Wind Energy

TECHNICAL INFORMATION GUIDE

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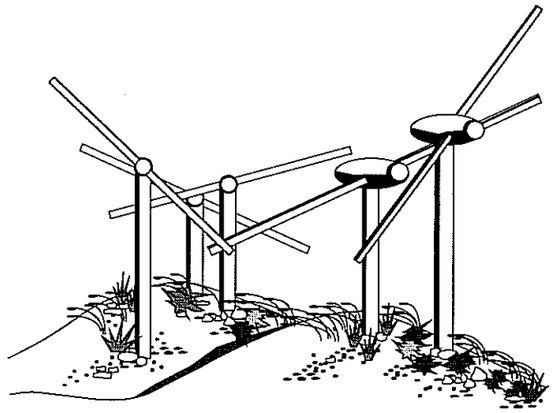

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Preface

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

This guide is designed to help you search for information in the wind energy field, ranging from its history and technology basics to the latest in research and development. It is written to help several audiences, including engineers and scientists who may be unfamiliar with a particular aspect of wind energy, university researchers who are interested in this field, manufacturers who need to learn more about specific wind topics, and librarians who provide information to their clients.

Please note that the annotated references appearing throughout this book do not represent all available material on a specific topic. The objective is to identify sources of basic information to begin a search. The selection of references and their placement in the guide are based on several factors, including relevancy to the particular topic, frequency of citation in the professional literature, recommendations from research staff, currency, and availability.

How to Use This Book

This book is divided into nine chapters. Chapters 1-6 provide background on wind energy development (including its history and current status) by topic. An overview is provided within each topic accompanied by references to relevant publications or information sources. Chapters 7 and 8 contain directories listing research centers and major technical information sources, respectively. Chapter 9 lists many useful models and design tools for wind energy systems, as well as several software directories. Finally, two indexes provide alphabetical access to organizations and subjects. The organization index covers research centers, associations, and major information sources.

The publisher or sponsoring organization listed in the citation is often the primary distributor of the document. The entries include a description of the resource as well as information on how to contact the organization or obtain the document. Documents that are produced by the federal government are distributed to the public through the Government Printing Office (GPO) and the National Technical Information Service (NTIS). The appropriate stock number or order number is included in the citation. Older NTIS documents do not have an order number; the report number, without the slashes and hyphens, is used instead (for example, LBL12200). Requests for government documents can be sent to

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(703) 487-4650

Requests for U.S. Department of Energy (DOE) or DOE contractor reports can be sent to

National Technical Information Service
Energy Distribution Center
P.O. Box 1300
Oak Ridge, TN 37831

(615) 576-1301

ASME reports and publications listed in this guide may be obtained, for a fee, from

American Society of Mechanical Engineers
345 East 47th Street
New York, NY 10017

Information on IEA reports and pbulications listed in this guide may be obtained from

International Energy Agency
(Agence Internationale de l'Energie)
2, rue Andre Pascal
F-75775 Paris Cedex 16 France

Libraries offer the most expedient method for locating the majority of documents cited in this guide, including government reports and other relevant materials. The documents can be borrowed through public, academic, and special libraries with which the reader is affiliated. Most libraries also offer an interlibrary loan (ILL) service to patrons. Through the ILL cooperative arrangement, a library is able to borrow documents or obtain photocopies of items not in its collection. Charges for acquiring some materials might be collected from the requester.

Often, the best way to access data bases is also through libraries. Libraries that subscribe to a computer search service, such as DIALOG or BRS, can perform data-base searches for patrons. Commercial search services have standard charges for online search time and printed results.

In addition to local libraries, several information centers provide assistance specifically for inquiries concerning energy. The Conservation and Renewable Energy Inquiry and Referral Service (CAREIRS), affiliated with DOE, provides information on the full spectrum of renewable energy technologies and energy conservation. In addition, the service maintains contact with a nationwide network of public and private organizations that specialize in highly technical or regionally specific information. Information is available from

Conservation and Renewable Energy Inquiry and Referral Service
Renewable Energy Information
P.O. Box 8900
Silver Spring, MD 20907

(800) 523-2929 (United States, including Virgin Islands and Puerto Rico)
(800) 233-3071 (Alaska and Hawaii)

The National Appropriate Technology Assistance Service (NATAS) provides tailored information and technical assistance on energy-related appropriate technologies. NATAS provides engineering and scientific, as well as commercialization, technical assistance. It is funded by DOE to provide aid to new businesses and renewable energy innovators. Contact NATAS at

National Appropriate Technology Assistance Service
P.O. Box 2525
Butte, MT 59702-2525

(800) 428-2525
(800) 428-1718 (Montana only)

The National Energy Information Center (NEIC) is the branch of the Energy Information Administration (EIA) in charge of answering inquiries and disseminating information. EIA is the information arm of DOE; it collects and analyzes data on many aspects of energy. NEIC answers questions on production, consumption, prices, trends, and resource availability. It can also provide references to other sources of energy information. Contact NEIC at

National Energy Information Center
1000 Independence Avenue, S.W.
Forrestal Building, 1F-048
Washington, DC 20585

(202) 252-8800

The Technical Inquiry Service is funded by DOE to provide information to the research, business, and industrial communities. The service provides individualized responses to questions re-

garding research at the Solar Energy Research Institute (SERI) and other similar organizations. The renewable technologies covered are wind, photovoltaics, biofuels, and solar heat. Contact the Technical Inquiry Service at

Technical Inquiry Service
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

(303) 231-7303

The National Climatic Data Center (NCDC) is the national collection center and custodian of U.S. weather records. It is also the repository for the Wind Energy Resource Information System (WERIS) (see Databases section). Principal areas of research interest are: climate, including temperature, pressure, precipitation, and wind; meteorology; solar radiation; and other atmospheric phenomena. Contact NCDC at the

National Climatic Data Center
Federal Bldg.
Asheville, NC 28801

(704) 259-0682

Finally, many states have an energy office or an energy extension service that provides assistance to residents on energy matters. The State Energy Conservation Program/Energy Extension Service (SECP/EES) provides grants to state energy offices to conduct a range of energy conservation activities in the residential, commercial, agricultural, and transportation sectors. The principal user of SECP and EES information services is the state energy office; public inquiries should be directed there. Contact SECP/EES at

State Energy Conservation Program/Energy Extension Service
Office of Energy Management and Extension
U.S. Department of Energy
1000 Independence Avenue, S.W.
Washington, DC 20585

(202) 252-8288

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Chapter 1
Introduction

History of Wind Power

Since earliest recorded history, people have been harnessing the energy of the wind. There is evidence that wind energy was used to propel boats along the Nile River as early as 5000 B.C. Within several centuries before the birth of Christ, simple windmills were used in China to pump water, and vertical-axis windmills (with woven reed sails) were used in Persia and the Middle East to grind grain.

Windmills were used extensively throughout the Middle East by the 11th

Torrey, Volta. (1976). *Wind-Catchers: American Windmills of Yesterday and Tomorrow.* Brattleboro, VT: The Stephen Greene Press; 226 pp.

Wind Catchers presents a broad, historical summary tracing wind energy from its beginnings to its use in the United States. The text is supplemented with many photographs and illustrations. Appendices include listings of other information sources, wind engine manufacturers, and associations.

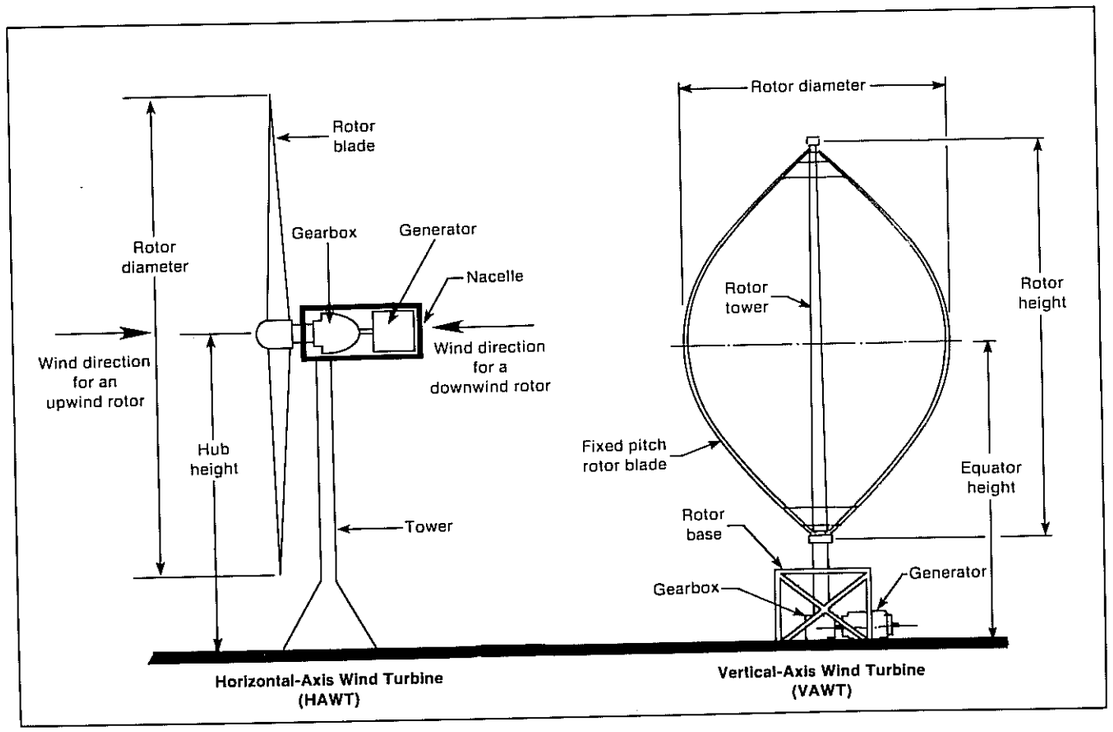
Overview of the Wind Energy Field

Wind energy is the kinetic energy in the movement of large masses of air resulting primarily from the earth's rotation and uneven heating of the earth and atmosphere by the sun. Wind energy conversion systems (WECS) convert this kinetic energy into electric power or mechanical energy for applications such as water pumping.

