 | NA |

[a]Real GDP in 1987 dollars except where noted.
[b]Based on GDP deflators in 1987 dollars, except where noted.
[c]Real GNP in 1982 dollars. Represents the average growth, assuming annual growth of 2.4 percent between 1990 and 2000 and 2.1 percent between 2000 and 2010.
[d]Average of 1990 to 2000 inflation (3.2 percent) and 2000 to 2010 inflation (4.1 percent), then rounded.

Sources: **EIA:** *AEO93* Forecasting System runs AEO93B.D0918921 (Reference Case), HMAC93.D091692C (High Economic Growth Case), and LMAC93.D0916924 (Low Economic Growth Case). **WEFA:** The WEFA Group, *U.S. Long-Term Economic Outlook,* Vol. 1 (Second Quarter 1992). **GRI:** Gas Research Institute, *Implications of the GRI Baseline Projection of U.S. Energy Supply and Demand*, 1993 Edition (Aug. 11, 1992), and *Draft of GRI93 Baseline Projections* (Aug. 21, 1992). **DRI:** DRI/McGraw-Hill, *Energy Review* (Second Quarter 1992). **UCS:** The Union of Concerned Scientists, *America's Energy Choices: Investing In A Strong Economy and A Clean Environment* (Cambridge, Massachusetts 1991).

[16]Sources: **WEFA:** The WEFA Group, *U.S. Long-Term Economic Outlook*, Vol. 1 (Second Quarter 1992). **DRI:** DRI / McGraw-Hill, *Energy Review* (Second Quarter 1992). **GRI:** Gas Research Institute, *Implications of the GRI Baseline Projection of U.S. Energy Supply and Demand*, 1993 Edition (Aug. 11, 1992) and *Draft of GRI93 Baseline Projections* (Aug. 21, 1992). **UCS:** The Union of Concerned Scientists, *America's Energy Choices, Investing in a Strong Economy and a Clean Environment* (Cambridge, Massachusetts 1991).

## Table 11. Comparison of Electricity Forecasts, 2010

| | EIA Reference Case | WEFA | DRI[a] | GRI[a] | UCS Reference Case | UCS Climate Stabilization Case |
|---|---|---|---|---|---|---|
| **Generating Capability** (Net Summer Capability) (Gigawatts) | | | | | | |
| Conventional Hydroelectric | 76.9 | [b]97.9 | 71.6 | 71.5 | 99 | NA |
| Geothermal | 8.5 | | | | 7 | NA |
| Biomass/Waste (MSW) | 19.5 | [c]9.1 | [c]9.9 | 4.1 | 15 | NA |
| Solar | 1.9 | | | | 6 | NA |
| Wind | 6.3 | | | | 8 | NA |
| Total Renewables (Utilities and Nonutilities | 113.1 | 107.0 | NA | NA | 135 | NA |
| Total Capacity | 880.1 | 879.8 | NA | NA | 953 | NA |
| Percent Renewables | 12.9 | 12.2 | NA | NA | 14.2 | NA |
| Total Renewables (Utilities Only) | 81.0 | NA | 81.5 | 75.6 | NA | NA |
| Total Capacity | 766.3 | NA | 920.4 | 827.9 | NA | NA |
| Percent Renewables | 10.6 | NA | 8.9 | 9.1 | NA | NA |
| **Net Generation** (Billion Kilowatthours) | | | | | | |
| Conventional Hydroelectric | 306.5 | 331.2 | 335.8 | 283.3[b] | 326 | 343 |
| Geothermal | 62.1 | | | | 53 | 60 |
| Biomass/Waste (MSW) | 112.4 | [c]30.5 | [c]17.7 | 9.9 | 113 | 136 |
| Solar | 3.8 | | | | 13 | 39 |
| Wind | 16.2 | | | | 17 | 117 |
| Total Renewables (Utilities and Nonutilities) | 500.9 | 361.7 | NA | NA | 522 | 695 |
| Total Generation | 4,112.0 | 3,867.6 | NA | NA | 4,430 | 2,576 |
| Percent Renewables | 12.2 | 9.4 | NA | NA | 11.8 | 27.0 |
| Total Renewables (Utilities Only) | 335.2 | NA | 353.5 | 293.2 | NA | NA |
| Total Generation | 3,522.4 | NA | 3,867.1 | 3,394.8 | NA | NA |
| Percent Renewables | 9.5 | NA | 9.1 | 8.6 | NA | NA |

[a]Electric utilities only (excluding nonutilities), nameplate capacity.
[b]Includes pumped storage hydroelectric.
[c]Includes small amounts of "other," such as waste heat and petroleum coke.
NA = Not available.
Sources: **EIA**: AEO93 Forecasting System runs AEO93B.D0918921 (Reference Case). **WEFA**: The WEFA Group, *Energy Analysis Quarterly* (Summer 1992). **DRI**: DRI/McGraw-Hill, *Energy Review* (Second Quarter 1992). **GRI**: Gas Research Institute, *Implications of the GRI Baseline Projection of U.S. Energy Supply and Demand*, 1993 Edition (August, 1992), and *Draft of GRI93 Baseline Projections* (August, 1992). **UCS**: The Union of Concerned Scientists, *America's Energy Choices, Investing in a Strong Economy and a Clean Environment* (Cambridge, Massachusetts 1991).

Further, no projections expect large increases in hydroelectricity contributions over the forecast period. The alternative forecasts also indicate more rapid growth for the use of renewable resources other than hydroelectricity.

Although specific resources are not identified, the use of geothermal, biomass and waste (including MSW), solar, and wind resources is generally expected to expand more rapidly than capacity from fossil resources.

Finally, the alternative projections suggest a general consensus that renewable resources will continue to supply less than 13 percent of total U.S. electricity supply through 2010.

Only the Union of Concerned Scientists provided resource specific projections for comparison with the EIA forecasts. Most of the difference in the UCS higher forecasts for renewable resources is accounted by its projecting 20 billion kilowatthours more hydroelectric generation in 2010 than the EIA expects. Its forecasts for electricity generation using biomass and municipal solid waste (combined) and wind are very similar, despite differing capacity projections for these resource choices. On the other hand, the UCS projections forecast significantly less generation (9 billion kilowatthours) from geothermal resources, while projecting far more output from solar resources than does the EIA (13 billion kilowatthours compared with less than 4).

The UCS also provided another set of forecasts under assumptions very different from both the EIA and all other major projections. These forecasts give an alternative view of future electricity markets. The Climate Stabilization Case results in the greatest use of renew-able resources. The assumed introduction of end-use efficiency measures greatly cuts demands for capacity additions, coal-fired plants become much less com-petitive because of environmental constraints, and renewable energy is assumed much more competitive, particularly wind, solar, and geothermal. As a result of these assumptions, aggregate electricity demand is greatly reduced from the Reference Case, while renew-able resources are able to garner 27 percent of the total electricity market.

## Overall Conclusions

Many different scenarios for the U.S. economy, energy markets, electricity markets, and renewable resources could be envisioned. The EIA Reference Case portrays potential futures based upon what is currently known and what is reasonably likely to occur. From this forecast two general conclusions emerge:

First, hydroelectric power, the mainstay of renewable resources in electric power generation today, is not likely to enjoy rapid growth under current expectations. Even if somewhat more favorable regulatory policies are put into place, the lack of many additional large sites and environmental considerations constrains hydroelectric growth.

Second, the rapid growth of non-hydroelectric renewable resource use will offset the slow hydroelectric expansion, allowing renewables to increase their share of the electric market slightly, to over 12 percent of national electric generation. Nevertheless, as a general matter, renewable resources are not likely to replace fossil fuels as the major contributors of electricity supply over the next 20 years.

# 3. Issues Affecting the Growth of Renewable Resources in Electric Power

The current EIA forecast indicates that renewable resources will continue to play an important but nevertheless secondary role in U.S. electricity supply through 2010. Of course, events that might increase the future role of renewable resources could occur. This chapter identifies and briefly discusses the kinds of events that the EIA currently considers most likely to result in the increased use of renewable resources in electricity markets over the coming decades. Not all are certain, or even highly likely, to occur. Additional events that might reduce opportunities for increased use could also take place. Nevertheless, at least some of them will have to occur if the use of renewable resources for electricity supply is to expand more rapidly than in the EIA Reference Case.

## Demand Growth

The rate of growth of electricity demand will affect opportunities for renewable resources. The rates of overall U.S. economic growth and the consequent expansion in electricity demand are major determinants of all electric generating capacity growth, including capacity using renewable resources. Current projections assume a moderate growth in the Gross Domestic Product (GDP), averaging 2.0 percent a year; growth in electricity generation will average 1.5 percent a year.

Growth in electricity demand spurs demands for new electric generating capacity. During the 1960's, when electricity demand (as measured by electric utility sales) grew at a rate of more than 7 percent a year, electric utility generating capacity grew at a nearly identical rate, doubling within 10 years. In contrast, under the current EIA projections, over the next 20 years, total electric utility plus nonutility capacity will expand at an average rate of only 0.9 percent a year. As a result, opportunities for new facilities of any type, including those using renewable resources, are limited.

If, as a result of more rapid economic expansion, overall electricity demand grows faster than currently projected, demands for all types of new electric generating capacity will be greater, and additional growth of capacity using renewable resources could occur.

