22.1 INTRODUCTION

Wind energy has been one of the fastest growing new sources of electricity generation for the last several years in the United States. This report will describe some of the reasons for that growth and why it is expected to continue. Emphasis in the report is on the United States Department of Energy (DOE) and its role in leading efforts to develop new wind energy technology that will be economically competitive with other electricity sources, without the need for subsidies. Working with industry, electric utilities, state and local governments, and other stakeholder groups, DOE is organizing a new initiative called "Wind Powering America" that will sustain the growth in use of wind energy with the target to provide at least 5% of the nation's electricity by 2020.

22.2 NATIONAL POLICY

The Wind Energy Program, conducted by DOE, continues its leadership role, focusing on research and development (R&D) efforts to help U.S. industry develop wind energy technology as an economically viable energy supply option that is competitive in the growing domestic and global markets. The new Wind Powering America initiative under the DOE Wind Program is providing an important role in helping to move the technology to the market place. The initiative is planned to help support a dramatic increase in the deployment of commercial wind systems by partnering with and providing information on wind technology and business to stakeholder groups in the supplier, user, financial, regulator, and environmental communities. DOE also administers the Renewable Energy Production Incentive that provides financial incentives of $0.017/kWh for energy production by municipally owned wind power plants. In addition to DOE's programs, other Federal and state government agencies are expanding renewable energy application demonstration projects and incentive programs, some of which include wind systems. These agencies include the United States Department of Defense, Environmental Protection Agency, the Agency for International Development, and a growing number of state and local governments. The federally supported Wind Energy R&D Program is operated by DOE and is discussed in detail below.

22.2.1 Strategy

The general strategy of the DOE Wind Energy Program is to work in partnerships with industry and electric utilities to develop cost effective and reliable wind energy technology and establish understanding and use of wind turbine technology in a multi-regional application of wind systems. Specific objectives of the DOE Wind Energy Program are to: continue research on basic sciences needed to improve future wind energy technology, develop improved wind energy systems performance and reliability, participate in development of international consensus standards and U.S.-based wind equipment certification, and verify the performance of new technology in actual field operation.

The approach used in the DOE Wind Energy Program is to emphasize research that expands the knowledge base, explores new and innovative systems, and supports the cost-shared development and testing of improved, lower cost, higher efficiency turbines. National Laboratories operated for DOE conduct research and provide technical management and direction for the wind program that is implemented with industry, electric utilities, universities and other research organization partners that are selected through open competition.

New technology developed under the DOE program is field tested, evaluated, and its performance is verified in cooperative projects that are cost-shared by the users.

22.2.2 National targets

Under the Wind Powering America initiative, targets for wind energy development in the United States have been established between DOE and industry. These targets may be revised periodically depending on DOE program funding levels, changing policies on tax and other financial incentives for renewable energy development, cost of fuels for other power generating options, electric industry restructuring, and many other factors. Based on current projections for continuing progress on technology development programs, combined with financial incentives, and the Wind Powering America initiative, the following targets for wind power should be achieved:

- Provide at least 5% of the nation's electricity with wind by 2020
  - —5,000 MW online by 2005,
  - —10,000 MW by 2010, and
  - —80,000 MW by 2020.
- Double the number of states with more than 20 MW installed (from eight to 16) by 2005, and to 24 by 2010.
- Provide 5% of electricity used by the federal government (the largest single consumer of electricity in the United States) by 2010 (1,000 MW).

22.3 COMMERCIAL IMPLEMENTATION OF WIND POWER

One of the fastest growing markets for large-scale wind power plants is in the United States. There are several reasons for the renewed growth in wind energy deployment in the United States. First, new and better turbines are now available and their performance has been proven in operation. Also, prices for turbines and the resulting cost of energy are decreasing, making wind energy more competitive. Economics and available financial incentives are discussed later in this report.

22.3.1 Installed capacity

During 1999, the installed capacity in the United States increased to about 2,455 MW, up from 1,890 MW at the end of 1998. The largest construction surge occurred during the period from July 1998 through June 1999 (when the tax credits for new wind plants were scheduled to expire). During that twelve-month period, the U.S. wind industry added a record 1,014 MW of new installations that included 841 MW of new generating capacity as well as 173 MW of re-powering projects, where new turbines replaced older, less efficient machines, generally in California. New installations were mainly in the Midwestern section of the country. Most of the new turbines were in the 600 to 750 kW size range.

