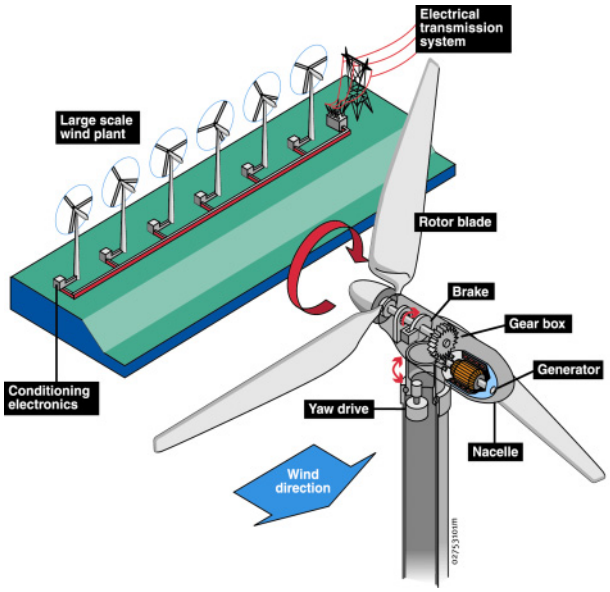
2.3 RENEWABLE ENERGY AND FUELS

2.3.1 WIND ENERGY

Technology Description

Wind turbine technology converts the kinetic energy in wind to electricity. Grid-connected wind power reduces greenhouse gas emissions by displacing the need for natural gas- and coal-fired generation. Village and off-grid applications are important for displacing diesel generation and for improving quality of life, especially in developing countries.



System Concepts

- Most modern wind turbines operate using aerodynamic lift generated by airfoil-type blades, yielding much higher efficiency than traditional windmills that relied on wind "pushing" the blades. Lifting forces spin the blades, driving a generator that produces electric power in proportion to wind speed. Turbines either rotate at constant speed and directly link to the grid, or at variable speed for better performance, using a power electronics system for grid connection. Utility-scale turbines for wind plants range in size up to several megawatts, and smaller turbines (under 100 kilowatts) serve a range of distributed, remote, and standalone power applications.

Representative Technologies

- Two machine configurations are commonly used today. Three-bladed wind turbines are operated "upwind" of the tower, with the blades facing into the wind. The other common wind turbine type is the two-bladed, downwind turbine. To improve the cost-effectiveness of wind turbines, technology advances are being made for rotors and controls, drive trains, towers, manufacturing methods, and site-tailored designs.

Technology Status/Applications

- Thirty-seven states have land area with good winds (13 mph annual average at 10 m height, wind Class 4, or better). By the end of 2003, 19 states are expected to have more than 20 megawatts (MW) in operation, and wind energy installations across the United States are expected to approach 6,000 MW.
- Current performance is characterized by levelized costs of 4-6¢/kWh (depending on resource quality and financing terms), capacity factors of 30-40%, availability of 95-98%, total installed costs of $800-$1,000/kW, and efficiencies of 65-75% of theoretical (Betz limit) maximum.

Current Research, Development, and Demonstration

RD&D Goals

- Wind-farm cost/performance varies by wind resource class, ownership type, and time. Current costs range from 4¢-6¢/kWh.
- By 2004: 3¢/kWh at sites with annual average wind speeds of 16 mph (wind Class 6).
- By 2012: 3¢/kWh at sites with average wind speeds of 13 mph (wind Class 4).

RD&D Challenges

- Developing wind technology that will be economically competitive at low (13 mph) wind-speed sites requires optimizing increasingly large turbine designs for 30-year life in a fatigue-driven environment with minimal or no component replacements, requiring improved knowledge of wind inflow, aerodynamics, structural dynamics and materials, and optimal control of turbines and wind farms.
- Developing information and strategies to facilitate and optimize integration of wind power into electric grid systems.

- Develop offshore wind technology to take advantage of the immense wind resources in shallow and deep waters of U.S. coastal areas and the Great Lakes near large energy markets.
- Conduct analysis and R&D to explore the role of wind power in the production of hydrogen, in both large-scale and distributed systems.