There are two basic wind turbine designs: HAWTs, in which the rotating axis is horizontal, and VAWTs, in which the axis is vertical. Both designs convert the wind's kinetic energy to mechanical movement or electricity.

The conversion process begins as air flows over both surfaces of an airfoil-type blade. Air passes more rapidly over the longer (upper) side, creating lower pressure above the airfoil than beneath it. The pressure difference results in an upward force known as aerodynamic lift, which causes the blade to rotate about a central hub and shaft. This rotational energy can be used to operate a mechanical device, such as a water pump, or to produce electricity by means of a generator.

Although wind energy conversion is relatively simple in concept, turbine design can be quite complex. For example, the amount of power produced by a wind turbine is reduced by drag forces that result from air flow between the blades. This makes a high-lift-to-drag ratio one of the prime considerations in blade design. The number of blades also becomes an issue; one-bladed rotors minimize energy loss from drag forces, but two-and three-bladed rotors are considered the best tradeoff for stability, aerodynamic performance, and cost.



Basic wind turbine configurations.

The amount of power available in the wind is proportional to the cube of the wind speed, an important fact to consider in siting wind turbines. For example, if the average wind speed at a site is 20% higher than expected, the turbine may produce 73% more energy. Conversely, overestimating a site's wind speed by 20% will result in about half the expected power.

Available power also is proportional to the area swept by the rotor, yet rotor size is limited by factors such as material and joint strength, weight, and cost. The wind industry has traditionally built HAWTs rated at less than 200 kilowatts (kW) because of lower installed costs and ease of maintenance. However, with today's improved technology, windfarm operators are beginning to use intermediate-sized machines with power ratings of 200 kW to 600 kW.

Rated power is the machine's designed power output, which occurs at its rated wind speed. Winds greater than the rated speed can lead to undesirably high components loads (stresses) with resulting fatigue and possibly failure. Therefore many turbine designs include an aerodynamic braking mechanism, such as blades with pitchable (twistable) tips, to slow or stop blade rotation before damage can occur.

System efficiency is determined by the combined efficiencies of both rotor and generator. Today's best HAWTs and VAWTs can convert about 40% of the wind's energy to mechanical energy. With a typical drive-train/generator efficiency of about 85%, today's machines can achieve a maximum overall efficiency of about 35%. This conversion efficiency exceeds that of many other renewable energy technologies—including photovoltaics, where typical commercial modules have efficiencies of less than 15%—and also compares favorably with the 30% to 40% thermal efficiency of some conventional power plants. With windfarm availability (the amount of time a windfarm is able to produce power) often reaching 95%, wind power has proven itself to be a realistic energy supply alternative.

Applications vary with wind machine size. Small electrical systems of 1 to 100 kilowatts (kW) usually serve isolated communications installations, residences, and farms. Large-scale systems (100 kW to more than 1 MW) are suitable for farm irrigation systems, electric utilities, and industries.

Sources of State-of-the-Art Information

The most difficult type of information to obtain in any technology is that which reports the latest developments in the field. Understandably, the publishing process takes time and creates gaps between the accomplishment and its documentation. The following suggestions offer alternatives to waiting for the latest information to appear in print. The most up-to-date information can be obtained by talking to those directly involved in particular aspects of the field. For example, Chapter 7 of this publication lists the organizations performing wind energy research (including government laboratories) and information on their areas of research.

Hunt, V. Daniel. (1981). *Windpower: A Handbook on Wind Energy Conversion Systems.* New York: Van Nostrand Reinhold Co.; 610 pp.

This book provides a comprehensive collection of contemporary wind energy information. Major topics include history; wind characteristics; fundamental WECS operation; system design characteristics; towers; electric power; conversion and storage systems; WECS applications; commercialization; environmental, institutional, and legal barriers; international development; and the future of wind power. An extensive bibliography, a section of technical reference data, and a listing of technical contacts (including manufacturers and distributors) also are included.

Naar, Jon. (1982). *The New Wind Power.* West Hanover, MA: Halliday Lithograph; 251 pp.

The author describes how wind energy systems work and, using a case-history approach, examines the development of this technology. The experiences of government, universities, large corporations, and small businesses are used to describe the research, legislation, and industry of the new wind machines. Finally, six different perspectives for the future of wind energy are presented.

Eldridge, Frank R. (1980). *Wind Machines.* 2d. ed. New York: Van Nostrand Reinhold Co.; 214 pp.

This book surveys the history, taxonomy, state of the art, and future potential of various types and sizes of wind machines. Information on possible applications, siting problems, performance characteristics, and systems designs is also provided.

Moretti, Peter M. and Divone, Louis V. (June 1986). "Modern Windmills." *Scientific American* (254:6) pp. 110-118.

The article provides an overview of windmill technology, with an emphasis on the production of electricity by modern wind machines. A historical survey examines technological developments in capturing the wind and the resulting applications. Modern windmill development has shifted from torque to energy-maximizing designs. Recent research has focused on airfoil shape, blade aerodynamics, and control system improvements. Future trends in wind-turbine development include decreases in costs, increases in reliability, and power generation for developing countries and power grids.

Eggleston, D. M. and Stoddard, F. S. (1987). *Wind Turbine Engineering Design.* New York: Van Nostrand Reinhold Co.; 352 pp.

This overview of wind turbine engineering design includes a presentation of basic technical facts, recommended procedures, and a guide to the most useful handbooks and references. Part I discusses basic methods for modeling rotor aerodynamics, details of rotor design, digital programs for wind-turbine design and analysis, performance, economics, and siting. Part II discusses structural dynamics, including system engineering models, blade motions, blade and hub loads, instabilities, and load specification. Part III has chapters on system engineering, including discussions of fatigue, electric generators, and control systems.

Wind Energy Conversion Systems Terminology. (1985). AWEA Standard 5.1-1985. Alexandria, VA: American Wind Energy Association; 11 pp.

A glossary of standard wind energy terms.

Recommended Practices for Wind Turbine Testing and Evaluation: 8. Glossary of Terms; Issue 1, March 1987. (March 1987). Elliot, G., ed.; 11 pp.

Submitted to the Executive Committee of the International Energy Agency Programme for Research and Development on Wind Energy Conversion Systems, this document provides a glossary of wind energy terms.

"Power Generation, Wind, Ocean." (1989). *Encyclopedia of Architecture: Design, Engineering, and Construction, Volume 4.* Wilkes, J.A., ed. New York: John Wiley & Sons, Inc.; pp. 32-39.

This article describes the availability of the earth's wind and ocean energy resource. The historical evolution of wind energy systems and types of modern wind turbines are reviewed. Ocean thermal energy conversion systems discussed include salinity

Workshops and conferences provide a forum for researchers and others to present their latest findings and note industry trends. Information on recent conferences can be found in the conference section of this chapter as well as in other chapters (by specific topic).

Although less timely than personal contact, journals are the best source of authoritative published information. For example, *Windpower Monthly* provides news on current developments and activities in the field, and *Wind Engineering* contains scholarly articles describing research findings and techniques. Chapter 8 lists journals useful in the wind energy field.

The publications cited here summarize developments in wind energy. They discuss the technology and also its potential and likely impacts.

Conferences and Other Educational Activities

Conferences, workshops, and other events are often the best way to find the latest developments in the field. Many organizations sponsor conferences, with a few of them being regular sponsors. These organizations include the national laboratories responsible for components of the Federal Wind Energy Program, the American Wind Energy Association, the American Institute of Aeronautics and Astronautics, the European Wind Energy Association, the British Hydromechanics Research Association (BHRA) Fluid Engineering, the International Energy Agency, and the International Solar Energy Society.

Educational activities, such as specific wind energy courses or programs offered through conventional post-secondary educational institutions, are somewhat more difficult to identify. Fourteen programs with wind energy components are listed in the *National Solar Energy Education Directory* published in 1981. The educational institutions listed in the Research Centers portion of this publication (Chapter 7) also may allow special studies or projects in wind energy even though they may have no official wind program. Finally, conferences and seminars provide good opportunities to learn about wind energy whether or not they give official credit or degrees.

"Wind Energy Systems." *New and Renewable Energy in the United States of America: The United States National Paper for the 1981 United Nations Conference on New and Renewable Sources of Energy.* (June 1981). DOE/S-0006. Washington, DC: U.S. Government Printing Office; pp. 50-58. Work performed by the Solar Energy Research Institute, Golden, CO, for the U.S. Department of Energy and U.S. Department of State.

This report describes the technical characteristics, applications and status, economics, barriers, and impacts of wind energy as well as private and government activities advancing its development and use.

Flavin, Christopher. (March-April 1988). *Harvesting the Wind.* Worldwatch Paper Volume 1, No. 2. Washington, DC: Worldwatch Institute; pp. 12-17.

Principles of wind energy, current issues, and options for future use are surveyed in this report.