In September 1999, the world's largest wind power generating facility was dedicated near Storm Lake, Iowa (See Figure 22.1). Owned and operated by Enron Wind Corporation, the 193-MW facility includes 257 of the 750-kW turbines jointly developed and tested by Enron Wind, with technical support from DOE.

American companies manufacturing small wind turbines with less than 100 kW peak capacity are deploying machines in the rapidly expanding domestic and international markets. The United States is considered a world leader in sales volume for this market segment. Four active U.S. manufacturers are estimated to supply 30% of the new small turbine capacity added during 1998 worldwide and this market share was expected to be similar in 1999. Preliminary estimates indicate that the United States has 15 MW of small wind turbines installed in the 50 states. The last two years have seen a growth rate approaching 30% per year. Both

Figure 22.1 This 193-MW wind power plant at Storm Lake, Iowa uses Zond Energy Systems 750-kW turbines

off-grid and isolated diesel-based power generation applications are expected to grow even more rapidly.

22.3.2 Rates and cost trends

Wind can currently compete economically in selected markets in the United States. At current costs, large wind power plants can produce energy at about $0.04/kWh with favorable financing. This cost of wind energy is competitive where new generating capacity is needed in high wind regions where fossil fuel cost is high, or where there are other incentives available to encourage the use of clean energy. With utility industry restructuring, discussed later in this report, wind must increasingly compete against power pool spot prices, as low as $0.01 to $0.025/kWh for non-firm power. Therefore cost reductions in wind power systems, meeting the targets discussed in Section 22.6 on Economics, are considered both necessary and technically feasible for wind energy to compete without subsidies in the vast windy regions of the United States.

22.3.3 Contribution to national electricity demand

Energy production from all wind systems in the United States during 1999 is estimated to have been 5.9 terrawatt-hours, assuming an average capacity factor of 27%. Currently, wind energy is only 0.2 % of the national electricity supply, but it is of growing importance in local areas with good wind resources and incentives for development.

22.4 MARKET SUPPORT AND STIMULATION

The price for wind energy is continuing to decline so the need for market support and stimulation is limited. In addition, utility restructuring is progressing and states are resolving power purchase, transmission access, and other related issues. Uncertainties relating to utility restructuring had delayed wind project development in some regions in the past. Third, and most important, financial incentives are being implemented at the national and state levels that are considered a primary driver of wind power growth in the United States along with growing public support and green power pricing.

22.4.1 National level market incentives

At the national level, the wind energy Production Tax Credit (PTC) has been extended for 2.5 years and other additional financial incentives are under consideration. The PTC, started in 1993, was scheduled to expire in June of 1999, but has now been extended through December 2001. Currently the tax credit is $0.017/kWh (all $ are USD), adjusted annually for inflation. For municipal utilities that do not pay taxes, there is a payment of $0.017/kWh from DOE (subject to funds availability) under the Renewable Energy Production Incentive (REPI). Payments totaling $124,000 were made to four municipal wind plants under REPI during 1998 and are expected to be about the same for energy produced

during 1999. The payment period for REPI or for the tax credits end ten years after the plant begins operation.

DOE is also working to expand the use of wind power in facilities owned by the United States government. In June 1999, President William Clinton issued an Executive Order on "Greening the Government" that included a goal to reduce greenhouse gas emissions attributed to Federal facility energy use by 30% by 2010. One of the provisions in that Order directed each government agency to expand the use of renewable energy within its facilities and in its activities by implementing renewable energy projects and by purchasing electricity from renewable energy sources. Responding to the Order, the U.S. Army is considering plans and options to develop wind resources on bases in the United States, and perhaps overseas. There are many other vast areas of land owned by the government that have excellent wind resources, which potentially could be used for wind power plant development.

22.4.2 State level market incentives

There are a variety of incentives that are implemented independently at the state level. These incentives include: price premiums (up to $0.02/kWh) for "green energy" such as wind, waivers or reductions on property taxes for wind energy facilities, reductions or elimination of sales taxes for wind equipment, net billing for electricity bought and sold, low interest loans, accelerated depreciation of wind equipment for tax purposes, and mandatory additions of wind power or other renewables to utility generation portfolios.