Of course, the exact amounts of new growth, their proportional contributions, their fuel types, and the technologies used, along with many other features, will depend on the specific characteristics of the new electricity demands, including the types of demand and where they occur. Growing baseload electricity demands (needed at all times) will tend to elicit baseload capacity, such as geothermal, MSW, biomass, or hydroelectric (or possibly wind or solar thermal generating capacity if energy storage devices are added). A disproportionate growth in peaking demand (only needed for short periods) may favor other technologies, such as solar thermal, photovoltaic, or wind. Wood use for electricity generation will be heavily affected by the rates of growth of demand for the products of the timber and wood products industries. The locations of growth will also affect the choice of technology. Heavy demand growth in Illinois (the Midwest region), for example, would not likely spur major geothermal expansion because Illinois lacks readily available geothermal resources.

Changes in markets for alternative uses of renewable resources and in substitutes for electricity use will also affect the growth rate of demand for electricity generating capacity using renewable resources. Some renewable resources can be used to produce goods or services other than electricity. Changes in demands for those alternatives can be expected to affect the rate of growth of generating capacity using renewable resources. MSW, for example, can be recycled. The greater the Nation's success in recycling combustible materials, the less MSW will be available to fuel waste-to-energy plants. Also, MSW can be used to provide steam for heat or industrial processes, rather than electricity. Water too has many alternative uses, some incompatible with hydroelectric generation. For example, water may be stored or diverted for agricultural uses, or released around (rather than through) turbines to protect migrating fish. Biomass, such as forest waste, may be left to help replenish the soil or for habitat; some forest wastes, found to be commercially useful, may no longer be available for combustion. Land suitable for the development of wind power plants may have more lucrative applications in recreational or agricultural development. To the extent these alternative uses of renewable resources grow more or less rapidly than currently assumed, the rate of growth of renewable resources in electric power will be affected.

Demand is also affected by substitutes. Consumers may also choose nonelectricity substitutes (for example, wearing warmer clothing rather than increasing use of electric furnace), thereby reducing the demand for electric power. Solar water heaters could substitute for electricity in water heating. Conservation could reduce the demand for electricity. To the extent energy saving measures such as insulation, high efficiency motors and lamps, and timing and control devices, become cost effective, the growth of electricity demands from all sources could be inhibited. Or they may find additional uses for electricity, thereby increasing its demand. For example, the AEO93 assumes the addition of 4.6 million electric vehicles by 2010, increasing total U.S. electricity demand by 17.6 billion kilowatthours (a little less than one-half percent). As a result, demand for all kinds of generating capacity is increased, including capacity powered by renewable resources.

## Prices of Other Fuels

The prices of other fuels, particularly of coal, natural gas, and oil, can be expected to heavily influence opportunities for renewable resources over the forecast period, both competing for some markets (as substitutes) and assisting in the general market growth (as complements). Currently in the EIA Reference Case, world oil prices are projected to rise by only 1.3 percent a year through 2010; natural gas wellhead prices are expected to rise by 3.7 percent a year. If the prices of fossil fuels rise more rapidly than projected, renewable resources will serve as more competitive substitutes, and electric generating capacity using renewable resources will grow more rapidly. Should fossil fuel prices rise more slowly, or should they decline, the use of renewable resources may slow. However, general economic growth, on which all expansion depends, is tied to world oil prices. Relatively low world oil prices spur economic growth, while high oil prices retard it. Therefore, the growing use of renewable resources may need low fossil fuel prices to drive economic growth, which will increase demands for all kinds of new electric generating capacity.

## Technology Costs

Although true costs of electricity from all sources is debated, the general reluctance of the electricity marketplace to select technologies using renewable resources on a large scale suggests that often they are not cost competitive today. Costs need to be lowered if technologies using renewable resources are to compete with technologies using fossil fuels. In addition, operating reliabilities and efficiencies need to be improved (see Appendix C for technology descriptions).

Very little consistently defined historical data exists on the trend of costs in generating electricity using renewable resources. Nevertheless, some general characteristics are clear. First, the costs per kilowatthour of generating electricity using fossil resources dropped dramatically during the first eight decades of the U.S. electric power industry (into the 1960's), but flattened and continue to face the increasing burdens of environmental requirements.[17]

Second, the costs of generating electricity using some renewable resources have also dropped dramatically in recent years, in a manner analogous to those earlier years of fossil fuel use. As displayed in Chapter 1, the costs of generation for wind, solar photovoltaic, and solar thermal generation have dropped from far above most practical applications to be competitive in niche markets and in some locales. Some, such as wind power, seem poised for far wider applications.

Clearly if costs for technologies using renewable resources can continue to decline, wider use of these resources for electricity generation will occur. Where technology costs are not likely to decline significantly, such as for hydroelectric, municipal solid waste, or geothermal power, opportunities for expansion are likely to be as much affected by increases in costs of alternatives (such as for fossil fuels) or in related markets (such as for waste disposal).

The Energy Policy Act of 1992 could serve to lower the costs of technologies using renewable resources if authorized demonstration and commercialization provisions are funded. The Act authorizes the Department of Energy, on a cost-shared basis with industry, to fund demonstration and commercialization programs using renewable resources. Eligible technologies include those using biomass, solar, wind, or geothermal resources. If these programs were funded, the costs of using these technologies to produce electricity could decline.

[17]For historical information on electricity prices and the costs of generating electric power using fossil resources, see the Energy Information Administration report, *Annual Outlook for U.S. Electric Power 1985*, DOE/EIA-0474(85) (Washington, DC, 1985).

## Externalities

Consideration of externalities could accelerate the use of renewable resources. The term “externality” refers to some economically valuable cost or benefit imposed on or enjoyed by a third party (not the buyer or seller) in a transaction. The price the buyer pays to the seller does not reflect this external cost or benefit and the buyer pays less or more than the total social value of the product. Some contend that, because of external costs imposed on society, the true (higher) costs of using fossil fuels are not accurately represented in current market prices. In energy markets today, two general categories of externality are discussed: preferential tax treatment or subsidies and environmental costs and benefits. For example, depletion allowances granted to the extractive industries such as coal, oil, and natural gas, are viewed by some as tax advantages favoring fossil fuels but denied renewable resources.[18] Environmental externalities are argued to exist when some environmental costs of fossil fuels are not borne by fossil fuel users. Sulfur dioxide and nitrogen oxide emissions, which contribute to acid rain, and carbon dioxide emissions, viewed by some as principal contrib-utors to global warming, may impose costs on the entire community which users of the fuels are excused from paying.

The Clean Air Act Amendments of 1990 (Public Law 101-549) exemplify the possible effects of accounting for externalities. By requiring electric utilities to reduce sulfur and nitrogen oxide emissions produced when using fossil fuels, costs of electricity produced with those fuels rise relative to other fuels. By “internal-izing” (imposing the costs of emitting on the electricity consumers), the full costs of fossil fuels are imposed on the electricity consumer and not on the public. At the same time, the costs of using renewable sources for electricity generation become relatively less expensive and more competitive with fossil alternatives.

Precise accounting for all externalities for all fuels is probably impossible. Nevertheless, concerns about the magnitude of unaccounted external costs of fossil fuels is prompting some actions at least to estimate the costs and impose them to assist efficient energy choices. Some States (among them Massachusetts, New York, Nevada, and California) include compensatory amounts when considering proposals for new generating capacity. Many other states are considering such amounts. For example, in the competitive bidding process, coal projects may be assigned a 2-cent-per-kilowatthour additional cost when compared with other fuels projects. In effect, projects using renewable resources, whose costs are no more than 2 cents per kilowatthour greater than the coal project, would be selected before the coal project. Therefore, to the extent that costs of externalities favoring renewable resources are intro-duced into the capacity selection process, technologies using renewable resources may be chosen more readily for U.S. electricity supply additions.

## Resource-Specific Challenges

In addition to the generally applicable forces likely to affect renewable resources over the next two decades, each renewable resource faces its own challenges in meeting electricity demand growth. General success in the marketplace is likely to occur only when investors, utilities, and consumers become confident that renewable-resource based technologies can be counted on to deliver electricity reliably and at a cost no higher than conventional alternatives.

### Hydroelectricity

Hydroelectric generation faces some of the greatest challenges to expansion. Concerns over destruction of fish and fish habitat may lead to marked changes in the approval of new dams and the operation of existing dams, lowering hydroelectric output. In the Northwest, for example, three species of Pacific salmon have been listed for protection under the Endangered Species Act of 1973 (P.L. 93-205). The Snake River sockeye salmon have been listed as endangered, as have two species of the Snake River chinook salmon. In response, hydroelectric operations along the Columbia River may be changed and power generation reduced to facilitate migration of the Pacific salmon between the Pacific Ocean and their Northwestern spawning grounds. Reservoirs may be drawn down and waters “spilled” (released without passing through the turbines) to increase overall water flow and assist migration without killing fish in the turbines. While the exact effects on hydroelectric generation are not known at this time, preserving fish populations could reduce hydroelectric generation from current facilities and discourage future hydroelectric expansion, both in the Northwest and throughout the country wherever fish populations are at risk.

In addition to fish preservation, alternative water and watershed uses could also affect potential hydroelectric generation. Particularly in the West, where growing populations, agricultural and other water uses, and recent droughts have highlighted conflicts over water priorities, water may be diverted for other uses. Water use for recreation, including fishing, boating, rafting, and swimming, may result in modified operation of reservoirs and streams and reduce the generating opportunities for hydroelectric facilities.