Spera, D. A. and Thresher, R. W. (1987). "Preview of the ASME/DOE Wind Turbine Technology Book." *Sixth ASME Wind Energy Symposium: The Tenth Annual Energy Sources Technology Conference and Exhibition; Dallas, Texas; February 15-18, 1987.* SED-Vol. 3. Thresher, R. W., ed. New York: American Society of Mechanical Engineers; pp. 41-42.

Technical reports on wind energy research are a valuable resource that document the evolution of technology for all configurations of wind turbines. However, there is a need for a comprehensive publication documenting the most significant results and placing them in perspective. In addition, the extensive experience that industry has had with wind-power generation needs to be summarized to identify trends and guide future development. To meet these needs, the American Society of Mechanical Engineers and DOE are cosponsoring a book for technical readers that will present a comprehensive review of wind turbine technology. Publication is scheduled for 1989.

Available proceedings of recent conferences on wind energy include:

Windpower '88 Proceedings; Honolulu, Hawaii; September 18-22, 1988. (1989). Arlington, VA: American Wind Energy Association; 573 pp.

Holmes, J. D.; Jackson, P. S.; and Melbourne, W. H. (1984). *Wind Engineering 1983: Proceedings of the Sixth International Conference on Wind Engineering, Gold Coast Australia, March 21-25, and Auckland, New Zealand, April 6-7, 1983.* New York: Elsevier; 3 Vols. (published as a special issue of *Journal of Wind Engineering and Industrial Aerodynamics*, Vols. 13-15).

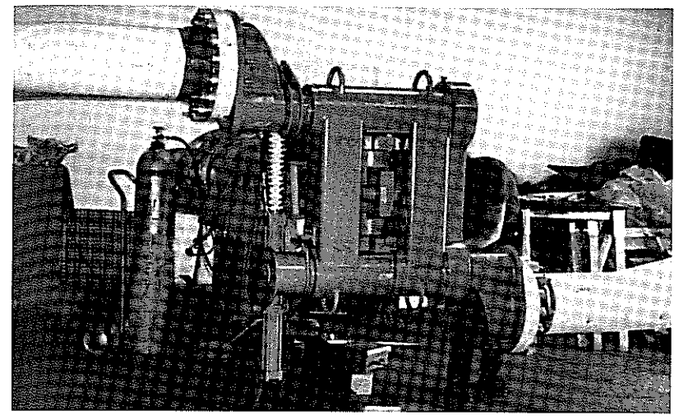
Anderson, M. B. and Powles, S. J. R., eds. (1986). *Wind Energy Conversion 1986: Proceedings of the 8th British Wind Energy Association (BWEA) Conference; Cambridge; March 19-21, 1986.* London: Mechanical Engineering Publications Limited; 312 pp.

Proceedings, Wind Energy Expo '86 and National Conference, American Wind Energy Association, Cambridge, MA, September 1-3, 1986. (1987). Alexandria, VA: American Wind Energy Association; 313 pp. Available from AWEA, Arlington, VA.

"Special Issue on Small and Medium Wind Turbines." (1986). *International Journal of Solar Energy.* (4:3); pp. 121-165. Proceedings of a workshop held in Brussels, November 21, 1985, by the Commission of the European Communities Directorate-General (XII) for Science, Research and Development.

Thresher, R. W., ed. (1987). Sixth ASME Wind Energy Symposium; Tenth Annual Energy Sources Technology Conference and Exhibition; Dallas, Texas; February 15-18, 1987. SED-Vol. 3. New York: American Society of Mechanical Engineers; 216 pp.

European Wind Energy Association Conference and Exhibition; 7-9 October 1986; Rome, Italy. (October 1986). CONF-861062-13. Palz, W. and Sesto, E., eds. Rome, Italy: A. Raguzzi, Bookshop for Scientific Publications; 2 Vols. Available NTIS: Order No. DE89770030.



A teetered rotor designed by Northern Power Systems uses innovative hinges to reduce stress and thereby improve HAWT reliability.

Future Developments

Many projections for the future of wind energy predict a steady rise in electric power generation through the end of the 20th century. These projections often depend on the assumption that fossil fuel prices will continue to rise, thereby increasing wind's economic competitiveness. Large markets for WECS are also emerging abroad—particularly in developed countries in Europe that are heavily dependent on fossil fuels for electric power generation and in developing countries, where rural areas often lack centralized utility networks.

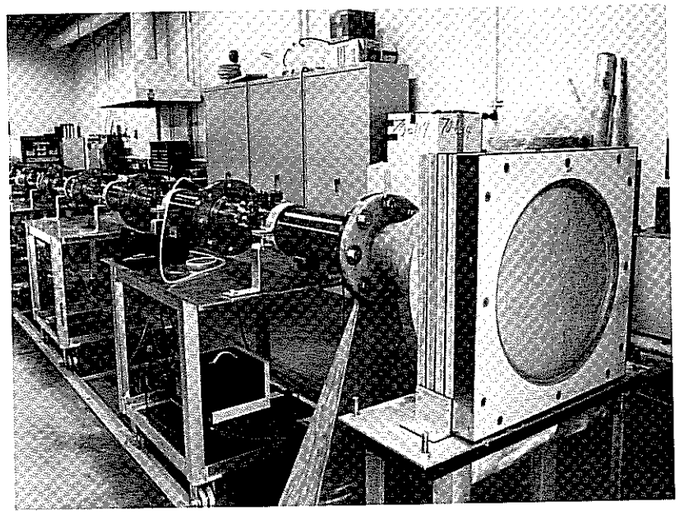
Wind Energy Mission Analysis. (February 1977). COO/2578-1/1 through 3. Philadelphia, PA: General Electric Company; 3 Vols.

Wind Energy Mission Analysis. (April 1976). SAN-1075-1/1 through 3. Burbank, CA: Lockheed-California Company; 3 Vols.

The objectives of these parallel studies are to assess the potential for WECS on a national scale; identify high-potential applications; define functional, performance, operational, and cost goals; evaluate the impact of wide-scale WECS deployment on energy suppliers and users; and identify the institutional and nontechnical problems associated with the acceptance of wind energy systems.

National Energy Policy Plan: Projections to 2010. (December 1985). DOE/PE-0029/3. Washington, DC: U.S. Department of Energy; 146 pp. Available NTIS: Order No. DE86014741.

This document provides energy projections developed within the U.S. Department of Energy by the Office of Policy, Planning, and Analysis. Underlying these projections are assumptions and results about key variables—world oil prices, economic growth, energy consumption and production potential. The projections try to account for uncertainty by providing a variety of scenarios that account for alternative future conditions (for example, high or low economic growth).



This facility at Sandia National Laboratories is used to calibrate highly accurate sensors for aerodynamics research.

Federal Program

The Federal Wind Energy Program is managed by the Wind/Ocean Technologies Division within the Office of Solar Electric Technologies, Conservation and Renewable Energy, U.S. Department of Energy (DOE). The division is responsible for program planning, establishing goals and objectives, formulating policy, budgeting, developing international agreements, and coordinating activities of participants in the wind program. Leonard J. Rogers is the current division director.

Since 1985, the program has been structured under two major research areas and seven research tasks under these areas:

Wind Turbine Dynamics Research
- Atmospheric Fluid Dynamics
- Aerodynamics
- Structural Dynamics

Advanced Components and Systems Research
- Advanced Concepts
- Supporting Research
- Applied Technology Testing and Analysis
- Multi-megawatt Systems.

Energy Security: A Report to the President of the United States. (March 1987). DOE/S-0057. U.S. Department of Energy; 450 pp.

This report provides an overall picture of current and projected energy use in the United States. For wind power, the report discusses current capacity factors, rated power output, energy production, and energy costs.

Merrill, O.; Schweizer, T.; Chernoff, H.; Conopask, H.; Knowles, R.; and Nagle, R. (August 1985). *Early Market Potential for Utility Applications of Wind Turbines.* EPRI-AP-4077. Palo Alto, CA: Electric Power Research Institute; 200 pp. Work performed by Science Applications International Corporation.

For wind turbines to be economically attractive to utilities, they must be made more reliable and less costly. If installed prices for reliable turbines decline to $1,100/kW (1980 dollars), cumulative nationwide market potential exceeds 21,000 MW by 2000. This figure does not represent a forecast of deployment levels but rather represents the potential market under reasonable expectations of electric demand, coal prices, oil prices, and related factors. Extensive sensitivity analyses were conducted to investigate effects of uncertainties in these factors on wind turbine market potential.

Five Year Research Plan 1985-1990, Wind Energy Technology: Generating Power from the Wind. (January 1985). DOE/CE-T11. Washington, DC: U.S. Department of Energy; 32 pp. Available NTIS: Order No. DE85008427.

DOE's current view of the research requirements for wind energy technology is presented. The goal of the Federal Wind Energy Program is to conduct research to establish a technology base and to support industry in confirming the viability of wind energy as an energy supply alternative. The federal program plan is outlined, and activities planned for fiscal years 1985 through 1989 are described.

Wind Energy Program Summary Fiscal Year 1988. Vol. I: Overview. (February 1989). DOE/CH10093-41; 12 pp. *Vol. II: Research Summaries.* (April 1989). DOE/CH10093-41; 68 pp. Golden, CO: Solar Energy Research Institute. Available NTIS: Order No. DE89000856 (Vol. I); DE89000857 (Vol.II).

Wind Energy Systems. Program Summary for Fiscal Years 1986 and 1987. (October 1988). DOE/CH10093-26. Golden, CO: Solar Energy Research Institute; 107 pp. Available NTIS: Order No. DE88001188.