Some states are setting capacity or "green energy" production goals. Texas, for example, has established a goal to add 2,000 MW of renewable energy generating capacity within the state by 2009. Intermediate goals are provided requiring an addition of 400 MW by 2003, another 450 MW by 2005, another 550 MW by 2007, and another 600 MW by 2009. To ensure that retail energy suppliers in Texas add their share of new renewable energy capacity, a Renewable Credits Trading Program will start January 1, 2002, and continue through 2019. Retailers in the state with insufficient new renewable capacity can buy credits from other suppliers or be subject to a penalty of $0.05 per KWh or 200% of the average cost of credits traded during the year. Wind plants are expected to dominate the new market in Texas.

22.4.3 Future restructured markets

Future domestic commercial markets for wind power are expected to be driven by a combination of several factors: (1) declining costs of wind energy, (2) new wind energy production tax credits that are discussed in Section 22.5 below, (3) expected increases in fossil fuel costs and the additional cost of reducing atmospheric pollution, (4) renewable energy portfolio standards with federal or state utility regulators mandating a portion of new generation be from renewable sources, (5) green power pricing where energy sales companies, in restructured utility markets, charge higher prices for electricity produced from "green" renewable energy sources, and (6) public pressures to reduce atmospheric emissions from power plants.

Many states pursuing utility restructuring have seen the importance of the last three factors and begun implementing some form of renewable energy incentive. Utility restructuring is underway in most states. See Figure 22.2.

In another approach to encourage wind energy market development, DOE works with and in some cases supports, a variety of organizations and stakeholder groups. A key organization is the National Wind Coordinating Committee (NWCC). The NWCC is a collaborative endeavor that