The Omnibus Western Water Act (P.L. 102-575), signed by President Bush in October, 1992, while authorizing several Western water projects, also raises the importance of protecting fish populations and other natural resources (such as the Grand Canyon). Possible revisions to the Clean Water Act and Endangered Species Act in 1993 could also significantly affect priorities in the use of water for electricity generation.

Relicensing of hydroelectric facilities could also slow development of hydroelectricity. The relicensing process highlights conflicts in the uses of water resources. Nonfederal dams require licenses issued by the Federal Energy Regulatory Commission (FERC). Many of the original 50-year licenses issued in the 1940's will expire by the end of the decade and are subject to reconsideration and reissuance—possibly to competing parties. Under the Electric Consumers Protection Act of 1986 (P.L. 99-495), FERC must consider protection, mitigation, and enhancement of fish and wildlife, energy conservation, protection of recreation uses, historic preservation, and other aspects of environmental quality along with power development when issuing hydroelectric licenses. Moreover, in the relicensing process, Federal, State, and local interests, many represented by government agencies with their own authorities and regulations, confront each other and private and local public power interests in determining who will control the water. Resolving the issues through FERC has itself become a difficult and time-consuming process, particularly as issues other than electric power have gained attention. As a result, the process of obtaining a license to develop hydropower at any site has become an expensive, uncertain, and daunting process.

## Geothermal

For technologies using geothermal resources to provide a greater share of new electricity supply, the costs of discovery and extraction of heat must be lowered and better methods of prolonging the life of resources must be developed. The costs of exploration and reservoir analysis must be reduced. Improved techniques are needed to map the boundaries of discovered reservoirs, determine reservoir properties, and improve the success rate of production. Once reservoirs are located, reservoir engineering needs to improve in order to reduce uncertainty and determine more efficient reservoir use, including fewer and better-placed wells.

The costs of drilling for geothermal resources must be lowered. Because temperatures are much higher for geothermal than for oil drilling, and rock types in geothermal are generally harder and more abrasive than rock above oil and gas reservoirs, more effective and durable drill bits and other drilling components must be developed. At locations where highly corrosive brines and gases are present, materials need to be developed for building equipment more resistant to corrosion. Because drilling costs are a major part of geothermal electricity production expenses, improvements in drilling technology and locating wells could make electricity generation using geothermal resources notably more competitive.

Future development of hot dry rock geothermal resources will also be affected by access to water resources for injection into wells as a heat transfer medium. Because many hot dry rock resources are located in the arid West, water rights and water access are critical issues in geothermal development.

Finally, the decline of pressure at The Geysers has made well pressure maintenance an issue of major concern. Market growth for geothermal resources is likely to be contingent partially on developing cost-effective and efficient fluid injection methods (to replace extracted fluids) to ensure the durability of the resources.

## Solar

Among the most pressing issues affecting the success of solar technologies are lowering capital costs and increasing electricity output per unit of capacity. For solar thermal systems, the highest-cost components are the solar trough and parabolic dish concentrators (see Appendix C), which focus sunlight on the fluids to be heated. The efficiencies of solar thermal concentrators in focusing sunlight have risen over the last decade and the costs-persquare-meter of concentrator surface have dropped steadily through the 1980's, but costs need to be lowered further to become more competitive. Reductions in the costs of storing and moving energy prior to electricity generation will also improve the competitive position of solar thermal power. Also, solar thermal systems must become more reliable, especially when the sun is obscured. Improved energy storage, via improved batteries or heat storage media, such as salt, could extend the operating hours of solar thermal-based electricity generating facilities. Improved heat engines should raise the conversion efficiency of parabolic dish systems.

To increase the market share of photovoltaic systems, cell and module costs must decline and cell efficiencies must improve. Improved concentrators may cost-effectively bring more sunlight to the cells. Thin-film photovoltaic cells, while less energy efficient, may prove far less expensive and decrease average costs per kilowatthour. Whereas current silicon cell manufacturing techniques require many expensive production steps, thin-film photovoltaics may allow spraying or otherwise depositing semiconducting layers on flexible background materials, which could significantly lower production costs. Module costs are also considered prime targets for additional cost savings.

## Wind

The market for electricity generating technologies using wind (Figure 5) will likely expand if costs continue to fall and reliability continues to improve. Should efforts to lower the costs of towers and blades prove fruitful, significant overall cost reductions could result. Simi-larly, if design problems of the past are overcome, reliability should continue to improve and maintenance costs should continue to fall. Success of the variable speed wind turbine, which adapts to rapidly changing wind speeds, could improve the reliability and the efficiency of wind units. As with solar technologies, the market for wind turbines could be helped by use of cost-effective energy storage devices, which could increase system reliability and provide energy during periods of low wind.

## Biomass and MSW

Because they employ mature generating technologies used for fossil fuels, biomass- and MSW-powered electricity generating technologies are not expected to enjoy large additional breakthroughs that lead to marked drops in production costs per kilowatthour. Of course, experience will bring incremental reductions. For biomass to make significantly greater contributions to the electric power market, two objectives must be achieved: (1) a dedicated feedstock (crop) must be developed and (2) conversion technologies must be improved. Biomass power stations depend upon the availability and variable quality of forest and agriculture residues and waste materials from the wood and paper products industry. Development of a more effective fuel supply system is critical to removing the current dependency. Biomass facilities that burn wood will be affected by the rate of growth of the parent industries, by alternative uses for combustible wood waste, and in the future by crops grown specifically for energy production. Growth in the use of crops dedicated for energy use is also dependent on demands for the use of land for other crops or other purposes.

Three potential paths for energy conversion improvements are available to enhance the competitiveness of biomass power: 1) improvements in direct combustion systems, including both conventional and fluidized bed boilers designed to handle biomass fuels; 2) development of biomass gasification systems capable of producing a gas suitable for firing combined gas and steam units; and 3) development of biomass liquefaction processes capable of producing clean gas turbine fuels.

Several factors will probably loom large in affecting the future growth rate of MSW. First, the rate of increase in landfill costs, which determines the per-ton price paid for accepting trash (tipping fee), will have a significant influence. If more distant jurisdictions site new landfills at prices lower than MSW combustion, MSW's opportunities for growth will be reduced. On the other hand, new requirements on landfills, such as regulations to install liners and leachate management equipment, will serve to raise landfill costs and make MSW plants relatively more attractive. Similarly, if recycling reduces the growth in landfill, prices paid to MSW plants could suffer. Second, environmental objections and industry responses to these objections could affect MSW expansion. Despite industry efforts, community resistance to MSW facilities occurs, both on aesthetic grounds and because of concerns of known or feared pollutants.

## Conclusion

From the beginning days of the electric power industry, renewable resources have contributed significantly to U.S. electricity supply. In recent years, hydroelectric generating capacity growth has slowed. However, other forms of renewable energy have begun generating electricity on a larger scale, with the result that renewable resources today provide about 12 percent of U.S. electricity supply.

Long-term projections indicate that the use of renewable resources will continue to grow and continue providing about 12 percent of U.S. electricity supply through 2010. If technologies do not improve dra-matically and the economy and energy markets remain structured essentially as they are today, significant increases in electricity generation from MSW, geo-thermal, and wind generating facilities should increase their share of the overall U.S. electricity market and offset reduced growth of conventional hydroelectric power.

However, renewable resources could make even more substantial contributions to future U.S. electricity supplies. If the relative costs of generating electricity from renewable resources should fall below generating costs using fossil fuels, much greater expansions could occur. Opportunities for such declines exist in achieving technological advances in the generating technologies; if recent rates of improvement can be sustained, certainly greater contributions could be expected. At the same time, if the costs of fossil fuels rise, either directly or because of changes in taxes or subsidies, or because of penalties imposed on them for environmental reasons, increased electricity generation using renewable resources would be more likely.

Appendix A

# Assumptions

# Appendix A

# Assumptions

This appendix presents assumptions underlying projections in the AEO93 for forecasts of renewable energy use in electricity supply. It also provides an introduction to the general assumptions and modeling used for the AEO93, particularly for electricity markets. A detailed discussion of the assumptions and models underlying the *Annual Energy Outlook 1993* (AEO93) can be found in the EIA report, *Assumptions for the Annual Energy Outlook 1993*.[19]

## AEO93 Forecasting System

The Energy Information Administration (EIA) projections presented in the AEO93 were prepared using a collection of individual computer models that forecast annual production, supply, distribution, and consumption of energy for the United States. These models produce an integrated energy market forecast through the use of the Intermediate Future Forecasting System (IFFS). As a system, IFFS accounts for many interactions of the different segments of the energy industries and provides an internally consistent forecast of prices and quantities for which supply equals demand.

In general, each of the supply models in the AEO93 Forecasting System determines the supply and delivered prices for each fuel, given the consumption levels projected by the demand models. Projections are generated through the year 2010.

The Electricity Market Module (EMM) of the IFFS represents the supply and price of electricity and computes the fuel requirements to generate electric power. A planning component determines the capacity expansion profiles of electric utilities, using a life-cycle cost methodology and assumptions of future fuel prices and electricity demand. A dispatch component allocates generation capacity to meet current demand by ranking the fuel and operating costs, subject to the constraints of the Clean Air Act Amendments of 1990. The financial component computes the price of electricity, accounting for all costs of construction and operation.

Production of electricity by cogenerators and by independent and small power producers is forecast by the nonutility component (Nonutility Generation Supply Model, NUGS), which competes with utility-generated electricity at the avoided cost of the utility sector.