This programmatic document summarizes the research and development activities sponsored by DOE's Wind Energy Program during fiscal years 1986 and 1987. The summary includes a description of the program, with historical background, the FY 1986/1987 budget, and an overview of accomplishments during those years. Also included are the highlighted activities of each field laboratory in FY 1986 and 1987; summaries of individual projects and contracts managed by each laboratory; and a bibliography of FY 1986/1987 publications.

Wind turbine dynamics research is focused on the basic physics of the interaction between turbines and the wind to produce energy. A better physical understanding of this interaction is needed to design more cost-effective wind turbines.

Under the atmospheric fluid dynamics research task, more accurate models of the wind are being developed. A better understanding of turbulence, atmospheric flow across complex terrain on a scale applicable to windfarms, and the effects of turbine wakes on wind flow will be attained by developing and verifying advanced models.

The aerodynamics research task is improving the understanding of wind turbine aerodynamic behavior and how the variability of wind forces affects wind turbine performance and reliability. Research in this area is divided into two topical areas: unsteady aerodynamics testing to better understand the mechanisms underlying the complex interactions experienced by wind turbines, with focus on techniques for visualizing the wind flow across the blade; and wind/rotor interaction modeling, with emphasis on refining predictive aerodynamic codes to predict forces along the blade and to predict stresses in the structural response models used in structural dynamics.

Advanced components and systems research is designed to identify, fabricate, and test components and system designs that will improve the cost, efficiency, and reliability of wind energy systems. Under the advanced components research task, areas that appear promising for improvements will be pursued. These areas include airfoil design, control concepts, and drive trains.

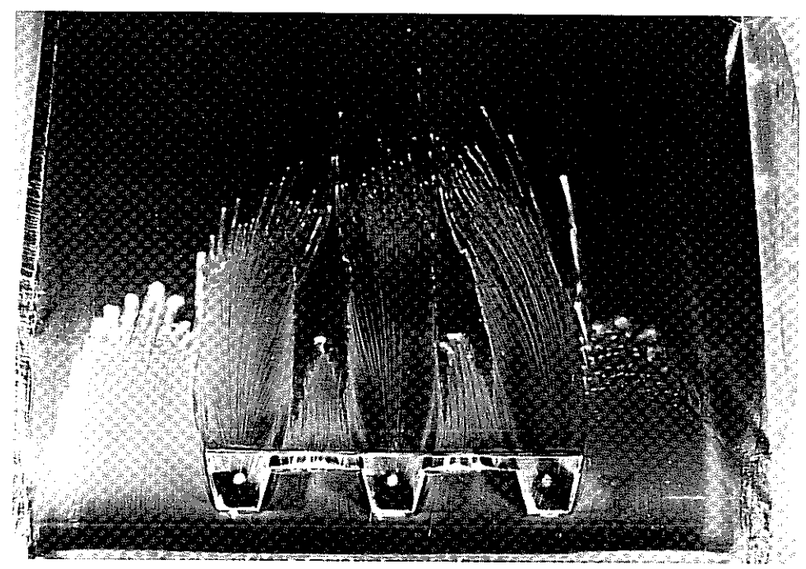
Airfoils are specialized shapes that produce aerodynamic lift. Until recently, aircraft airfoils have been used for wind turbines even though wind turbines must withstand large gravitational stress and operate in atmospheric layers that are more viscous and turbulent than those where aircraft operate. Under the advanced airfoils research task, airfoil shapes tailored to the operating conditions of turbines are being developed. These advanced airfoils will increase energy production, reduce

Miller, D. R., ed. (1977). *Wind Turbine Structural Dynamics Conference; Cleveland, Ohio; November 15-17, 1977.* NASA Conference Publication 2034. CONF-771148; 287 pp.

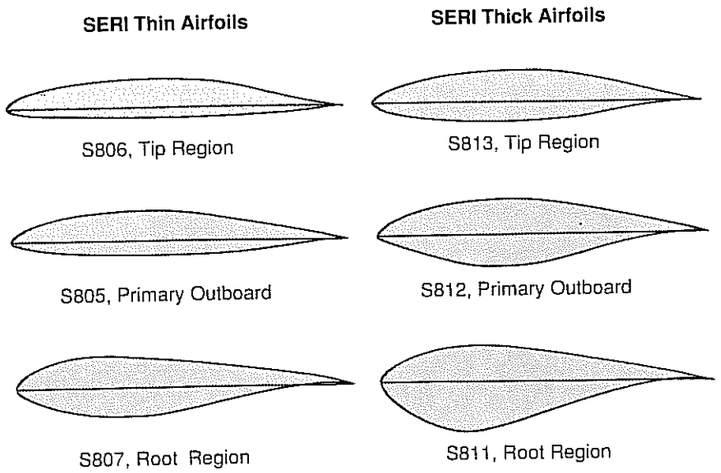
Twenty-nine short papers are presented. The following topics were discussed: turbine structural dynamics; methods for calculating dynamic loads; aeroelastic stability; wind loads, both steady and transient; critical design conditions; drive train dynamics; systems dynamics; and behavior of operating wind turbines.

Thresher, R. W., ed. (May, 1981). *Wind Turbine Dynamics; Proceedings: Cleveland, Ohio; February 24-26, 1981.* NASA Conference Publication 2185. CONF-810226; 450 pp. Available from NTIS: order no. DE 81027829.

Forty-eight papers on the dynamic behavior of large and small horizontal-axis and vertical-axis wind turbines were presented. Topics included aerodynamics, structural dynamics, electrical system dynamics, control dynamics, and acoustics. The objective of the workshop was to discuss and document recent progress in the analysis and prediction of the dynamic behavior of wind turbine generators.



In a technology developed by Sandia National Laboratories, liquid crystals applied to the surface of a wind turbine blade change color in response to changing airflow during rotation.



Advanced airfoils are being designed to meet the special requirements of HAWT blades. The "thin" family can be used to design fiberglass blades for rotors with diameters of 20 m or less; the "thick" family is more appropriate for wood composite or steel blades on larger rotors.

structural fatigue, improve power control, and reduce sensitivity to surface roughness caused by the accumulation of bugs and dirt.

Control systems are needed to protect turbines from exceeding load and rotational speed limits and for emergency stopping. In this research area, new mechanical, electrical, and aerodynamic control systems are being evaluated and tested to reduce fatigue and to control performance of wind turbines.

Research in advanced wind turbine drive trains focuses on further development and testing of variable speed generators. Improvements in airfoils, control systems, and generator-drive trains are integrated to develop advanced systems-level designs.

The supporting research task focuses on technology assessment, electrical systems, environmental impacts, and wind data collection and verification. Technology assessment encompasses a broad spectrum of activities such as utility system impact analyses and application assessments, including windfarms and wind/diesel hybrid generating systems. Electrical systems require analysis of issues such as power fluctuations, harmonics, voltage control, and reactive power demand. Environmental impacts include potential problems such as electromagnetic interference (especially television interference) and acoustic noise and the ways to address them. The wind data collection and verification is to expand and refine wind energy resource data.

The primary facility for testing services and programs is the Wind Energy Test Center at the Solar Energy Research Institute (SERI) in Golden, Colorado. SERI has facilities and technicians to provide atmospheric, electrical, structural, and other testing services. Analytical services such as engineering, reliability, safety, and life-cycle cost analyses are also available.

Until 1988, the NASA Lewis Research Center managed the research and development of multimegawatt HAWTs for the U.S. Department of Energy. This program was completed in 1988 following successful development of three generations of large horizontal-axis machines to extract the maximum amount of energy from a given amount of land area. The

The three MOD-2 wind turbines at Goodnoe Hills, Washington.

first-generation machines, including the experimental MOD-0A and MOD-1, demonstrated that large wind turbines could operate continuously in a utility network in a variety of environments. The MOD-2, a second-generation 2.5-MW prototype machine, underwent extensive testing at Goldendale, Washington, where a cluster of three MOD-2's generated more than 16 million kWh for the Northwest power grid. The third-generation machine, the 3200-kW MOD-5B, was built under a cost-sharing program with the Boeing Aerospace Company and Hawaiian Electric Renewable Systems, Inc., with technical and program management support from NASA. The MOD-5B features an advanced variable-speed generator, new aerodynamic systems and controls, and other extensive technology improvements. The research program for multimegawatt systems concluded with the sale of the MOD-5B to Hawaiian Electric Renewable Systems Inc. in January 1988, although operational data will be provided to DOE for the next five years.

The following laboratories have responsibility for various components of the continuing wind program and to publish reports on their research and development projects (current wind activities at these centers are described in more detail in Chapter 7). These reports, some of which are cited in this guide, contain general and technical information. Contact the National Technical Information Service for more information on available reports.

- Sandia National Laboratories (SNL) provide technical management of the Vertical-Axis Wind Turbine (VAWT) Machine Development Program and supporting research and technology development, including fatigue and materials research.

  Sandia National Laboratories
  Wind Systems Program
  Division 6225
  Albuquerque, NM 87185

  Publications contact: Sandia Document Distribution (505) 844-3850

  Technical information contact: Henry Dodd (505) 844-5253

- Pacific Northwest Laboratory (PNL) provides technical management for atmospheric fluid dynamics research in the areas of microscale turbulence, siting in complex terrain, wind turbine wakes, and array performance.

  Pacific Northwest Laboratory
  Atmospheric Fluid Dynamics Program
  P.O. Box 999
  Richland, WA 99352

- The SERI Wind Research Program provides technical management for the research and testing of horizontal-axis wind systems. The program also participates in cooperative projects and makes its Wind Energy Test Center available for industry-funded tests and evaluations.