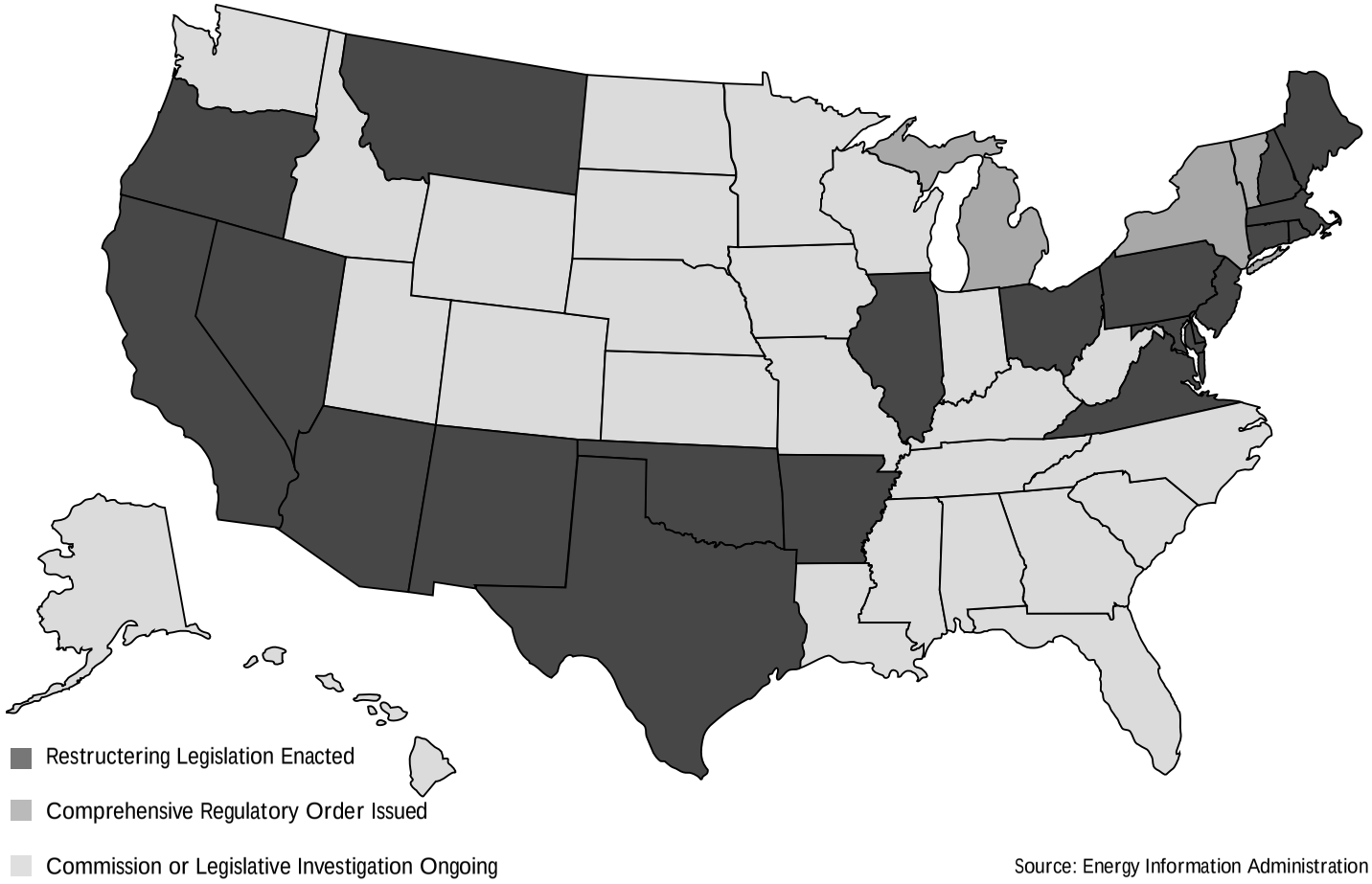

Figure 22.2 States that have issued deregulation orders and/or restructering legislation as of October 1, 1999

includes representatives from utilities, state legislatures and utility commissions, consumer advocacy offices, wind manufacturers and developers, environmental groups, and state and federal agencies. This Committee provides a forum and voice for stakeholders who envision a self-sustaining commercial market in the United States for wind power that is environmentally, economically, and politically sustainable. Another group supported partially by DOE is the Utility Wind Interest Group (UWIG), an independent nonprofit corporation formed by a group of 24 member utilities, and other organizations that promote utilities' interests in wind energy at the national level. This group serves as a source of information on government/utility cost-shared programs, and provides wind energy planning and implementation support to other utilities and to the public. These organizations are important partners in the Wind Powering America Initiative.

22.5 DEPLOYMENT CONSTRAINTS

Cost of wind energy has been the primary constraint on commercial development, but costs are declining and alternative sources for electricity generation are becoming more costly, especially when air pollution reduction costs are included. Environmental concerns can also be an issue in planning and development of wind plants. In some cases, areas populated with protected species of birds may have to be avoided. Visual impact is another consideration, but aesthetics is becoming less of an issue as landowners realize the income potential of harvesting wind energy. Considering the large land areas with excellent wind in the United States, avian and aesthetics are not considered to be significant constraints.

Until recently, turbine certification requirements in some international markets were constraints for U.S. turbine manufacturers. Wind turbines developed under the DOE program meet international standards for design and performance, but until recently there was no recognized third party, U.S. based, turbine certification agent. American manufacturers relied solely on European-based agents to certify that their machines met the internationally accepted standards. Recently however, Underwriters Laboratories (UL), which has a long history in the field of electrical equipment testing and rating, has developed a wind turbine certification program in partnership with the National Renewable Energy Laboratory (NREL). UL ratings are recognized worldwide in hundreds of other product areas, including fire and security equipment, insulation, fuses, transformers, relief valves and other safety systems, as well as many other types of industrial and commercial products. UL is using its background in electrical equipment certification and manufacturing quality reviews (ISO 9000), with NREL's turbine testing expertise, to implement a certification program that will meet International Electrotechnical Commission standards (IEC 61400 Series).

Currently, American utilities, wind plant developers and other customers in the United States do not require certification of entire wind systems, although turbine certification is needed to enter some of the international markets. In the domestic markets, customers tend to rely more on manufacturers' business track records, warrantees and independent assessments to reduce their risk. There are no plans to significantly change that approach.

22.6 ECONOMICS

The DOE Wind Systems Program has made major progress in reducing the cost of wind-generated electricity, but important targets have been set for further improvements. Since 1980 the cost of energy from wind systems has been reduced from $0.35/kWh (in 1980 dollars) to less than $0.04/kWh today. Current costs are based on large wind plants (100 MW or larger) operating at good wind sites with annual

average 6.7 m/s, measured 10 m above ground. Project financing costs are assumed to be 7.5% annual return on debt and 13% or less return on equity, which are considered to be reasonable rates for an established power generating company.

Future wind energy costs are projected to be among the lowest of five renewable energy technologies studied recently by DOE and the Electric Power Research Institute (EPRI). By 2010, wind was found to have by far the lowest Cost of Energy (COE) at $0.025 to $0.031/kWh, compared to other intermittent technologies (solar thermal and photovoltaics) with similar project financing assumptions. Wind was found to be directly competitive with geothermal energy, the lowest cost "dispatchable technology." The basis for these estimates and the projected evolution of wind and other renewable energy systems are discussed in a report titled *Renewable Energy Technology Characterizations* that is available on the DOE Office of Power Technologies Web site at http://www.eren.DOE.gov.