## Renewable Resources in Electricity Generation

Generating capacity and electricity generation for technologies using renewable resources are determined exogenously from the EMM and NUGS models. The capacities are provided by technology type, region, ownership category (electric utility and nonutility), and whether they are announced or projected additions. The announced additions for utility-owned capacity were obtained from the Form EIA-860, "Annual Electric Generator Report." The announced additions for nonutility-owned capacity were obtained from the Form EIA-867, "Annual Nonutility Power Producer Report." Planned and projected capacities for municipal solid waste (MSW) and wood generation were provided by the Oak Ridge National Laboratory (ORNL). Appendix Table A1 shows the projected renewable-fueled capacity, by technology type and ownership.

These projections assumed passage of the Energy Policy Act of 1992 (See Chapter 2). Incremental capacity in 2010 as a result of the Act are 1.5 gigawatts of wind-powered capacity, 0.7 gigawatts of solar thermal, and 0.4 gigawatts of geothermal generating capacity.

Biomass (wood) refers to all forms of wood-related material: logs, pellets, chips, sawdust, planer shavings, bark, other wood scraps, and black liquor, a waste product of the pulping process. A stand-alone econometric model was used to develop estimates of wood consumption by the industrial sector. The independent variables used in the model are real GNP, electricity price, world oil price, and lagged wood energy consumption. Additional information about modeling

[19]Energy Information Administration, *Assumptions for the Annual Energy Outlook 1993*, DOE/EIA-0527(93) (Washington, DC, January 1993).

**Table A1. Projections of Utility and Nonutility Electric Capability for Renewable Technologies**
(Gigawatts)

| Renewables | 2000 Utility | 2000 Nonutility | 2010 Utility | 2010 Nonutility |
|---|---|---|---|---|
| Conventional Hydroelectric | 75.0 | 1.9 | 75.0 | 1.9 |
| Wind | 0.0 | 3.6 | 0.0 | 6.3 |
| Solar Thermal | 0.1 | 1.2 | 0.3 | 1.7 |
| Geothermal | 2.8 | 2.4 | 4.3 | 4.3 |
| Photovoltaic | 0.0 | 0.0 | 0.0 | 0.0 |
| Wood | 0.4 | 7.3 | 0.5 | 7.6 |
| Municipal Solid Waste | 0.5 | 6.2 | 1.0 | 10.4 |
| **Total** | **78.7** | **22.5** | **81.0** | **32.1** |

Note: Totals may not equal sum of components because of independent rounding.
Source: Energy Information Administration, Office of Integrated Analysis and Forecasting.

wood energy use can be found in the report, *Wood Energy II, Forecasts of Regional Sectoral Wood Energy Consumption.*[20]

The energy contribution of municipal solid waste (MSW) is dependent on post-consumer solid waste generated at residences, commercial establishments, and institutions. Excluded from this stream are automobile bodies, demolition and construction debris, municipal waste water sludge, ash from industrial boilers, and industrial solid waste.

The forecasting approach for MSW follows four steps. First, the total quantity of MSW in the United States is projected. The current and future heat value of a typical pound of MSW is assessed in the second step. The third step addresses the total U.S. capacity to burn MSW with heat recovery. National projections of energy from MSW combustion are obtained by multiplying MSW quantity, Btu value, and percentage of MSW combusted. The final step disaggregates the national Btu totals into regional and sectoral projections for electricity and other energy forms.

Overall national totals on energy derived from MSW were computed by estimating the expected quantity of MSW based on real GNP, future heating value, and the share of MSW being combusted versus recycled or landfilled. Calculations of the portions of the overall totals used in the industrial sector are made by using individual unit data from Government Advisory Associates (GAA).[21]

The GAA data base includes data on average operating throughput, design capacity, average Btu per pound of MSW, and type of energy produced. Plants producing only steam or electricity are tabulated separately to compute the dispersed and nondispersed energy. In plants producing both steam and electricity, the amount of MSW used for electricity generation is estimated by taking into account the GAA data on kilowatthour per ton of MSW processed and the power output rating of each plant. The amount of electricity sold to the grid versus that used in-house is calculated using the “gross” and “net” ratings provided in the data base. The Btu for steam and electricity for each plant are totaled for all plants and proportions are calculated on a regional basis, then applied to develop national totals.

The major source of renewable energy for electricity is hydroelectric power. Capacity for the conventional hydroelectric and pumped storage facilities is assumed not to vary across scenarios. Overlapping regulatory processes, conflicting requirements for licenses and permits, and disagreements over environmental issues have constrained the development of hydroelectric power plants. Additions to hydroelectric generating capability have been small during the 1980's and are not likely to increase significantly in the foreseeable future.

[20]Oak Ridge National Laboratory, *Wood Energy II, Forecasts of Regional Sectoral Wood Energy Consumption* (1990-2010), ORNL/TM-12009 (Oak Ridge, TN, October 1991).
[21]Government Advisory Associates, Inc., *Resource Recovery Yearbook*, 1991.

The expansion of the other renewable resources (geothermal, wind, and solar thermal) are determined mostly by location of the resource, technological limitations, environmental requirements, and tax treatments of various projects. Although assumptions about economic growth and world oil prices are not the primary factors driving the development of most renewable energy sources, these variables are assumed to have impacts on the projections of MSW and wood.

## Capacity Factors

The capacity factors (the proportion of maximum annual generation a unit is expected to produce) for electricity generating technologies using renewable resources are shown in Appendix Table A2. They are based on historical performance. The capacity factors are assumed to improve over time with technological advancement from ongoing research and development.

## Costs

Costs for technologies using renewable resources are included in the EMM only to measure contributions to overall electricity costs, not for economic competition with other technologies. Their cost is accounted for in electricity pricing as an operating expense. The annual expense is determined as the amount of renewable generation times a rate equal to the average cost of nonutility generation sold to the grid. The nonutility renewable energy price is assumed to be 3.5 cents per kilowatthour (1991 dollars).

## EIA Alternative Case Assumptions

In the High Economic Growth Case, capacity projections for hydroelectric, geothermal, solar thermal, and wind are the same as the Reference Case. However, higher economic growth causes more waste generation leading to its greater use in MSW plants and thus additions to capacity. Similar relationships are assumed to hold in the paper and lumber industries, which cause higher estimates for wood-fueled facilities.

In the Low Economic Growth Case, the capacity projections for the conventional hydroelectric, geothermal, solar thermal, and wind are the same as the Reference Case. However, lower economic activity causes less waste generation and less activity in the paper and lumber industries, thus lowering the need for additional capacity in these areas.

In the High World Oil Price Case, capacity projections for conventional hydropower, municipal solid waste, and wood are the same as in the Reference Case. However, high world oil prices, which are associated with higher electricity demand, result in slightly higher geothermal, solar thermal, and wind capacity than in the Reference Case.

In the Low World Oil Price Case, capacity projections for conventional hydropower, municipal solid waste, and wood are the same as in the Reference Case. However, low world oil prices, which are associated with lower electricity demand, result in slightly less geothermal, solar thermal, and wind capacity than in the Reference Case.

**Table B1. Average Annual Capacity Factors for Generating Technologies Using Renewable Resources**
(Percent)

| Technology | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|
| Hydroelectric | 46 | 46 | 46 | 46 |
| Geothermal | 65 | 76 | 82 | 83 |
| Municipal Solid Waste | 40 | 42 | 46 | 54 |
| Biomass/Other Waste | 72 | 79 | 82 | 83 |
| Solar Thermal | 21 | 19 | 21 | 22 |
| Solar Photovoltaic | 0 | 0 | 0 | 0 |
| Wind | 21 | 29 | 29 | 29 |

Source: Energy Information Administration, Office of Integrated Analysis and Forecasting.

Appendix B

# Renewable Resources for Electricity Generation

## Appendix B

# Renewable Resources for Electricity Generation

The economic use of any resource for electricity generation is affected by its characteristics. The purpose of this appendix is to provide basic information on the physical aspects of renewable resources which affect their performance in the electric power market. The appendix presents the basic characteristics of the five major forms of renewable energy (hydropower, geo-thermal, solar, biomass and waste, and wind).

## Hydropower

Water resources (hydropower) for electricity generation (hydroelectricity) are the product of water volume and vertical drop. The total resource base for hydroelectric power consists of all the potential energy contained in precipitation falling on the United States as the water flows to sea level, with adjustments for evaporation and consumption.

Hydropower resources are not evenly distributed across the Nation but are generally concentrated where both precipitation and mountain altitudes combine to pro-vide large water volumes. The Nation's most favorable hydropower regions are in the Northwest, West, and Southeast, although some major facilities are located in other areas. According to estimates prepared by the Federal Energy Regulatory Commission (Figure B1), over 40 percent of the Nation's 146 gigawatts of developed and undeveloped conventional hydroelectric capacity is found in California, Oregon, and Wash-ington alone. Additional generating capacity needs

**Figure B1. U.S. Conventional Hydroelectric Generating Capacity, Developed and Undeveloped**
(Gigawatts)

Source: Federal Energy Regulatory Commission, *Hydroelectric Power Resources of the United States, Developed and Undeveloped*, FERC0070 (Washington, DC, January 1992).

would more likely be able to be met by hydroelectric power in these regions. It is much less likely that major new hydroelectric facilities could cost-effectively com-pete in regions with fewer resources, such as across the Nation's heartland.

Although large storage dams can extend some fraction of total water availability for years, most water must ordinarily be used for electricity generation within a few days or months of arrival. Therefore, changes in annual precipitation can dramatically affect the total volume of hydroelectric production. After reaching a record 332 billion kilowatthours net generation in 1983, for example, the United States' net hydroelectric generation (including pumped storage) dropped to 223 billion kilowatthours in 1988.[22] The tremendous variation between the two years represents differences in precipitation.

