Cost of Wind Energy Substantially Reduced

The Office of Power Technologies is part of the Office of Energy Efficiency and Renewable Energy

Government and industry collaboration has decreased wind energy costs more than sevenfold

In the seventies, the U.S. Department of Energy (DOE) Wind Energy Program set a goal to help industry reduce the cost of energy from wind to the point where it can begin to compete with conventional sources of electricity. With the levelized cost of energy from wind today at less than $0.05 per kilowatt-hour (kWh), the DOE-wind industry partnership is beginning to achieve this goal.

As new technology currently being developed is introduced into the market, costs will decrease even further.

Highlights

- *The cost of energy from wind has decreased from more than $0.35/kilowatt-hour (kWh) in the seventies to less than $0.05/kWh today.*
- *The installed capacity of U.S. wind power plants has grown to more than 1700 megawatts (MW).*
- *Millions of hours of operating experience have been recorded.*
- *Wind power plant performance has improved steadily, with new plant availabilities exceeding 98%.*
- *About two million tons of carbon emissions are avoided annually.*
- *The growth rate of worldwide markets for wind power is currently at an all-time high of 25% per year.*

Industry Leadership

The U.S. wind industry has achieved this cost reduction through real-world application experience, technology improvements, mass production of components, and establishment of utility-grade operation and maintenance (O&M) programs in the field. Capital costs for wind turbines have fallen dramatically, from over $3000 per kilowatt (kW) 20 years ago to less than $1000 per kW today.

At the same time, the productivity and reliability of the turbines have increased dramatically. Modern wind turbines achieve aerodynamic efficiencies as high as 75%. Furthermore, the average power output per unit area swept by the rotor (kW/m^2) has increased from 600 kW/m^2 20 years ago to over 1000 kW/m^2 today.

The Zond Z-40 turbine—developed in partnership between Zond Energy Systems, Inc., and DOE—is now operating in several locations in the United States, Europe, and Asia.

NREL/PIX 05612

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The NREL airfoils won the prestigious R&D 100 Award in 1991, given by R&D Magazine *to the 100 top scientific achievements of the year.*

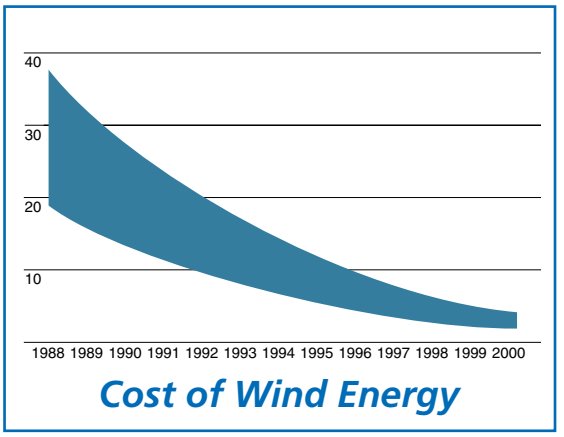
Technical Achievement

Technical advances in wind technology are key to industry progress. Scientific and engineering accomplishments are documented in technical literature, with the most effective projects involving a partnership between DOE and the wind industry. Significant advances have occurred in new airfoils, mechanical improvements, resource assessment, and turbine development.

DOE Program Achievements

- Established the scientific body of knowledge relating to aerodynamics for wind energy and developed and tested airfoils designed for wind turbine blades
- Developed computer design codes that have substantially improved the structural engineering and design of wind turbines and turbine components
- Supports industry in developing the next-generation wind turbines to achieve even lower costs of energy from wind.
- Completed a nationwide assessment of the size and location of the U.S. wind energy resource.

In addition, the DOE wind program achieved the building of the National Wind Technology Center (NWTC) near Boulder, Colorado, the world's premier research and development (R&D) facility for wind. The U.S wind industry has also worked in partnership with the DOE program in developing international standards for wind turbines and in testing U.S. turbines for certification that they meet these standards.



Cost of Wind Energy

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New Airfoils

When the U.S. wind industry was born, little was known about how aerodynamics affects turbine performance. In fact, turbine blades were built using airfoil designs for airplane wings. But airplane wings operate in a much different aerodynamic environment than wind turbines.