22.7 INDUSTRY

Six American companies are currently manufacturing turbines and numerous businesses are building components, developing projects, and providing engineering services and related equipment. Information on U.S. firms, including mail and email addresses, phone numbers, and other data are available on the American Wind Energy Association Web site http://www.awea.org.

Some of the larger European wind turbine manufacturers are establishing assembly and component manufacturing plants in the Midwest of the United States, including large turbines from NEG Micon and rotor blades built by LM Glasfiber, both Danish firms. Projects are also being developed in Europe with turbines manufactured under licenses by American Companies. For example, Enron Wind Corporation, a subsidiary of Enron Corporation, announced a 75-MW project will be built with turbines manufactured by a new subsidiary, Tacke Energia Eolica, S.L., in Spain.

22.8 DOE-SPONSORED PROGRAMS

Key elements in the DOE Wind Energy Program and current fiscal year funding are shown in Figure 22.3. The program funding was $34.1 million in Fiscal Year 1999.

22.8.1 Priorities

The emphasis of the DOE Wind Energy Program has been research and technology development. The DOE wind R&D program is structured with three elements:

1. *Applied Research*—to develop the basic wind energy sciences and technology;

KEY ACTIVITIES	APPLIED RESEARCH	TURBINE RESEARCH	COOPERATIVE RESEARCH & TESTING
Elements	• Aerodynamics • Structural dynamics • Materials • Hybrid systems	• Industry partnerships for advanced turbines 6 kW to 1.8 MW • Field verification	• National Wind Technology Center • Industry support • Certification testing and support • Wind farm monitoring
Fiscal Year 2000 Budget ($ millions)	10.7	15.8	7.6

Figure 22.3 U.S. DOE Wind Energy Program and Funding

2 *Turbine Research*—to develop and test advanced wind turbines in various sizes from less than 10 kW to more than one MW; and

3. *Cooperative Research and Testing*—to support industry in resolving near term technical issues and in concept evaluation, field testing, initial deployment, and certification of new wind energy systems and technology.

R&D efforts are focused at the National Wind Technology Center (NWTC), at the National Renewable Energy Laboratory, located near Golden, Colorado, with support from the Sandia National Laboratories, Albuquerque, New Mexico. The NWTC has staff, laboratory facilities, and equipment to conduct research and wind turbine system and component certification testing. Both Sandia and NWTC conduct in-house and contracted research, development, and testing for DOE and U.S. industry.

22.8.2 New programs and laboratory facilities

Wind Powering America—is a new initiative supported by DOE, working with industry to accelerate the use of wind energy in the United States. The Initiative is being formed as a partnership between a variety of government and private sector stakeholder organizations with a common interest in employing wind power for power generation; regional economic development, especially in rural farm communities; environmental improvement primarily by reduced air pollution; and increased energy security by diversifying energy sources.

Dynamometer—In mid-1999, installation of a major wind turbine drive train dynamometer was completed at the NWTC. This unique $3 million research facility allows wind turbine gearboxes and generators to be operationally tested at full power, up to 2.0 MW, under controlled laboratory conditions. Figure 22.4 shows two engineers standing next to a 750-kW wind turbine gearbox/generator system being tested on the new dynamometer. The electric drive motor, shown in the upper left of Figure 22.4, simulates the output from the wind turbine rotor. Additional information on the facilities at the NWTC is included in the 1998 IEA Annual Report and at http://www.nrel.gov.

Applied Research—The Applied Research activity addresses fundamental wind energy engineering and technology issues with a broad range of scientific studies conducted at the national laboratories, universities, and in industry. This effort is aimed at improving understanding of the fundamental behavior of the wind, atmospheric physics, interaction between the wind and wind turbines, structural dynamics, rotor aerodynamics, and electric power system integration issues.