Publications contact: Ruth Keefe (509) 376-6083

Technical information contact: Larry Wendell (509) 376-6653

Solar Energy Research Institute
Wind Energy Research Branch
1617 Cole Blvd.
Golden, CO 80401-3393
(303) 231-7199

Publications contact: Linda R. Brown (303) 231-1017

Technical information contact: Robert W. Thresher (303) 231-1262

International Developments

The promise of wind energy in meeting part of the growing world energy demand has motivated many foreign governments, utilities, and businesses to cooperate in the development of commercial wind systems. Both developed and developing countries have expanding programs. Denmark, the Federal Republic of Germany, Italy, the Netherlands , Spain, Sweden, and the United Kingdom have a strong commitment to wind power.

Denmark. As of December 1988, almost 2050 wind turbines were connected to the Danish electricity supply system, resulting in a total capacity of about 190 MW. Danish electric utilities are assisting that country's wind industry with an agreement to install wind turbines corresponding to a total electric capacity of 100 MW by 1990. To date, utility installations are based on windfarms with small- and medium-scale machines totaling about 25 MW.

Danish wind experts expect that large-scale turbines will be installed in greater quantities as more experience is gained with this technology. Danish demonstration projects using wind turbine models also are supported by grants from the European community.

Denmark provides tax incentives to Danish investors for wind projects in other countries using Danish wind turbines. And the Danish international aid agency—called Danida—has provided support for Danish-built wind projects in developing countries such as China and India. Currently, Denmark is the leading nation for wind turbine manufacture and sales.

Federal Republic of Germany. The commercialization of wind energy technology is in its early stages in Germany. Most research and development activity is supported by the Federal Ministry of Research and Technology (BMFT); activities include development of wind turbines from 50 kW to several megawatts in capacity in various configurations, including one-, two-, and three-bladed designs. Other projects include basic research in wind energy technology, detailed measurement of wind characteristics, and technical optimization of wind turbines. The German wind industry is supported by tax credits, favorable loans, and grants from the European Community.

Recently BMFT established a goal to have 100 MW of turbines erected in the next five years. To achieve this goal, the BMFT and coastal states will support up to 50% of the investment cost for individuals or utilities. In addition, a subsidy of 0.08 DM per kWh will be paid for energy production for a period of 10 years.

Ancona, D. A.; Pedersen, B. M.; and Pershagen, B. (October 1986). "The International Energy Agency Wind Energy Program." European Wind Energy Association Conference and Exhibition; 7-9 October 1986; Rome, Italy; Proceedings, Vol. 1. Palz, W. and Sesto, E., eds. Rome, Italy: A. Raguzzi, Bookshop for Scientific Publications; pp. 129-132.

The paper reviews activities of the IEA wind energy program since 1977. Six major technical tasks have been completed, three tasks are under way, and several new ones are being discussed; six documents on Recommended Practices for Wind Turbine Testing and Evaluation have been produced; and 15 topical expert meetings have been arranged. The sharing of research and information has clearly stimulated national wind energy programs and contributed to wind technology development.

Palz, W. and Sesto, E., eds. *European Wind Energy Association Conference and Exhibition; 7-9 October 1986; Rome, Italy.* (October 1986). CONF-861062-13. Rome, Italy: A. Raguzzi, Bookshop for Scientific Publications; 2 Vols. Available NTIS: Order No. DE89770030.

The following countries presented papers on their activities: Denmark, Sweden, the Netherlands, Italy, China, Canada, Egypt, Holland, and the United States. A brief overview of the European Community Demonstration Programme for Wind Energy was also given.

Selzer, H. (1986). *Potential of Wind Energy in the European Community: An Assessment Study.* Solar Energy R&D in the European Community, Series G, Vol. 2. Boston: D. Reidel Publishing Company; 148 pp.

The book provides a technical and macro-economic assessment of European wind energy potential. To develop reliable data, it was necessary to analyze the wind available in the various parts of Europe, study in detail all candidate sites for possible wind turbine installation, and review the technological cost-effectiveness of wind turbines. The availability of utility networks for grid connection of the wind turbines also was included in the analysis. The study concluded that there is a high wind energy potential in both northern and southern Europe, with the most potential for utilization along the coastal zones.

Lovas, J. (October 1986). "Opportunities and Obstacles in the European Community Member States: Legislative and Regulatory Measures Regarding the Development of the Wind Energy Sector." *European Wind Energy Association Conference and Exhibition; 7-9 October 1986; Rome, Italy; Proceedings, Vol. 1.* Palz, W. and Sesto, E., eds. Rome, Italy: A. Raguzzi, Bookshop for Scientific Publications; pp. 61-64.

This paper, based on two EC Commission-sponsored studies undertaken in 1984 and 1986, outlines legislative and regulatory measures adopted by EC member states. National measures relating to physical planning laws, construction requirements, safety precautions, electricity production, and public financial support as they apply to wind turbines are examined. The review of member states' provisions (or lack of them) enabled an assessment of national, or more importantly of Community, action that could best facilitate the further development of the wind energy sector in Europe.

Schmid, J. and Palz, W. (1986). *European Wind Energy Technology: State of the Art of Wind Energy Converters in the European Community.* Solar Energy R&D in the European Community, Series G, Vol. 3. Boston: D. Reidel Publishing Company; 303 pp.

The book is a result of an investigation of more than 150 wind turbines operating in the European Community member countries. Particular attention was paid to the long-term behavior of wind turbines with regard to mean efficiency, failures, and maintenance. Systems with the potential to contribute to the Community's future energy supply (for example, grid-connected turbines or large stand-alone systems), are emphasized. Detailed data sheets for the investigated machines are provided in Appendix I. Appendix II contains lists of wind turbine manufacturers; component manufacturers; and consulting, research, and information resources. These lists are organized by country.

Hohmeyer, O. (1988). *Social Costs of Energy Consumption.* Berlin-Heidelberg, Federal Republic of Germany: Springer-Verlag; 126 pp.

This study systematically examines the environmental (or "social") costs and benefits of electricity generation by wind and solar systems; it also compares them with electricity generation based on fossil or nuclear fuels, drawing on available literature where possible. Effects such as disease caused by air pollution and rising sea levels due to global warming are considered. An attempt is made to quantify monetary impact.

Meteorological Aspects of the Utilization of Wind as an Energy Source. (1981). Technical Note 175. Geneva, Switzerland: World Meteorological Organization; 180 pp.

The technical note includes a copy of the map of worldwide wind energy resource distribution estimates prepared by Pacific Northwest Laboratory. The chapter on "Wind—the Resource" discusses wind resources in various places in the world.

By 1989, installed capacity is expected to reach about 8 MW. This amount is expected to grow as German wind plant installers take advantage of the new federal support program.

In two experimental 1-MW windfarm projects, groups of small wind power plants have been installed with the objective of providing operational data to electric utilities. Also, several large German utilities are planning new large-scale turbine projects with machines rated at 1 to 3 MW and incorporating one, two, or three blades. A 1.2-MW plant is under construction on the North Sea island of Helgoland. Basic research will include areas of interest to industry, including turbine reliability, maintenance, service life, annual electricity production, and installation costs. Germany also has cooperative projects with Canadian industry, Spain, and Sweden.

United Kingdom. The U.K. Department of Energy, the North of Scotland Hydro-Electric Board, and the Central Electric Generating Board support the development of larger machines deployed in windfarms as the most appropriate approach for centralized electric generation. Three manufacturers of large machines—James Howden and Co., Wind Energy Group Ltd., and Vertical Axis Wind Turbine Ltd.—already are marketing wind turbine generators developed from government-supported prototypes with capacities of 150 to 750 kW.

In addition to exploring both horizontal- and vertical-axis technology in a wide range of sizes, the British government supports research and development in materials and materials testing, wind resource assessment, cost forecasting, and offshore wind system feasibility. The goal of these activities is to acquire substantial operating experience with different wind system designs and to accumulate reliable information on all aspects of wind turbine performance. The Central Electricity Generating Board plans to build three demonstration windfarm projects, each with a capacity of 8 MW, as well as the world's first offshore wind turbine (a 750-kW unit) between 1990 and 1992. The North of Scotland Hydro-Electric Board is considering the possibility of installing two demonstration windfarms as well. Commercial development of land-based windfarms might then be expected to proceed.

The Netherlands. In the Netherlands, an early movement toward wind-generated power stagnated as potential users—especially power companies—waited for wind system costs to be reduced. But costs could not be lowered until mass production occurred. To break this stalemate, the Netherlands established an Integral Wind Energy Program in 1986. Program activities are now designed to encourage the installation of 150 MW of wind-energy capacity by 1991 and 1000 MW by 2000. Financial support is provided to both manufacturers and operators of wind turbines; in addition, the Ministry for the Environment now offers an "environmental bonus" so that wind power will be concentrated in areas where production will be greatest, and environmental and social impact will be at a minimum. The Netherlands Energy Development Organization controls the environmental incentive scheme and also will oversee turbine certification as well as the collection of output figures and performance measurements for a number of units.

The Dutch are now installing turbines primarily of about 300 kW. However, because of land limitations, there is a strong market demand for machines of 1 MW or more. A 1-MW unit has been tested in several configurations and an advanced 1.5-MW unit is being developed.

Other European Countries. Most other European countries have expanding wind energy programs. In addition to those countries already mentioned, Spain, Sweden, and Italy are all developing MW sized machines. Italy is also installing two 10-MW experimental wind plants under ENEL (The Italian National Utility). The commission on the European countries is also expanding its research program to include wind and component modeling and measurements as well as turbine development both on and off-shore.

International Energy Agency. The development of wind energy technology in individual nations is supplemented by the activities of the International Energy Agency (IEA). This agency, formed after the 1973-1974 oil crisis, serves as a forum and an information exchange for its member nations.