To meet this challenge, the National Renewable Energy Laboratory (NREL), a DOE national laboratory located in Golden, Colorado, developed a set of airfoils designed specifically for wind turbine blades. These new blades capture 10%–35% more energy from wind compared to blades from earlier turbines, and at little additional cost. Soon after their introduction, the airfoils became the worldwide standard for the industry and substantially strengthened the competitive position of U.S. manufacturers.

Also in the fields of aerodynamics and structural response, DOE-funded researchers have established the role of turbulence in fatigue of turbine components resulting from the heavy loads placed on the equipment.

Wind Energy Technology Status*

Technology Characteristic	Cost/kWh	Operating Life	Capacity Factor (average)	Availability	Turbine Size
Before 1975	$0.50 – $1.00	1 – 5 years	10%	60% – 70%	< 20 kW
Current	$0.05 – $0.035	30 years	25%	98%	300 – 700 kW
2000	$0.04 – $0.025	30 years	35%	98%+	500 kW –1.5 MW

** For a wind site with an annual average wind speed of 7.0 m/s (15.5 miles per hour) measured at a height of 30 meters (100 ft). The low-end cost of energy assumes municipal utility financing.*

Mechanical Improvements

Improved design of mechanical and electrical components has proven to be a major factor in augmenting performance, increasing turbine lifetime and reliability, and reducing cost.

Structural engineers are today designing turbines that are both stronger and lighter in weight than their predecessors. They perform better, and they cost less to produce because they use fewer materials than heavier structures.

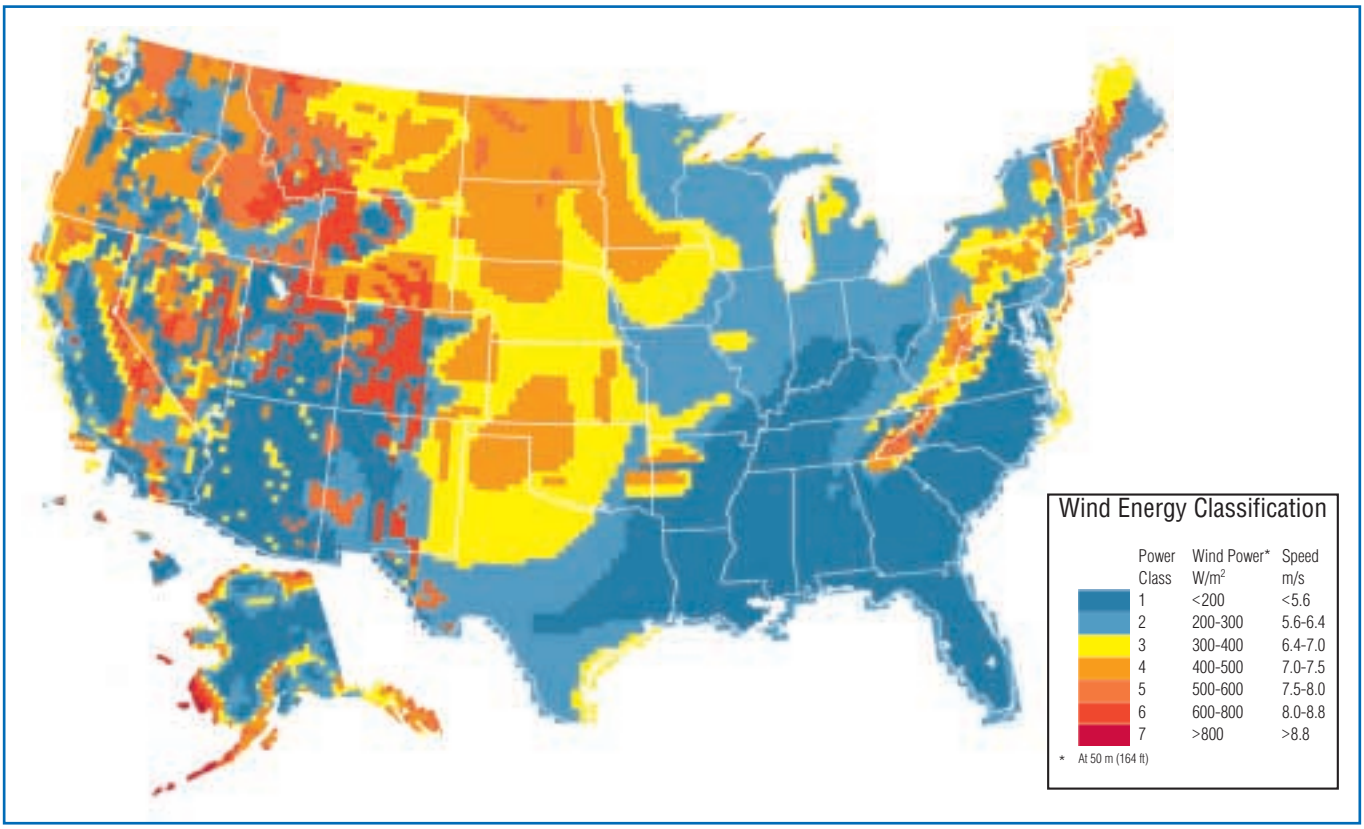
These new designs reduce stress by flexing, rather than rigidly withstanding harmful loads such as those caused by turbulence. Likewise, engineers have developed new, flexible mechanical components, such as teetered hubs, which reduce these loads by allowing the rotor to pivot away from turbulent winds and thus relieve stress.