One element of the Applied Research Activity is a joint research task underway between NWTC and Sandia, is called the Long-term Inflow and Structural Test Program (LIST). Comprehensive measurements on a full-scale turbine rotor are planned, in an effort to relate types of atmospheric events to blade fatigue damage. A full season of wind data will be collected at two sites with different wind regimes, one on flat terrain in Texas and the second at the NWTC. Part of the

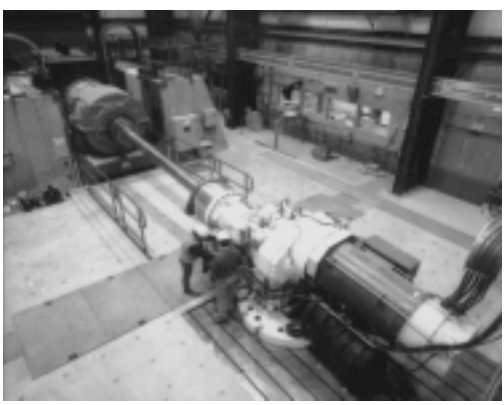

Figure 22.4 New 2.0-MW wind turbine dynamometer located at the National Wind Technology Center

Figure 22.5 Aerodynamics research wind flow visualization study test at the National Wind Technology Center

LIST testing includes wind flow visualization studies shown in Figure 22.5.

A related element of aerodynamics research is being conducted in the wind tunnels at the National Aeronautics and Space Administration (NASA) Ames Laboratory. A 10 m diameter 19-kW experimental wind turbine will be tested in different configurations in the 80 x 120 foot section of the open throat wind tunnel beginning early in 2000. The NASA tunnel, in Figure 22.6, is normally used for testing full-scale models of sub-sonic aircraft.

Figure 22.6 Inlet for the NASA Ames wind tunnel being used for testing wind turbine rotor and blade configurations

A new effort beginning this year is called Wind PACT, meaning Wind Partnerships for Advanced Component Technologies. Wind PACT is designed to support development of new high-risk technologies, such as, flexible rotors, new drive trains, on-site blade manufacturing, and self erecting towers for wind turbines. Results of this research will be publicly available.

Turbine Research—The role of the Turbine Research activity is to provide an opportunity for U.S. industry to apply the new technology and design tools resulting from Applied Research in developing advanced technology wind turbines. This role is implemented through close partnerships between the Wind Program's National Laboratories and U.S. companies via competitively awarded, cost-shared turbine development subcontracts. These subcontracts include research and development of wind systems for a variety of applications and in different turbine sizes. Turbines currently under development are shown in Figure 22.7, along with dates of expected deployment.

Specific goals are set by DOE for the turbine development projects under the Turbine Research Program. These program goals are based on the required cost of energy for new turbines systems being developed to be economically competitive in broad markets, which are key to achieving the national targets described above. Using cost of energy as the primary design goal has the benefit of integrating the effects of all aspects of a new turbine system, accounting for improved high performance technology and for lower projected turbine costs resulting from simpler, light weight designs. The goal for utility-scale, grid-connected wind power systems is to produce electricity at a cost of