IEA has implemented two agreements concerning wind energy: a program for WECS research and development and another for the development of large-scale wind systems. WECS R&D agreement activities carried out since 1978 have featured participation by Austria, Belgium, Canada, Denmark, Germany, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, the United Kingdom, and the United States. Cost- and task-shared projects have included wind meteorology, wake effects, offshore WECS, wind/diesel systems, and the development of recommended practices for testing and evaluating wind turbines. Results from these projects are documented in technical reports and papers presented at conferences and published in scientific journals. As of October 1987, about 80 reports and papers had been issued. The IEA WECS program also issues annual reports on member-nation activities.

Nine countries participate in the cooperative agreement for developing large-scale wind systems, including Canada, Denmark, Germany, Italy, the Netherlands, Spain, Sweden, the United Kingdom, and the United States. By 1986, 13 large-scale systems in six countries had been connected to grids. More than 22 MW of additional capacity will be placed on line in these same countries before 1990, bringing the cumulative capacity of large-scale systems to about 42 MW.

IEA holds topical meetings and workshops on large-scale wind system technology. Although experts attend these informational exchanges upon invitation only, the proceedings are published by the Kernforschungsanalagen Juliche and are available to all IEA member nations. Information disseminated in this fashion has contributed to wind technology development throughout the world.

Chapter 2
Wind Technology Research and Design

General Design Studies and Techniques

The objective in WECS design is to develop machines that, given a certain set of site conditions, will provide the desired energy conversion at the lowest possible cost per kilowatt-hour. Research provides more understanding of the principles of wind machine operation. These principles are then used to optimize WECS design. Although topics in this section are concerned with research and design, many of those listed in other sections are closely interrelated (such as performance or wind characteristics).

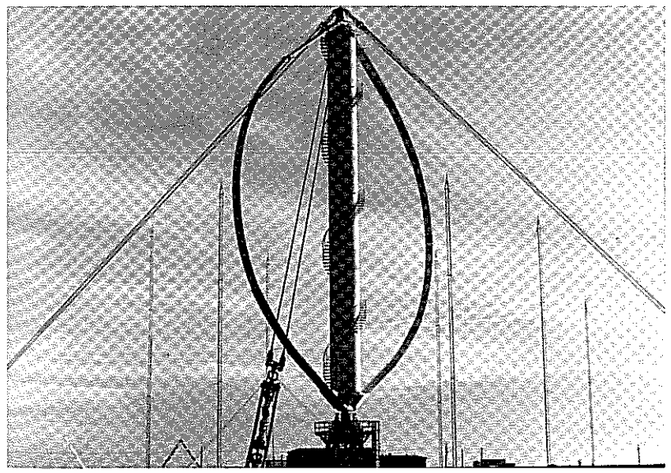
Design Criteria Recommended Practices: Wind Energy Conversion Systems. (1988). AWEA Standard AWEA 3.1-1988. Arlington, VA: American Wind Energy Association; 25 pp.

Describes recommended practices for wind turbine design, including environmental, service, component and system considerations. Also includes a listing of applicable reference publications, codes, standards and papers.

Wind Turbine Systems Dynamics

Several major challenges are involved in advancing the understanding of wind turbine dynamics. First, wind turbines operate under environmental conditions that can be severe, unpredictable, and poorly defined. Moreover, the basic physical processes involved in generating electricity from the wind are characterized by complex, dynamic interactions; accurate modeling of these processes will require major advances in analytical capability. Finally, the response of a wind turbine to its operating environment will depend on its particular design characteristics. Therefore, wind turbine dynamics research must address a wide variety of machine sizes and configurations.

Current research activities in systems dynamics include atmospheric fluid dynamics, aerodynamics, and structural dynamics, all of which will improve our understanding of the basic physical processes created by a



The DOE/SNL 34-m VAWT Test Bed in Bushland, Texas, will allow basic research and testing of advanced concepts for vertical-axis machines.

Stoddard, F. S. (December 1978). *Structural Dynamics, Stability, and Control of High Aspect Ratio Wind Turbines.* RFP-3027/67025/3533/79-9. Amherst, MA: University of Massachusetts; 311 pp.

The publication discusses blade dynamics and vibration of wind turbine generators with high aspect ratio (slender) blades.

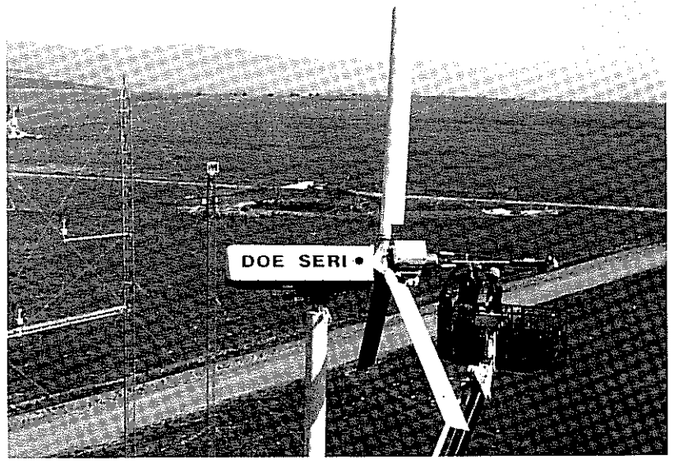
Miller, R. H.; Dugundji, J.; Martinez-Sanchez, M.; Gohard, J.; Chung, S.; and Wendell, J. (September 1978). *Wind Energy Conversion Volume 1: Methods for Design Analysis of Horizontal Axis Wind Turbines.* COO-4131-T1 (Vol. I). Washington, DC: U.S. Department of Energy; 253 pp. Work performed by Massachusetts Institute of Technology, Department of Aeronautics and Astronautics, Aeroelastic and Structures Research Laboratory, Cambridge, MA.

Three design topics are covered: aerodynamics; dynamic characteristics of the blade; and dynamics of rotor, tower, and drive train. Charts allow a designer to select desired blade characteristics to meet particular requirements and operating conditions.

Thresher, Robert W., ed. (1981). *Wind Turbine Dynamics: Second DOE/NASA Wind Turbine Dynamics Workshop; Cleveland, OH; 24-26 February 1981.* SERI/CP-635-1238. Cleveland, OH: NASA Lewis Research Center; 445 pp.

The workshop covered the dynamic behavior of horizontal-axis and vertical-axis wind turbines. Topics included aerodynamics, structural dynamics, electrical system dynamics, control dynamics, and acoustics.

Wright, A. D. (December 1981). *Tower Dynamics Analytical Models: Comparison and Evaluation.* RFP-3340. Golden, CO: Rocky Flats Wind Systems Program; 154 pp.



SERI's "combined experiment" uses a video camera and highly accurate sensors to study complex aerodynamic interactions during blade rotation.

wind turbine's interaction with its environment. To explore the effects of machine size and configuration, field tests are being conducted with a wide variety of machines, including DOE experimental turbines and existing commercial machines in windfarms. Wind tunnel tests and theoretical analyses also are being conducted. The purpose of these research activities is to provide the necessary data for the development and validation of models, which will serve as design tools for industry to develop more cost-effective wind machines.

The aerodynamics research area deals with the motion of air and other gaseous fluids as well as with the forces acting on bodies moving through such fluids. A knowledge of aerodynamics is important in the design of WECS rotor blades for optimum performance and for the determination of aerodynamic loads for structural design.

Until recently, much of the information on aerodynamics was developed by the aeronautics industry. The reports published by the National Aeronautics and Space Administration (NASA) are excellent sources of airfoil data; the American Institute of Aeronautics and Astronautics (AIAA) is another important source of information. The most current data can be obtained from reports by SERI and SNL, which have continuing programs in airfoil research.

Several tower dynamic analysis methods are evaluated by comparing computed results to actual tower test results. The four methods discussed are the Rayleigh, Rayleigh-Ritz, finite element, and matrix iteration. Recommendations are made as to which methods give adequate results for various towers. A listing and description of the computer codes are given in the appendices.

Christie, R. J. (March 1982). *Vibration Analysis of Three Guyed Tower Designs for Intermediate Size Wind Turbines.* NASA CR-165589. Cleveland, OH: NASA Lewis Research Center; 109 pp.

A method for analyzing the vibrations of horizontal-axis wind turbines was used to analyze three guyed tower designs for intermediate-size wind turbines. The four lowest natural frequencies of vibration of the three tower concepts were estimated, and a parametric study was performed on each tower to determine the effect of varying tower properties.

Stoddard, F. S. and Porter, B. K. (January 1986). *Wind Turbine Aerodynamics Research Needs Assessment.* DOE/ER/30075-H1. Washington, DC: U.S. Department of Energy; 126 pp. Work performed by Washington Consulting Group, Washington, D.C. Available NTIS: Order No. DE86009189.

This report discusses the need for basic research in the federal program, the need for a new field of aerodynamic study, other important engineering applications studies, and aspects of the recommended federal R&D program.

Xudong, C.; Hansen, A.; and Siedschlag, N. (February 1988). *Yaw Dynamics of Horizontal Axis Wind Turbines: First Annual Report.* SERI/STR-217-3309. Golden, CO: Solar Energy Research Institute; 105 pp. Work performed by the Department of Mechanical Engineering, University of Utah, Salt Lake City, UT. Available NTIS: Order No. DE88001137.

The report describes a theoretical analysis being developed by the University of Utah to predict yaw behavior. Researchers developed two simple models: one that describes yaw motion with a single degree of freedom for a completely rigid rotor; and one that analyzes blade flap motion under prescribed yaw conditions.