Hydroelectric demands must also compete with other needs, e.g., irrigation, drinking, navigation, flood control, recreation, and environmental priorities. Often, multiple demands can be met; however, conflicts can occur, resulting in foregoing dam construction altogether or in less-than-maximum electricity generation.[23]

## Geothermal

Geothermal resources (Figure B2) account for the largest portion of the total energy resource base. Unfortunately, most geothermal energy is trapped below the earth's outer crust, well below current economic drilling access. Of four resource categories—hydrothermal (heated water, liquid, and vapor), hot dry rock, geopressured, and magma—only hydrothermal resources are currently being exploited on a commercial basis. Hydrothermal reservoirs are located primarily in the western United States, with the most easily accessible high-temperature resources being in California, Nevada, and Utah. The four States reporting geothermal electricity production in 1990 were California, Nevada, Utah, and Hawaii, where relatively recent geologic activity (creating shallow and accessible high temperature sites) has occurred. However, these resources are frequently remote, so environmental impact and transmission costs and access become significant issues.

Development of other categories of geothermal resources depends on development of new and improved technology and on water availability. A large resource of geopressured fluids exists along the Gulf Coast of the southern United States, in conjunction with petroleum reservoirs, where geopressured water contains dissolved methane along with the pressurized hot water. If commercial technology emerges to utilize geopressured resources, development would be possible in Texas and Louisiana, as well as in other petroleum producing states and off-shore areas. Technology using hot dry rock could extend develop-ment of geothermal resources across the entire United States. However, growth in the use of hot dry rock resources, many of which are in the arid West, is dependent upon gaining access to water supplies for injection into the hot dry rock. The geographic distribution of potential magma resources is only speculative at this point, but prospects are probably the best in the western portion of the United States.[24]

## Solar

Solar energy is energy received from the sun. For energy purposes, solar energy generally refers to solar radiation and not to solar energy converted to organic matter (biomass). Outside the earth's atmosphere the rate of solar radiation is nearly constant. However, the amounts of solar energy reaching any point on the earth (insolation) vary with changing atmospheric conditions (clouds, dust), the changing position of the earth relative to the sun, and solar conditions (sunspots, flares). Insolation is greatest in the West and Southwest, where atmospheric conditions are favorable (Figure B3). 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. Nevertheless, all regions possess useful solar resources.

Even so, solar energy also faces limitations for electricity conversion. Solar energy is very dispersed (scattered), which increases its cost for electricity generation. Furthermore, solar energy is often not available at low cost during times of need. Unless storage devices are employed, solar opportunities decline with each sunset and with increases in cloud cover, limiting applications for power applications.[25]

[22]Energy Information Administration, *Annual Energy Review 1991,* DOE/EIA-0384(91) (Washington, DC, June 1992).

[23]For additional information on U.S. hydropower resources, see *Hydroelectric Power Resources of the United States, Developed and Undeveloped,* published by the Federal Energy Regulatory Commission, FERC-0070, (Washington, DC, January 1988).

[24]For additional information on U.S. geothermal resources, see *Geothermal Energy in the Western United States and Hawaii: Resources and Projected Electricity Generation Supplies,* published by the EIA in September, 1991 (DOE/EIA-0544).

[25]For additional information on U.S. solar resources, see *Solar Radiation Resource Assessment - An Overview,* (SERI/SP-220-3978) published by the U.S. Department of Energy Solar Energy Research Institute (now the National Renewable Energy Laboratory), November, 1990.

demand centers to be economically useful as a generating fuel. It is currently unlikely that crops farther than 50 miles from a demand center would be cost effective for electricity generation. MSW offers energy producers a distinct advantage in that municipalities pay producers to take the waste (tipping fees). Nevertheless, the additional costs of handling MSW, both for combustion and for residue disposal, significantly raise the costs of producing electricity from such sources. Furthermore, where landfill space can be obtained less expensively, tipping fees may be inadequate. As a result, MSW resources are most likely to be used for electricity production where large volumes of trash cannot be landfilled at lower cost.

## Wind

Wind resources provide kinetic energy in an air medium. Winds are created by changes in atmospheric pressure induced by changes in earth and atmospheric temperature. Wind is also affected by the earth's rotation and by frictional encounters with the earth's topography.

Just as with other renewable resources, winds are not uniformly distributed (Figure B5). Winds are characterized by wind-power density classes, ranging from class 1 (the lowest) to class 7 (the highest). Good wind resources, class 4 and above, with an average annual wind speed of at least 13 miles per hour, can be found in many regions of the country. Wind speed is a critical feature of wind resources, because the energy in wind is proportional to the cube of the wind speed. Many regions of the country enjoy at least some good wind resources. Only the Southeast and parts of the Midwest lack significant resources.

Uses of wind for electric power generation are constrained by a number of factors. Because of the uncertainty attending wind occurrences and intensity, winds are not generally considered sufficiently reliable as to guarantee performance. Because winds cannot be stored (unless batteries are used), not all winds can be harnessed to meet the timing of electricity demands. Further, winds are often located far from electric power demands. Finally, wind resources compete with other uses for the use of land; alternative uses may be preferred for some sites. Environmental objections include visual and noise pollution and impacts on birds.[27]

Appendix C

# Electricity Generating Technologies Using Renewable Resources

# Appendix C

# Electricity Generating Technologies Using Renewable Resources[28]

Many techniques are used to convert renewable resources into electricity. These techniques differ from those used for fossil fuels to access, prepare, store, handle, and dispose of the resources. The principal differences occur in the process of converting the resource to mechanical power in the turbine and in waste disposal. Aside from conversion and waste disposal, except when photovoltaics are used, the actual process of generating electricity is usually almost identical with electric generation using fossil fuels. Continuing advances in technology are lowering the costs of renewable energy use, making it more competitive with fossil fuels. This appendix presents the technologies currently using renewable resources (hydropower, geothermal, solar, biomass and waste, and wind) to generate electricity. In particular, each section notes whether each technology is most appropriate for baseload (able to operate at all times), peaking (able to operate at times of greatest demand), or intermittent (able to operate less than all the time and not necessarily at peak) operation.

## Hydroelectricity

Hydroelectricity is obtained when water is directed through a rotary turbine connected to an electric generator. The kinetic energy in the falling or moving water is converted to mechanical energy by the turbine and then to electricity by the generator. The water can come from many sources—rivers, streams, canal systems, or reservoirs. Hydropower projects are typically classified as either conventional or pumped storage. Conventional hydroelectric facilities pass water through the turbines once and discharge into the waterway; pumped storage facilities repeatedly recycle water, and use low cost, off-peak (usually night-time) electricity generated by other fuels to pump discharged water from a lower retaining pool back into an upper storage facility for peak power electricity generation.

Because pumped storage plants are essentially energy storage facilities for fossil or nuclear power, the renewable resource application of hydroelectric power covers only conventional hydropower options.

Figure C1 shows a conventional hydroelectric plant. The electricity generation potential of a site is proportional to the vertical drop (head). Driven by the force of gravity, water enters the dam through large screened gates and flows down a pipe, called a penstock, to reach the turbine-generator system. The turbine blades are connected to a shaft which converts the kinetic energy in the water into mechanical shaft power. Water exits the turbines through another pipe, called the draft tube, into the tail waters.

Regulations such as the Public Utility Regulatory Policies Act (PURPA), affect the classification of conventional hydroelectric plants. For instance, PURPA classifies all hydropower generation plants with a capacity equal to or less than 30 megawatts as small and all plants with a capacity greater than 30 megawatts as large. Sometimes hydroelectric projects are referred to as mini-hydro (capacity of less than 1 megawatt) or micro-hydro (capacity of less than 100 kilowatts (kW). The U.S. Department of Energy (DOE) defines low-head hydroelectric plants as those with 20 meters of head or less.

Conventional hydroelectric plants are categorized into three types: storage, run-of-river, and diversion. The geographic and hydrological characteristics of specific sites determine the appropriate type of hydroelectric development. Storage plants feature reservoirs created from incoming stream flow. These plants are typically multipurpose facilities, designed for flood control, water supply, irrigation, and recreation, as well as electricity generation. (A reservoir management plan dictates water uses during the year.) Storage facilities make excellent baseload and peaking plants. Their high capital and low operating costs make them most cost

[28]Much of the information presented in this appendix was assembled for the Energy Information Administration by Science Applications International Corporation (SAIC), "Technical Report Preparation, Final Report," (McLean, Virginia, July 1992).

effective when continually used. However, increasingly they are also being used for peaking power because they can be started or stopped quickly and inexpensively. As a result, hydroelectricity's flexibility in meeting both baseload and peak demands makes it attractive for utility applications.

Run-of-river plants use natural streamflow for power generation, although a small dam is used to increase head in a run-of-river project. The rate at which water flows into the “headpond” upstream from the dam roughly equals the flow rate of water through the plant. Therefore, such projects impound little or no water. At some projects, only a portion of the flow is diverted to the turbines. Other plants employ “pondage,” a practice that impounds water behind the dam to store enough energy to shift maximum power output to peak electric demand hours. Run-of-river plants tend to be smaller than reservoir storage projects, although run-of-river projects on large rivers can produce several hundred megawatts of electric power. Run-of-river projects are typically operated as baseload capacity, running continuously when sufficient water is available. In low-water seasons (i.e., seasons with little precipitation) such units can run as peaking capacity if they employ some pondage.