RD&D Activities

- Core and university research: wind characteristics and forecasting, aerodynamics, structural dynamics and fatigue, and control systems for turbines and wind farms.
- Turbine research: cost-shared design and testing of next-generation utility-grade technology for low wind-speed sites, performance verification of new prototypes, development of advanced small turbines for distributed power applications, and component and system testing at the National Wind Technology Center (NWTC).
- Cooperative research and testing: collection of wind turbine-performance data, power-systems integration, resource assessment, industry technical support, participation in international standards development, wind turbine-certification assistance, and regionally targeted outreach.

Recent Progress

- In 1989, the wind program set a goal of 5¢/kWh by 1995 and 4¢/kWh by 2000 for sites with average wind speeds of 16 mph. The program and the wind industry met the goals as part of dramatic cost reductions from 25¢-50¢/kWh in the early 1980s to 4¢-6¢/kWh today.
- Wind power is the world's fastest-growing energy source. The worldwide wind market continues to grow at an annual rate above 30% with new markets opening in many developing countries. During 2002, more than 7,000 MW of new capacity was added to the electricity grid in the world.
- Domestic public interest in environmentally responsible electric generation technology is reflected by new state energy policies and in the success of "green marketing" of wind power throughout the country. U.S. wind energy installations have grown at an average rate of 24.5% during the past five years.
- The National Wind Technology Center (operated by the National Renewable Energy Laboratory in Golden, Colorado) is recognized as a world-class center for wind energy R&D and has many facilities – such as blade structural test stands and a large dynamometer – not otherwise available to the domestic industry or its overseas competitors.

Commercialization and Deployment Activities

- Installed wind capacity expanded by nearly 10% in the United States during 2002 to 4,685 MW, with 410 MW of new equipment going into service. California has the greatest capacity, followed by Texas, Iowa, Minnesota, Washington, Oregon, Wyoming, and Kansas. Worldwide, more than 31,000 MW are installed, and large growth rates illustrate the industry's ability to rapidly increase production with the proper market incentives.

- Wind technology is competitive today in bulk power markets with support from the production tax credit – and in high-value niche applications or markets that recognize noncost attributes. Its competitiveness by 2005 will be affected by policies regarding ancillary services and transmission and distribution regulations. Substantial cost reductions are expected for wind turbines designed to operate economically in low wind-speed sites, which will increase the resource areas available for wind development by 20-fold and move wind generation five times closer to major load centers.

- The principal markets for wind energy are substitution for new natural gas combined-cycle plants (expected to be 97 GW in 2010 and 696 GW in 2030) or displacement of fuel from existing plants, and replacement of coal-generated power plants (expected to be 315 GW in 2010 and 328 GW in 2030).
- Utility restructuring is a critical challenge to increased deployment in the near term because it emphasizes short-term, low-capital-cost alternatives and lacks public policy to support deployment of sustainable technologies such as wind energy.
- In the United States, the wind industry is thinly capitalized, except for General Electric Wind Energy, which recently acquired wind technology and manufacturing assets in April 2002. About six manufacturers and six to 10 developers characterize the U.S. industry.
- In Europe, there are about 12 turbine manufacturers and about 20 to 30 project developers. European manufacturers have established North American manufacturing facilities and are actively participating in the U.S. market.
- Initial lower levels of wind deployment (up to 15%-20% of the total U.S. electric system capacity) are not expected to introduce significant grid reliability issues. Since wind blows intermittently, intensive use of this technology at larger penetrations may require modification to system operations or ancillary services. Transmission infrastructure upgrades and expansion will be required for large penetrations of wind energy to service major load centers.
- Small wind turbine sales are increasing dramatically as a direct result of state incentive programs. California, for example, implemented a rebate of up to $4,500 for the purchase of a wind turbine rated at less than 10 kW. As a result, one small wind turbine manufacturer sold more than 10,000 of their 400 watt and 1,000 watt turbines in 2001 and 2002. About half were sold domestically and half exported. Another manufacturer, whose sales increased 30% in 2002, now has machines ranging from 1 to 10 kW operating in all 50 states and in more than 90 countries.