Electrical components such as generators continue to improve dramatically. For example, some new turbines come equipped with variable-speed generators (and drives) with power electronics. Other advances include a low-speed generator that will eliminate the need for a mechanical gearbox, reducing costs accordingly.

Engineers at NREL and Sandia National Laboratories located in Albuquerque, New Mexico, have also developed a series of computer programs for designing state-of-the-art wind turbines. Using these programs, turbine designers can test new design ideas using sophisticated computer systems to model how they will perform and hold up under operating stresses before building expensive hardware. These codes lie at the heart of modern technological innovation, especially for using new, lightweight materials.

Resource Assessment

In the last few decades, scientists have greatly expanded our understanding of the size and nature of the wind energy resource. The sheer



OT 23766-4

Every region of the country has some areas with good wind energy resources. And some states, such as those that lie on the Great Plains from Texas to North Dakota, have a huge electricity-generating potential from the wind.

Cost of Wind Energy Substantially Reduced

The Electric Power Research Institute has reported that alone among the emerging alternative energy technologies, wind power offers utilities with good wind resources pollution-free electricity that is nearly cost-competitive with today's conventional sources.

size of wind potential is astounding; the energy in class 4 and higher winds (see map) has the potential to supply more than one-and-a-half times the current electricity consumption of the United States. This number excludes urban and environmentally sensitive lands, totalling 35% of the total windy land area that are not considered suitable for wind power developments.

Scientists have also learned much about the site-specific nature of the wind resource. Wind power plants can now be sited scientifically, and as a result, economic performance can be projected based on accurate resource data. DOE is also helping utilities develop ways to forecast windy periods based on weather projections so they know in advance when electricity output from wind power plants will be high. Wind resource science has developed to the point where some U.S. companies now specialize in conducting resource assessments and siting wind power plants.

Turbine Development

Cost-shared projects with industry have produced advances in wind technology resulting in the development of several new, innovative wind turbines for utility applications at home and small-power applications abroad.

One new turbine that was developed with financial and technical support from DOE, the Zond Z-40, is currently undergoing evaluation by utilities in Texas and Vermont. Zond Energy Systems, Inc. (now a subsidiary of Enron Wind Energy Corporation, Tehachapi, California), improved on existing turbine designs by applying value engineering. The utilities are operating this turbine in small power plants and evaluating its performance against their own utility standards.

Looking to the future, DOE is helping to develop the next generation of wind turbines. This initiative is slated to cost $50 million, of which 30% of the cost will be paid for by private industry. With technical support from the DOE laboratories, engineers from industry are designing, building, and testing new turbines from the ground up, incorporating many years of R&D lessons learned. These next-generation turbines should be capable of producing electricity at $0.025 per kWh at excellent wind sites by early in the next decade, achieving a new cost milestone for wind technology.

Project Partners

U.S. Department of Energy

Electric Power Research Institute

Enron Wind Energy Corporation

National Renewable Energy Laboratory

The Wind Turbine Company

Sandia National Laboratories

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U.S. Department of Energy Wind Energy Program:
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The National Wind Technology Center:
http://www.nrel.gov/wind

Publications:
The Cost of Electricity from Wind Turbines.
http://www.nrel.gov/wind/cost.html

Wind Energy as a Significant Source of Electricity.
http://www.nrel.gov/wind/atlpap2.html

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