Diversion, or conduit, plants involve a man-made channel or aqueduct of sufficient slope to create enough head to drive the turbine. Some of these structures are built solely for hydroelectric power, although many diversion projects are located at existing irrigation or municipal water supply conduits. Diversion projects usually have no storage capacity; however, some projects have reservoirs, which provide storage capacity.

Hydropower facilities primarily use three kinds of turbines (Figure C2). The simplest and the smallest turbine is the Pelton wheel, which is found in small, high head plants. Water jets sequentially strike the concave blades (buckets) of the turning wheel, rotating the attached shaft in the generator. The other two turbines, the Kaplan and the Francis, are featured in larger facilities. A Kaplan turbine resembles a ship's propeller. Water from the penstock strikes the blades, turning the turbine shaft. A Francis turbine resembles a fallen-over waterwheel. In a Francis turbine, water from the penstock completely surrounds the turbine and provides a constant pressure around the wheel. Fixed or adjustable openings called wicket gates control the water flow. Water strikes the turbine blades, transfers its energy to the blades and exits through the turbine's middle.

## Geothermal

Geothermal generating technologies can be divided into two broad categories: (1) resource handling technologies for access, production, conversion, return, and injection of geothermal fluids, and (2) generating plant technologies. Because the generating plant technologies are not unique, only the resource handling features are discussed here.

Hydrothermal (heated water) resources are formed when water, trapped in fractured rock or sediment below the surface, is heated. Technologies using hydrothermal energy are the most technically advanced and cost competitive of all the geothermal energy types, and hydrothermal energy is the only geothermal resource developed commercially in the United States.[29] In hydrothermal reservoirs magma intrusions heat the water, turning it into steam or high-temperature water.

Vapor-dominated hydrothermal resources (dry-steam) employ the simplest production technology now being used. Steam flows through a well from the geothermal reservoir to the surface and is piped directly to the steam turbine (Figure C3). The most prominent example of this technology is at The Geysers in Northern California, where most of the U.S. electricity currently attributed to geothermal resources is produced. Scaling

**Figure D1. Geothermal Electricity Generating System for Vapor-Dominated Hydrothermal Resources**

Source: Petroleum Information Corporation, The Geothermal Resource, (A.C. Nielsen Co., 1979).

and corrosion of the turbine and other surface equip-ment is reduced by removing corrosive gases before the steam enters the turbine. The waste steam is condensed and injected back into the reservoir.

Liquid-dominated hydrothermal resources can be used to generate electricity by using any of three technologies: single flash, double flash, or binary. In a single-flash system (Figure C4), hot water produced from wells is allowed to boil (flash) in a boiler by lowering its pressure in a separator. The resulting steam is fed directly into a turbine. The remaining liquid (brine) is injected back into the reservoir, along with the condensed waste steam.

In a double-flash system (Figure C5), a second separator is added to extract more steam. The water remaining after the first-stage separation is flashed once more in the second-stage separator at a lower pressure than in the first stage. The two steam stages are used to turn a turbine which has both a high and low pressure stage. This additional step makes double-flash systems 10 to 20 percent more efficient than single-flash systems.

The binary-cycle system (Figure C6) incorporates two distinct fluid loops, with the heat of the geothermal fluid in the first loop being transferred to a low boiling point working fluid in the second loop. The geothermal fluid transfers its heat to the working fluid (such as isobutane), which rapidly vaporizes. The vaporized working fluid drives the steam turbine. After condensing, the working fluid is returned to the heat exchanger to begin a new cycle. The used geothermal fluid is injected back into the reservoir to help maintain reservoir pressure. This system is chosen primarily when the geothermal resource contains high levels of dissolved solids and corrosive liquids or when the resource temperature is too low for a flash process to operate efficiently (300º - 400ºF).

Geothermal generating facilities are typically baseload. Given the high capital costs of exploratory drilling, such plants make best economic sense when operated a high portion of the time. However, experiments are being conducted to test the ability of hydrothermal resources operating in a part-time or load-following mode. This would help conserve the pressure reservoir in areas of pressure decline, such as The Geysers.

## Biomass

Biomass is subdivided into three categories: wood (fuelwood, wood byproducts and waste wood), waste (municipal solid waste and manufacturing process waste) and biofuels for transportation. Electricity generating technologies using biomass are similar to fossil fuel burning steam plants because fuels are combusted in a boiler to produce steam to drive a conventional steam turbine. The primary differences between the technologies occur in fuel storage, handling, preparation, and waste disposal.

## Biomass/Wood

Historically, utilities and industry have used direct combustion-steam boiler and steam turbine technologies to generate electricity from biomass resources. The technologies use components (steam boilers, steam turbines, etc.) similar to those found in coal-fired electricity generation plants. As a result, biomass fuels can be used for either baseload or peaking applications. The differences between coal-fired and biomass-fired generation requirements arise from differences in the fuels. For instance, biomass / wood differs from coal in moisture content. Also, biomass / wood and coal fuels differ in content of nitrogen and sulfur compounds that can lead to nitrogen oxides ($NO_x$) and sulfur oxide ($SO_x$) emissions; thus, requirements for environmental control technology differ.

Direct combustion systems can burn a variety of bio-mass feedstocks—including chunk wood, chips, bark, wood pellets, and sawdust—to supply heat to steam boilers. Biomass / wood-waste electric generation systems are differentiated by the type of burner used to combust the biomass. The four kinds of burners used to produce boiler heat are pile burners, spreader stokers, suspension and cyclone burners, and fluidized bed combustors. The most commonly used biomass combustion configurations are the pile burner and the spreader-stoker.[30] Feedstock particle size and moisture content are critical parameters for direct combustion systems. Feedstock moisture content must not exceed 60 percent.[31]

Direct combustion systems require facilities for handling the biomass feedstock that is to be combusted and for removing the ash produced from combustion. Feedstock must be stored on-site, properly sized for the combustor, screened to remove non-combustibles, and conveyed to the burning system. Feedstock is stored on-site in open piles, bins, silos, or drying barns. The biomass fuel must be protected from absorbing excess moisture.[32] Feedstock is sized for use in the combustor either prior to storage or prior to burning. Common sizing technologies include hammermills, chippers, grinders, and saws. Prior to moving the feedstock to a silo that feeds the combustor, the feedstock is screened to remove any noncombustible matter. Wood or other biomass wastes are stored on-site. From a storage silo or bin, the fuel is moved by a conveyor or other fuel handling system to a metering bin that feeds the fuel to the boiler at the proper feed rate. The feed system includes grates to do final wood sorting, sizing, and removal of non-combustibles. The stoker moves the feedstock to fixed or moving grates on which the feedstock is burned. For ash removal the combustion chamber is secured periodically to remove the accumulated ash. Once collected, the ash is disposed of in a landfill.

Combustion of the biomass feedstock occurs in the boiler (Figure C7). The heat from the combusted biomass is transferred to water in the boiler pipes, producing steam for the turbine. Waste steam is sent to a cooling tower, where it is condensed into water.

Pile and spreader-stokers directly combust biomass to produce energy. Both technologies burn large-particle biomass. These stokers are used to provide baseload electricity because the time needed to burn large particle size fuel and the rate of heat generation cannot be adjusted quickly enough to use them for intermediate or peak power generation. In the boiler combustion chamber, the wood is suspended on grates, where it is burned. Different grate system designs lead to four boiler combustion options: pile burners include incline grate systems, traveling grate spreader-stokers, fixed grate spreader-stokers, and dumping grate spreader-stokers.

Cyclone and Suspension burners (Figure C8) combust biomass mixed in a turbulent stream of air. Particulate biomass for suspension and cyclone burners must be less than 0.25 inches in size and have a moisture content of less than 15 percent.[33] The air-biomass mixture improves combustion efficiency relative to pile burners or spreader-stokers because the surface area of biomass exposed to oxygen in the air is increased.

[30]California Energy Commission, Energy Technology Status Report, 1988.
[31]United States Biomass Industries Council, *The Biofuels Directory*, March 1990.
[32]United States Biomass Industries Council, *The Biofuels Directory*, March 1990.
[33]The U.S. Export Council for Renewable Energy, *Private Financing for the Power Sector: The Renewable Energy Option*, June 1989.

**Figure H1. Biomass Electric Generation System**

Source: U.S. Export Council for Renewable Energy, *Private Financing for the Power Sector: The Renewable Energy Option*, June 1989.

These technologies have the power generation output control needed to provide baseload and peak power needs, since the rate of heat output from such combustion systems can be controlled and timed by adjusting the fuel feed rate.

The suspension burner mixes particulate biomass in an air stream over the main fuel bed in the combustion chamber. The mixing increases combustion surface area, thereby increasing combustion efficiency. Before the particulate biomass enters the combustion chamber, the cyclone burner mixes it with an air stream. The resulting turbulent mixture is burned in the combustion chamber. In both the suspension and cyclone burner configurations, the heat from combustion is transferred to water circulating through the boiler tubes. The rest of the electricity generation process is the same as that described above for the pile and spreader-stoker burners.

The fluidized bed combustor (Figure C8) is a combustion chamber containing a medium, such as sand or limestone, that is suspended in the chamber by hot air. Biomass feedstock with a wide variety of size, shape, and moisture content specifications can be combusted in a fluidized bed. Combustion is rapid and efficient because of the high surface area exposed to air and because of the heat held in the medium. Heat is transferred to the water in the boiler tubes in the combustion chamber to generate steam. The resulting steam flows through a steam turbine to generate electricity.