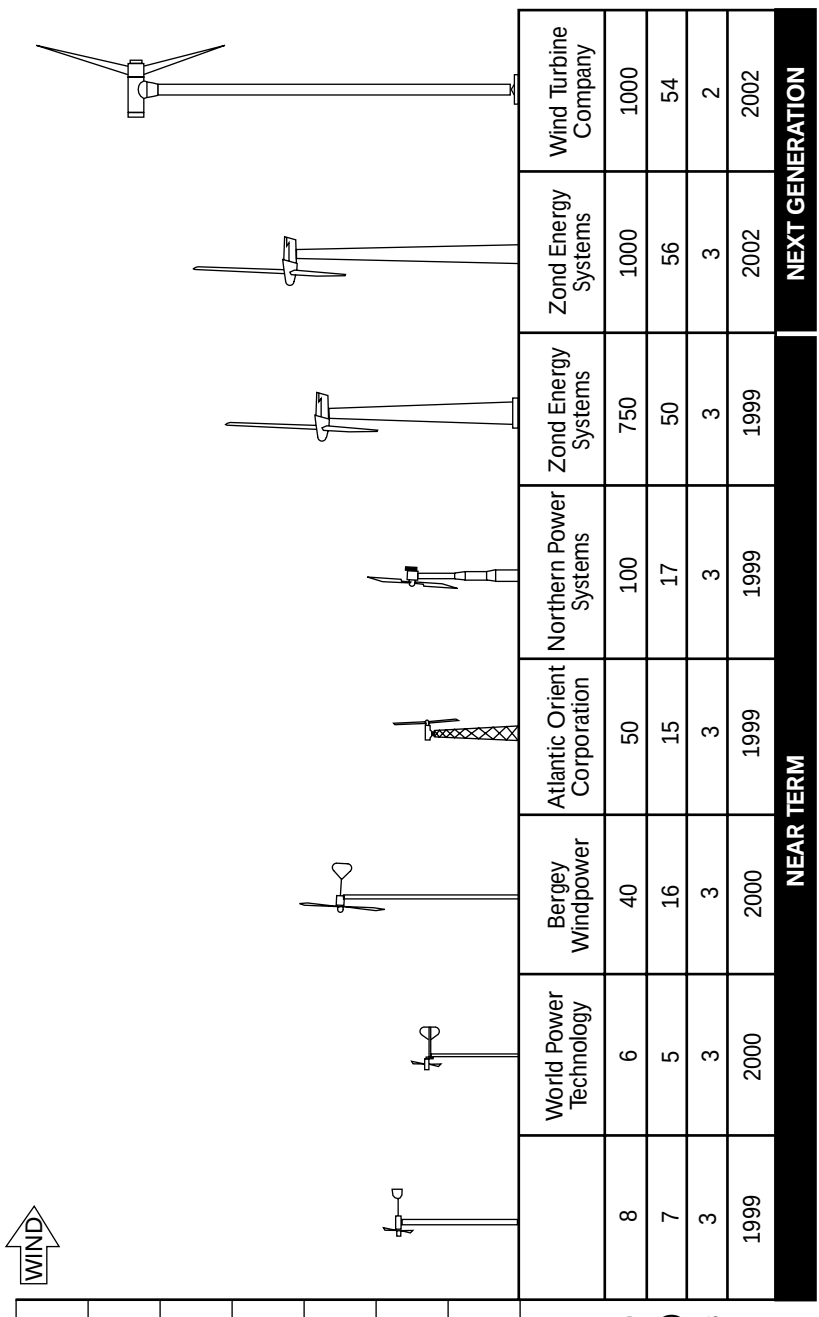

Figure 22.7 Wind turbines under development by industry with DOE/NREL support

$0.025/kWh by year 2002, at good wind sites with 6.7 m/s (15 mph) average wind speed measured at 10 m height and with low cost financing. This target includes all turbines, land, and the balance of station costs for a 50-MW wind power plant project located near power transmission lines. See Section 22.4, Economics, below for more details. For the DOE small turbine development program, the cost goal is to significantly reduce the cost of energy from machines with peak power ratings from 5 to 40 kW. Specific machine goals depend on the type of turbine and the planned operating environment and application requirements.

Two large-scale (at least 1 MW), next generation turbines are being developed for bulk electric power markets without the need for subsidies. Subcontracts with industry to develop and test next-generation turbines include, Zond Energy Systems, Incorporated in Tehachapi, California (a subsidiary of Enron Wind Corp.), and The Wind Turbine Company in Belleview, Washington. Each company will cost-share 30% of their $20 million contract. Individually hinged rotor blades are one concept being considered for The Wind Turbine Company machine and this configuration will be tested on a sub-scale proof-of-concept turbine installed in 2000. See Figure 22.8.

Field tests of advanced utility-scale turbines have been underway for several years under the Turbine Verification Program. This Program is jointly funded by DOE and Electric Power Research Institute to document actual turbine performance and other operational data at seven wind power plant sites. More information is available at http://www.epri.com.

Six companies are developing near-term turbines for both grid-connected and off-grid power generation. The companies selected to develop the new machines are: World Power Technologies, Inc. from Duluth, Minnesota, for a 6-kW turbine; WindLite Company (that was recently acquired by the Atlantic Orient Corporation), for an 8-kW turbine; Bergey Windpower from Norman, Oklahoma, for a 40-kW turbine; Atlantic Orient from Norwich, Vermont, for improvements to their 50-kW machine; and Zond for improvements to their 750-kW commercial turbine. The 100-kW turbine is being developed by Northern Power Systems located in Moretown, Vermont, under a cooperative program between the National Aeronautics and Space Administration (NASA), the National Science Foundation, and DOE. This machine is being designed for the frigid environments of northern Alaska and Antarctica.

Cooperative Research and Testing—The Cooperative Research and Testing activity includes a wide range of support for industry, verification of advanced turbine performance in field tests, utility applications analysis, and support for the development of standards and for turbine certification testing. Grants were recently awarded to industry and state energy offices for small turbine field performance verification in a variety of applications in projects in ten states.