Wilson, R. E. and Chaiyapinunt, Somsak. (September 1983). *Analysis of Wind Turbines in Yaw.* RFP-3678. Golden, CO: Rocky Flats Wind Energy Research Center; 168 pp. Work performed by Oregon State University, Corvallis, OR. Available NTIS: Order No. DE84013620.

The yaw problems of a three-bladed, downwind, horizontal-axis wind turbine are examined in this report. A computer code was developed to obtain the numerical values of coefficients of the equations of motion, thus allowing the cause of yaw instability to be studied.

Kocurek, D. (June 1987). *Lifting Surface Performance Analysis for Horizontal Axis Wind Turbines.* SERI/STR-217-3163. Golden, CO: Solar Energy Research Institute; 319 pp. Work performed by Computational Methodology Associates, Hurst, TX. Available NTIS: Order No. DE87001176.

This 600-kW Westinghouse turbine was used in a cooperative dynamic response test between Westinghouse Electric Company and SERI. The design was recently updated to 660-kW and is the largest intermediate-scale model produced by a U.S. company.

This report describes how numerical lifting-surface theory is applied to the calculation of a horizontal-axis wind turbine's aerodynamic characteristics and performance. The report also describes how such an application is implemented as a computer program.

Wilson, R. E. and Walker, S. N. (1985). "State-of-the-Art in Wind Turbine Aerodynamics." *Windpower '85; San Francisco, California, August 27, 1985*; Alexandria, VA: American Wind Energy Association; pp. 30-38. Work performed by Oregon State University, Corvallis, OR.

The current state-of-the-art in wind turbine aerodynamics is reviewed for HAWTs and VAWTs, starting with data bases and extending through the methods and approaches used to predict loads and performance. The review concludes with a discussion of the shortcomings of current methods and areas requiring further development.

deVries, O. (July 1979). *Fluid Dynamic Aspects of Wind Energy Conversion.* AGARD-AG-243. London, England: Technical Editing and Reproduction, Ltd. Also available from NTIS.

This report discusses aerodynamic theories of both HAWTs and VAWTs. It also examines several wind concentrator concepts and inhomogeneous flow and turbulence effects, array turbine control and wake interference effects.

Miley, S. J. (February 1982). *A Catalog of Low Reynolds Number Airfoil Data for Wind Turbine Applications.* RFP-3387. Golden, CO: Rocky Flats Wind Energy Research Center; 615 pp. Work performed by Texas A&M University, College Station, TX.

Airfoil data at low Reynolds numbers, (applicable to small WECS) were screened and compiled into this catalog. Each entry includes airfoil coordinates, lift, drag, and pitching moment characteristics in both graphic and tabular form.

Rohrbach, C.; Wainauski, H.; and Worabel, R. (December 1977). *Experimental and Analytical Research on the Aerodynamics of Wind Driven Turbines.* COO-2615-T2. Windsor Locks, CT: Hamilton Standard; 250 pp.

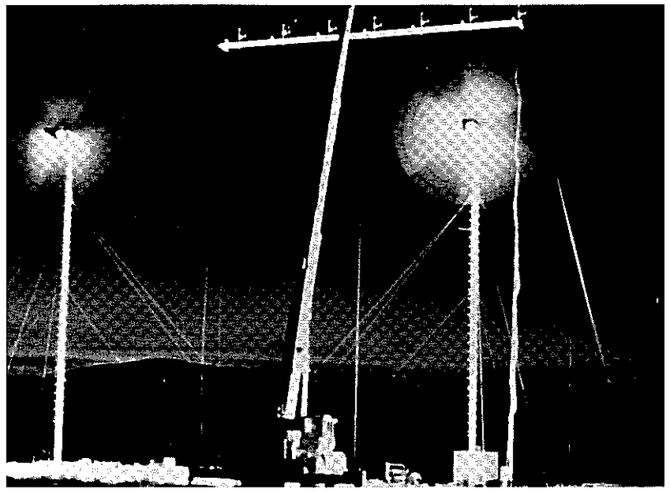
This research is aimed at providing a reliable, comprehensive data bank on a series of wind turbine models covering a broad range of the aerodynamic and geometric variables needed for sound aerodynamic design.

Sheldahl, R. E. and Klimas, P. C. (March 1981). *Aerodynamic Characteristics of Seven Symmetrical Airfoil Sections Through 180-Degree Angle of Attack for Use in Aerodynamic Analysis of Vertical Axis Wind Turbines.* SAND 80-2114. Albuquerque, NM: Sandia National Laboratories; 120 pp.

The report describes a series of wind tunnel tests conducted at moderate Reynolds numbers in which angles-of-attack force and moment data were obtained for four symmetrical blade-candidate airfoil sections.

Wake Considerations

For wind energy to have a significant effect on U.S. electric power production, wind turbines have to be grouped in arrays or "windfarms." Since wind turbines create wakes of low-energy air, wake interference is a significant factor in the design of these arrays. Close spacing can put downwind machines in the wakes of upwind units, causing possible detrimental effects on power output and structural integrity. Considerable attention has been given to wake interference problems, as shown in these recent studies.



In this cooperative research project, PNL researchers used a downwind, horizontal boom to measure wake deficits.

Barnard, J. C. and Wegley, H. L. (January 1987). *A Preliminary Evaluation of the Performance of Wind Tunnel and Numerical Modeling Simulations of the Wind.* PNL-6105. Richland, WA: Pacific Northwest Laboratory; 30 pp. Available NTIS: Order No. DE87004634.

This report analyzes physical and numerical model simulations of wind flow over complex terrain. The specific area to which these models were applied was a windfarm in Altamont Pass, California.

Barnard, J. C. (December 1985). *Calculation of Wake Power Losses in a Two-Level Array: A Simple Case Study.* PNL-5721. Richland, WA: Pacific Northwest Laboratory; 20 pp. Available NTIS: Order No. DE86005671.

This report estimates the wake interference that could be expected in a two-level array of wind turbines. Interference is estimated for a typical situation that may be encountered by a windfarm developer.

Wegley, H. L. and Barnard, J. C. (November 1986). *Using the NOABL Flow Model and Mathematical Optimization as a Micrositing Tool.* PNL-6070. Richland, WA: Pacific Northwest Laboratory; 138 pp. Available NTIS: Order No. 87004224.

This report describes the use of an improved mass-consistent model intended for diagnosing wind fields in complex terrain. Report topics include model software structure, assembling an input file, processing model output, and certain cautions about the model's operation. The use of the model is illustrated by a test case.

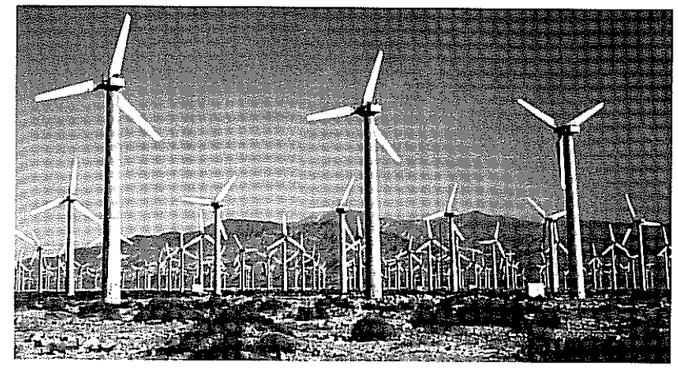
Barnard, J. C.; Wegley, H. L.; and Hiester, T. R. (September 1985). *Improving the Performance of Mass-Consistent Numerical Models Using Optimization Techniques.* PNL-5566. Richland, WA: Pacific Northwest Laboratory; 33 pp. Available NTIS: Order No. DE86001224. An article based on this report appeared in *J. Clim. Appl. Met.*, 26(6): 675-686.

This report describes a technique of using a mass-consistent model to derive wind speeds over a microscale region of complex terrain.

Elliott, D. L.; Buck, J. W.; and Barnard, J. C. (April 1988). *An Examination of Wake Effects and Power Production for a Group of Large Wind Turbines.* PNL-6528. Richland, WA: Pacific Northwest Laboratory; 58 pp. Available NTIS: Order No. DE88009906.

Data from a group of three MOD-2 wind turbines and two meteorological towers at Goodnoe Hills were analyzed to evaluate turbine power output and wake effects and the atmospheric factors influencing them.

Eberle, W. R. (September 1981). *Wind Flow Characteristics in the Wakes of Large Wind Turbines: Volume 1 — Analytical Model Development.* DOE/NASA/0029-1; NASA-CR-165380. Cleveland, OH: NASA Lewis Research Center; 211 pp. Prepared by Lockheed Missiles and Space Company, Huntsville, AL.



Turbines in the center of this large San Gorgonio windfarm (top) often experience structural problems caused by turbulence. It's an ideal location for performance tests of SERI's unique fiberglass blades, which are mounted on a Micon 65 turbine (bottom) owned and operated by SeaWest Energy Group of San Diego, Calif.

Wind Systems Integration

Wind is a variable resource; consequently, wind systems produce fluctuating amounts of power. Wind turbines are normally connected to a utility grid that supplies power backup when the wind does not blow.

The references cited here provide more information on the integration of wind systems with utility grids. This subject is an area of supporting research in the Federal Wind Energy Program, and is documented in reports by SERI.

This report presents the development of an analytical wake model for calculating wind speed profiles at selected distances downwind of the turbine.

Lissaman, P. B. S.; Gyatt, G. W.; and Zalay, A. D. (June 1982). *Numeric Modeling Sensitivity Analysis of the Performance of Wind Turbine Arrays.* PNL-4183. Richland, WA: Pacific Northwest Laboratory; 97 pp.