Fluidized bed combustors are environmentally favorable technologies. The limestone in a fluidized bed reacts with combustion-generated sulfur dioxide ($SO_2$) to form calcium sulfate, a solid waste (gypsum) that can be handled and disposed using established procedures. Additionally, low combustion temperatures in fluidized beds (1,500° F to 1,600° F) result in lower nitrogen oxide production.[34]

## Municipal Solid Waste (MSW)

Municipal solid waste-to-energy facilities are usually less than 80 megawatts in size. They can serve the

[34]California Energy Commission, "Energy Technology Status Report," 1988.

electricity market as either baseload or peaking facilities. The plants are usually located near urban load centers. Some cogenerate electricity and industrial steam; during peak hours, steam services can be reduced and electric power increased.

Energy can be recovered from municipal solid waste (MSW) through mass burning of unprocessed MSW; burning of refuse-derived fuel (RDF), which is derived from unprocessed MSW by removing noncombustible material; and burning of methane gas mined in landfills.

Mass burn facilities (Figure C9) burn MSW as a boiler fuel. First, the MSW is received at the plant site and stored. Minimal processing prior to combustion usually involves removal of materials that are oversized and difficult to combust, such as mattresses and large tree stumps. The MSW is next transferred from the receiving area to a refuse fuel pit and then to a refuse feed hopper that feeds the boiler. Boiler temperatures exceed 2000$^o$ F. The waste steam is condensed and sent to a cooling tower where its temperature is lowered through evaporation before it is released into the local water supply. The mass burn system releases combustion gases and ash. The combustion gases must be subjected to flue gas cleaning in a scrubber to remove toxic substances and gaseous pollution. Treatment also involves an electrostatic precipitator or fabric filter to remove particulates from the waste combustion gas. Finally, ash residue must be hauled away and disposed of in landfills, some of which are designed specifically for ash.

Refuse-derived fuel (RDF) is MSW after varying degrees of waste separation and size reduction (Figure C10). Noncombustible materials (e.g., glass, metals), which represent as much as 30 percent of the original MSW, are removed. Conversion to RDF next includes various stages of shredding, crushing, and material separation using sorting screens, magnetic separators, and cyclone separators. Further processing includes shredding, then screening out the oversize material via trommel (box) or disk screens, and removing the ferrous components via magnetic separation. Oversized material can be returned to the shredder for reprocessing or discarding. The remaining refuse is RDF. It has a uniform particle size, moisture content, and heating value that is desirable for stable combustion in boilers, easier storage, and economical transportation. RDF also possesses a higher energy value per pound than unprocessed MSW.

The RDF can be burned in a dedicated RDF boiler to produce steam that drives a steam turbine-generator to produce electricity. The steps from RDF combustion in the boiler to steam turbine generated electricity are very similar to the process described for MSW mass burn facilities (Figure C9). The RDF can be combusted in spreader-stokers, in multi-fuel suspension, and in fluidized bed boilers. Dedicated RDF boilers have typically been designed with traveling grate spreader-stokers.

In an RDF-fired fluidized-bed boiler, combustion takes place within a sand and ash bed supported by a strong turbulent stream of air. This strong forced convection causes the RDF, sand, and ash combination to behave similar to a liquid throughout the combustion process, which occurs in suspension. The forced turbulence within the combustor creates a relatively even temperature distribution and high heat transfer rates. The heat storage properties of the sand bed allow a fluidized bed boiler to smooth the operating temperature range in the system, which could otherwise fluctuate because of the different heat contents of various non-homogeneous RDF sources.

Landfill gas results from the digestion by anaerobic (oxygen free) bacteria of MSW in landfills. This digestion produces a gas that contains methane, carbon dioxide, and other trace products. Landfill gas is collected through a network of porous pipes in wells in a landfill (Figure C11). The gas is filtered and compressed before it is used as a fuel for a gas engine, gas turbine, or steam boiler.

# Solar

Solar technologies collect the sun's energy to generate electricity. Solar technologies are separated into two categories by the type of energy used: solar thermal for heat energy and photovoltaic for radiant energy.

## Solar Thermal

Solar thermal technology encompasses a group of mirror options that use sunlight as a heat source in the process of creating steam. To concentrate sunlight effectively, the reflective surfaces for each solar thermal technology are designed to track the movement of the sun, either only vertically or horizontally (single-axis tracking), or both (dual- axis tracking). The heat generated by the concentrated sunlight, attaining temperatures in the range of 3600$^o$ F, is transferred to a working fluid (e.g., water, or oil, salt). The heat transforms the working fluid into steam. The steam drives a steam turbine-electric generator. Waste steam is condensed and returned to the collector to absorb more heat. Alternatively, the heat absorbed by the working fluid can be used to drive a heat engine/electricity generation system (e.g., parabolic dish systems with Stirling engines).

Parabolic trough systems act as primary heaters for boiler steam. A parabolic trough receiver (Figure C12) is a single- axis tracking collector that concentrates sunlight onto a receiver tube positioned at the focal line of the trough. A working fluid (e.g., water or oil) flows through the receiver tube and absorbs the heat. The heated fluid is transported to a central facility to generate electricity, either directly or for supplementary heating, and is used in a steam turbine. The parabolic trough technology has been operated in a hybrid mode using a natural gas-fired heater as a supplementary heat source that boosts the temperature of the working fluid. The natural gas heat supplement allows the parabolic trough system to operate during periods when sunlight is insufficient.

Parabolic dishes (Figure C13) use dual-axis tracking to focus sunlight onto receivers located at the focal point of each dish. Each dish is limited by the structural requirements of the movable dish to an electricity generation capacity of 10 to 50 kilowatts. Heat engine-electric generators mounted at the receiver focal point convert solar heat to electricity. The heat engine currently being developed is the Stirling engine. A Stirling engine contains a working fluid that expands when heated by the concentrated sunlight. The fluid expansion causes it to push a piston that drives the shaft of an electric generator to produce electricity. The expanded fluid is then cooled (condensed). When the working fluid is cooled, it occupies less volume. The piston moves back into place, compressing the fluid into a smaller volume. The cycle repeats as the heat from the concentrated sunlight expands the working fluid and condensation reduces it.

An alternative to the heat engine is transporting the working fluid from the focal point to a central electricity generation station. Solar One, a 10-megawatt pilot plant near Barstow, California, funded by both the Department of Energy and an industry consortium, generated electricity from 1982 to 1988. Central receiver systems (Figure C14), such as Solar I, use fields of dual-axis tracking mirrors (called heliostats) to reflect sunlight onto a single, tower-mounted central receiver. The central receiver contains a heat transfer fluid for steam production.

**Figure C13. Parabolic Dish System**

Solar thermal generating units are most efficient during times of peak sunlight. As a result, solar thermal technologies are not baseload, but peaking technologies. However, the introduction of energy storage media could extend solar thermal applications beyond peak hours.

## Photovoltaic

Photovoltaic system technology utilizes semiconducting materials to convert radiant energy (sunlight) into electricity. It is the only technology that does not convert renewable resource energy into mechanical energy to generate electricity. Power is obtained through direct conversion of radiant energy without moving parts and emissions. Although photovoltaic systems are most efficient during peaking hours of sunlight and are basically viewed as sun-correlated peaking units, these technologies produce electricity even under reduced lighting conditions.

Figure C15 illustrates the technology elements in a photovoltaic system. The basic unit in a photovoltaic system is a solid-state device called the photovoltaic, or solar, cell. Solar cells are composed of semiconducting materials that produce electricity when sunlight is absorbed. Photons striking a solar cell are reflected or absorbed by the cell, or they pass through the cell. The absorbed photons transfer energy to the cell. Several photovoltaic cells are interconnected and mounted on a support backing to form a photovoltaic module. Several modules can be interconnected and mounted together to form an array. The modularity of photovoltaic systems makes it possible to design systems to meet a variety of sizes of electric load. The electricity generated by a photovoltaic array is in the form of direct current (DC). Power conditioning equipment, the primary balance of system component in a photovoltaic system, is used to transform the DC electricity into alternating current (AC) and to protect the utility transmission network. From the power conditioner, electricity may be used directly or transmitted by power lines to meet the electricity requirements of end-user loads. Electricity may also be stored in batteries for future use.

The single crystal silicon photovoltaic cell provides a simple model for understanding the photovoltaic effect. A single crystal silicon photovoltaic cell is composed of a symmetrical lattice of silicon atoms each sharing electrons with four neighboring silicon atoms. When a photon of sunlight is absorbed by a single crystal silicon photovoltaic cell, the photon may transfer enough energy to an electron to free it from its position in the crystal lattice. The space left by the freed electron is called a “hole.” The electron is now free to move in the crystal lattice.

An electric current is generated in the photovoltaic cell by bringing together a semiconductor that has a tendency to be positively charged with a semiconductor that tends to be negatively charged. The single crystal silicon cell is actually a sandwich of two different types of silicon, n-type (negatively charged) and p-type (positively charged) silicon (Figure C15). When p-type and n-type silicon are put together, an electric field forms where the layers meet. This is the p-n junction. Free electrons and holes are attracted to each other by their opposite charges; their mobility allows them to move across the p-n junction, creating an electric field. When light (photons) at a sufficient energy level is absorbed by the photovoltaic cell, an electron-hole pair is created. Photovoltaic cells are constructed so that these pairs can move into the electric field at the p-n junction. This movement creates an electric current. If an external circuit is connected to the cell, electrons can flow through the circuit to get from the n-type silicon to the p-type silicon to combine with holes on the p side. This process enables photovoltaic cells to provide electricity for external loads.