Standards development is another element of the Cooperative Research and Testing Activity. Under this element the NWTC works closely with the International Energy Agency (IEA) to develop recommended practices and with the International Electrotechnical Commission (IEC) to develop appropriate international standards and testing procedures. In addition, NWTC is now an accredited testing laboratory for certification of wind turbines for international markets. Although there are currently no domestic requirements for turbine certification in the United States, the NWTC is now accredited by the American Association of Laboratory Accreditation, for conducting wind turbine power performance, structures, and noise certification testing.

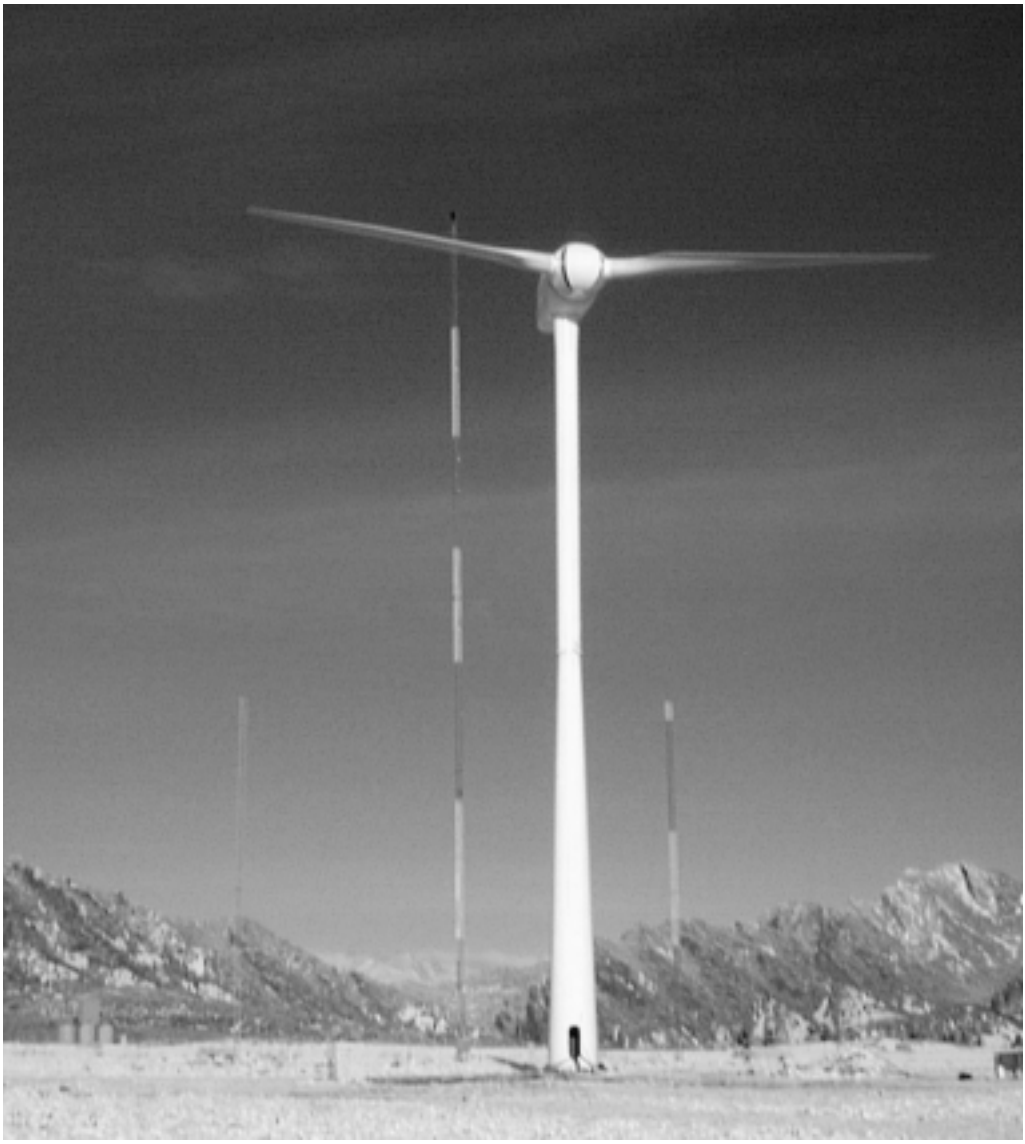

Figure 22.8 This 250-kW proof-of-concept turbine has hinged rotor blades

The certification test results from NWTC can be used by the U.S. certification agent, UL, or by others, as the basis for certifying the designs of U.S. industries' machines.

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