Photovoltaic technology options can be divided into two categories: cell technology and module/array technology. Photovoltaic cell technology includes single crystal (si) silicon, semicrystalline silicon, polycrystalline silicon, polycrystalline thin-film, and amorphous silicon. Photovoltaic module/array technology includes flat plate and concentrator technology.

The most common photovoltaic cells commercially available today are made from Si wafers, which are produced from single crystal Si ingots. Figure B16 shows the structure of a single crystal silicon cell. Production of a photovoltaic cell starts with a seed crystal, which is dipped into molten silicon and withdrawn slowly to form a cylindrical single crystal silicon ingot. The ingot is sliced into thin wafers. The single crystal silicon wafer is converted into a cell by layering: (1) a thin layer of silicon (usually n-type) about one millionth of a meter thick (referred to as the collector) and (2) a silicon base layer (usually p-type), placed opposite the collector. When these layers are joined, a p-n junction is formed. An electricity conducting grid is added on top of the n-junction layer. The grid and silicon cell surface are covered with nonreflective coating to maximize sunlight absorption. A back-contact electrode is laminated to the bottom of the cell.

each crystal grain, electric charges move freely and produce electrical current flow at the boundary between two grains, where free electrons and holes are likely to combine and produce electricity. Conversely, polycrystalline cells are made of multiple crystals, or grains, which form the body of the cell. The single crystal grains are about 40 to 100 microns in diameter.

**Figure D1. Photovoltaic Cell Materials**

Source: Solar Energy Research Institute, *Photovoltaic Fundamentals*, SERI/TP-220-3957, September 1991.

Polycrystalline thin-film cells are composed of materials such as gallium arsenide (GaAs), copper indium diselenide ($CuInSe_2$), and cadmium telluride (CdTe). Thin-film cells are deposited in very thin, consecutive layer of atoms, molecules, or ions on a low-cost substrate (e.g., glass, metal, or plastic). The deposition process involves three steps: (1) creating an atomic, molecular, or ionic species; (2) transporting the species to a substrate; and (3) condensing the species on a substrate. Another thin-film cell, amorphous silicon, is made from thin layers of randomly arranged noncrys-talline silicon material deposited on glass or other substrate (Figure C17). The basic structure of the cell differs from those used for other photovoltaic technologies. The primary difference is amorphous photovoltaic modules are composed of thinner layers of material.[35]

## Photovoltaic Module/Array Technology

Flat plate photovoltaic systems consist of flat plate collectors, composed of a number of cell modules, mounted on a flat surface (Figure C18). The cell surface is encapsulated with a transparent covering that

[35]Thin film PV cells are fabricated as films of semiconductor material. The cell thickness is usually 1 to 10 microns, compared to 100 to 300 microns for single crystal silicon cells. A film thickness of only 1 to 2 microns is required to absorb essentially all of the sunlight. The crystal morphology of a thin film cell may be polycrystalline or amorphous.

**Figure E1. Amorphous Silicon Cell Structure**

Source: Solar Energy Research Institute, *Photovoltaic Fundamentals*, SERI/TP-220-3957, September 1991.

transmits sunlight to the cell and protects the cell from water and dirt damage. The incidence of sunlight on a flat plate photovoltaic cell does not need to be perpendicular. However, sunlight at a sufficient energy level must be absorbed by the flat plate cell for electricity generation to occur.

Photovoltaic concentrator arrays provide another option for utility power generation. A concentrator module consists of one or more lenses that focus and concentrate incident sunlight on one or more photovoltaic cells (Figure C18). The lenses are usually made of plastic and essentially replace much of the area that would be occupied by photovoltaic cells in a flat plate module with plastic lenses. Unlike flat plate systems, concentrator systems require a tracking technology which moves the concentrator cell array so that it is always pointing directly at the sun to receive directly (perpendicularly) incident sunlight.

The primary balance-of-system component in a photovoltaic system is the power conditioning technology used to process the electricity from photovoltaic arrays into a form that can be fed to the utility grid or the end user. Power conditioning equipment controls current and voltage to maximize power output, matches photovoltaic electricity to a utility AC electrical network, and safeguards the utility network and its personnel from possible harm (for example, from transmitting electricity over lines thought to be disconnected from generators). Photovoltaic system power conditioning equipment also includes an inverter, a device used to convert the DC electricity produced by photovoltaic cells into AC electricity that can be fed to a utility grid or an end user.

## Wind

Because winds do not always blow, even at the best sites, wind power plants are not baseload units. Unfortunately winds do not necessarily coincide with demand peaks either, limiting wind applications as peaking units. To date, wind power plants have most often been viewed as fuel savers but not as part of the capacity base, that is, they are viewed as reducing the costs of fuels that utilities would have consumed, but not as offsets to generating capacity. However, as experience with winds continue, on some occasions they may be considered part of peaking or other capacity.

Wind turbines convert the kinetic energy in wind to electricity. The wind turns the turbine rotor, which then drives an electric generator. There are basically two wind turbine designs, the horizontal axis wind turbine (HAWT, Figure C19) and the vertical axis wind turbine (VAWT, Figure C20). The turbine designs are differentiated by the axis of rotation of the turbine rotor. In the HAWT design, the rotation occurs on an axis that is parallel to the ground. In the VAWT design, the axis is vertical.

**Figure H1. Vertical Axis Wind Turbine (VAWT)**

Source: American Wind Energy Association.

The HAWT has two or three bladed rotors, mounted on a tower to raise them to an elevation of sufficient wind speed and lower turbulence. A wind turbine blade is similar in design to an airplane propeller blade. Rotors can be either upwind (in front of the tower) or downwind in relation to the tower. There are also different designs for attaching wind turbine blades to the turbine. Fixed-pitch turbines have the blades attached to the rotor hub in a fixed position and rotor orientation. Variable pitch turbines allow the blades to rotate around their own axes (pitch) in order to aid in starting, stopping, and regulating power output. Teetered blades are attached to the hub with flexible couplings and can help absorb the wind loads experienced by the turbine.

Upwind turbine rotors may be pushed out of the path of the wind (yaw). Such turbines require yaw control systems to keep the rotor directed into the wind. Downwind turbines tend to be self-correcting, since the rotor acts as its own yaw control. However, downwind turbines suffer interference from the tower in front of the blades. There are several mechanisms designed to keep the blade oriented properly in the wind stream. A turbine may have a tail vane or rudder to control the turning yawing motion. Typically, larger machines have active motor-driven systems controlled by micro-processors. Most of the recently installed horizontal axis turbines have yaw control systems.

The tower on a HAWT elevates the turbine and rotor about 90-150 feet above the ground. In current and past generations of constant speed wind turbines, the tower had to be composed of materials that gave it rigidity and strength to withstand wind gusts and varying wind speeds. With the use of new composite materials, towers are lighter yet strong. Variable speed wind turbines allow the wind turbine to generate electricity more efficiently, making use of gusting winds.

The VAWT (Figure C20) has two to four blades that revolve around a vertical central shaft. The Darrieus blade design is the most common commercially available VAWT turbine. Darrieus wind turbines have curved blades connected at the top and bottom of the axis of rotation. Advantages of the Darrieus vertical axis turbines include not having to track the direction of the wind and easier access to blade and gear box equipment for servicing and maintenance. The main disadvantage is that they do not benefit from the stronger winds farther from the ground, since the rotors are not suspended as high above ground as those of a horizontal axis turbine.

Wind systems include electronic power controls that evaluate wind speed and flow patterns. The system optimizes turbine operation as wind conditions vary. In the current generation of wind turbines, optimization means ensuring that the wind turbine operates at a constant speed as wind speed changes or as wind gusts occur. The variable speed wind turbines now being developed can operate in gusty wind conditions. These turbines require electronic power controls.

Power conditioning equipment is also important in wind turbine systems. Variance in wind speed means that the turbine may not always be operating optimally to produce a continuous flow of electricity that has the same physical characteristics as electricity being transported through electric utility transmission lines. Power conditioning equipment converts the electricity from a wind turbine into a form that is compatible. For instance, power conditioning equipment ensures that the electricity to the utility transmission lines has the same frequency as electricity from the utility (60 Hertz).

Appendix D

# The Federal Regions

# Appendix D

| Region | States |
|---|---|
| New England | Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island |
| New York/New Jersey[a] | New York, New Jersey |
| Mid-Atlantic | Pennsylvania, Maryland, West Virginia, Virginia, District of Columbia, Delaware |
| South Atlantic | Kentucky, Tennessee, North Carolina, South Carolina, Mississippi, Alabama, Georgia, Florida |
| Midwest | Minnesota, Wisconsin, Michigan, Illinois, Indiana, Ohio |
| Southwest | Texas, New Mexico, Oklahoma, Arkansas, Louisiana |
| Central | Kansas, Missouri, Iowa, Nebraska |
| North Central | Montana, North Dakota, South Dakota, Wyoming, Utah, Colorado |
| West[b] | California, Nevada, Arizona, Hawaii |
| Northwest | Washington, Oregon, Idaho, Alaska |

[a]Puerto Rico and the Virgin Islands are included in the definition of the New York/New Jersey Region, but are excluded from this report.
[b]American Samoa and Guam are included in the definition of the West Region, but excluded from this report.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.