This report evaluates the Lissaman-Bate numerical model for predicting the performance of wind turbine arrays. A detailed analysis of the Goodnoe Hills wind turbine cluster has been made to show how power output can vary with ambient turbulence, wind speed, and wind direction.

Doran, J. C. and Packard, K. R. (October 1982). *Comparison of Model and Observations of the Wake of a MOD-0A Wind Turbine.* PNL-4433. Richland, WA: Pacific Northwest Laboratory; 43 pp.

Using a series of wind velocity measurements upwind and downwind of the MOD-0A wind turbine near Clayton, New Mexico, the authors determined some characteristics of wakes within approximately two blade diameters of the machine. The magnitudes and shapes of the wind velocity profiles downwind of the turbine were compared with results obtained from the Lissaman-Bate numerical model.

Buck, J. W. and Renne, D. S. (August 1985). *Observations of Wake Characteristics at the Goodnoe Hills MOD-2 Array.* PNL-5565. Richland, WA: Pacific Northwest Laboratory; 77 pp. Available NTIS: Order No. DE85018282.

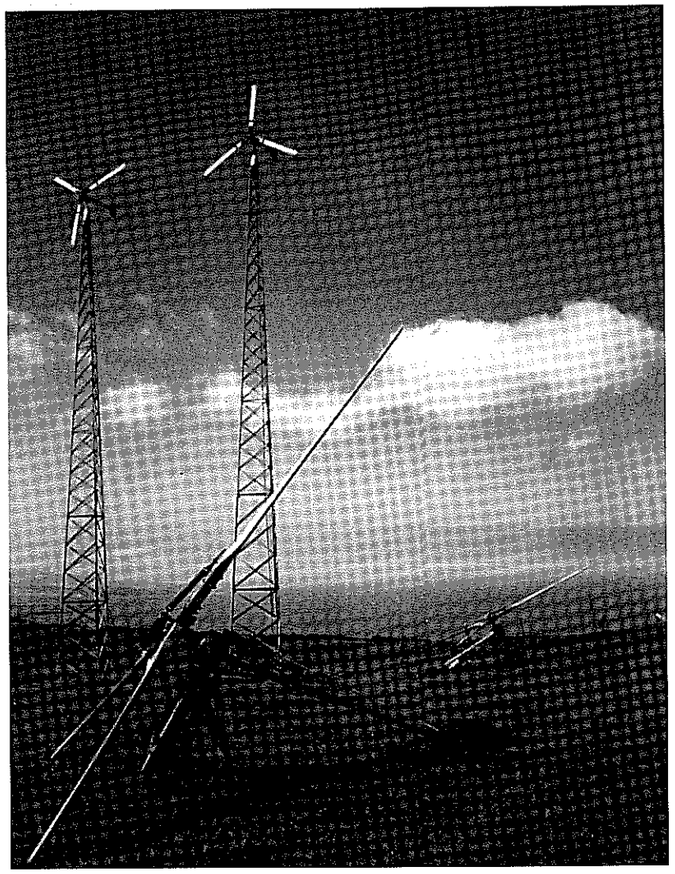
This report describes the analysis of data measured at the turbines and towers from August 29 to November 12, 1982. Background flow characteristics were also examined to determine if flow variations across the site could mask wake measurements.

Lissaman, P. B. S.; Zambrano, T. G.; and Gyatt, G. W. (March 1983). *Wake Structure Measurements at the MOD-2 Cluster Test Facility at Goodnoe Hills.* PNL-4572. Richland, WA: Pacific Northwest Laboratory; 49 pp.

This report presents the results of field measurements at hub height (200 ft) between July 12 and August 1, 1982. The study was conducted to determine the rate of decay of wake velocity deficit with downwind distance under various meteorological conditions. Recommendations for further research are included.

Neill, D. R. and Nakamura, A. (1987). "Progress in Wind Energy Utility Interface R&D." *Sixth ASME Wind Energy Symposium: The Tenth Annual Energy-Sources Technology Conference and Exhibition; Dallas, Texas; February 15-18, 1987.* SED-Vol. 3. Thresher, R. W., ed. New York: American Society of Mechanical Engineers; pp. 141-145. Work performed by Hawaii Natural Energy Institute, University of Hawaii, Honolulu, and Hawaii Electric Light Company, Hilo, Hawaii.

This paper discusses cooperative research between SERI, the Hawaii Natural Energy Institute, and the Hawaii Electric Light Company. The program identified potential problem areas for wind system integration.



The Kahua Ranch windfarm on the Big Island of Hawaii produced about 5 million kWh of electricity in 1988. The ranch also hosts SERI experiments in array power quality and battery storage.

Hinricksen, E. N. and Nolan, P. J. (November 1981). *Dynamics of Single- and Multi-Unit Wind Energy Conversion Plants Supplying Electric Utility Systems.* DOE/ET/20466-78/1. Washington, DC: U.S. Department of Energy; 139 pp. Work performed by Power Technologies, Inc., Schenectady, NY.

This study analyzes the dynamic performance of single and multiple wind turbine generators connected to electric utility power systems. Results are intended for wind turbine designers and power system planners.

Wind-Hydroelectric Energy Project—Wyoming. (August 1982). Washington, DC: Department of the Interior, Bureau of Reclamation; 181 pp.

The report describes the environmental, economic, and social impacts of incorporating large wind turbines with the federal hydrosystem. This configuration may allow the reservoirs to serve as storage, while the existing installed hydrogeneration provides the firming capacity.

Applied Research on Energy Storage and Conversion for Photovoltaic and Wind Energy Systems; Final Report. (January 1978). HCP/T-2221-01/1. Philadelphia, PA: General Electric Company; 3 Vols.

The study assesses selected storage concepts and evaluates the effects of selected parameters on the desirability of energy storage with respect to WECS.

IECEC '87: 22nd Intersociety Energy Conversion Engineering Conference; Philadelphia, PA: 10-14 August 1987. (1987). New York: American Institute of Aeronautics and Astronautics; 4 Vols.

Typically, IECEC conferences have many presentations dealing with the storage of energy. Topics include batteries, compressed air, thermal, mechanical, and flywheel energy storage techniques.

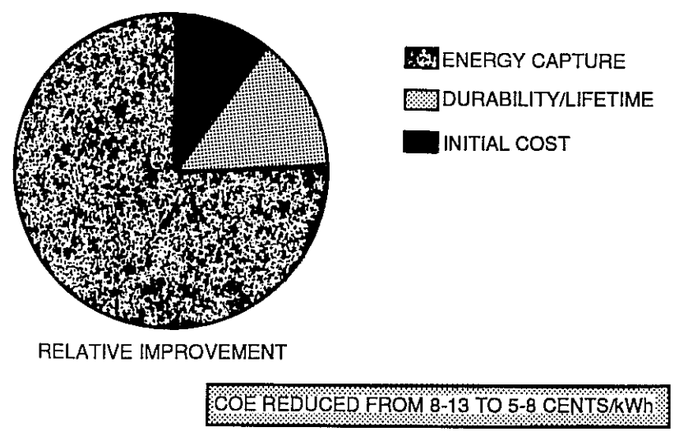
Chapter 3
Wind Energy System Development

Horizontal-Axis Systems

Small-Scale. Small wind turbines have power ratings of less than 100 kW (most are typically less than 25 kW). An average U.S. home located in an area with average wind speeds greater than 12 mph could meet most of its electricity needs with a 3- to 5-kW wind turbine. Although most small machines are designed to produce electricity, they also are used to produce mechanical shaft power (especially water pumping) and thermal energy.

The typical small wind machine has a horizontal-axis configuration with two to four thin, propeller-type blades oriented upwind of the tower by means of a tail. Manufacturers often use strong, economical, lightweight blades constructed of metal, wood, or fiberglass. Downwind rotors are also common, with the nacelle and blades acting as a vane.

Until the mid-to-late 1970s, most small wind machines were designed for remote locations, producing direct current that could be stored in batteries. During the 1970s, a new kind of machine was developed for use in conjunction with utility-derived power. Rather than generating direct current, these new wind turbines use either an induction generator or a synchronous inverter to produce alternating current—the form of electricity found in most utility lines. As a result, when there is ample wind but little electricity is needed, excess power can be fed into the utility lines. When the machine is not producing enough power for the user's needs, the user can draw power from the utility lines just like any other customer.



Reduction of cost of energy (COE) for matured technology will be achieved from improvements in three basic areas.

Coleman, C. and Mayer, D. J. (May 1982). *North Wind 4 Kilowatt Wind System Development. Phase I Design and Analysis; Volume II Technical Report.* RFP-3424-2. Golden, CO: Rocky Flats Wind Energy Research Center; 157 pp. Work performed by North Wind Power Company, Inc., Moretown, VT.

This report presents the results of Phase I of a program to design and fabricate a cost-effective wind turbine of 3-6 kW.

Coleman, C. C.; Curran, H. D.; Hunnicut, W. E.; Marr, M. J.; Meyer, H.; Pautzke, A. W.; and Porter, D. G. (August 1982). *Windworks 8 kW Wind System Prototype Development Report.* RFP-3587. Golden, CO: Rocky Flats Wind Energy Research Center; 143 pp. Work performed by Windworks, Inc., Mukwonago, WI.

This report summarizes Phase I (design and analysis) and Phase II (fabrication and test) activities of a DOE contract to produce a wind system capable of generating 8 kW in winds of 9 m/s. The prototype design was a 10-m, three-bladed, downwind, flapping rotor connected to a three-phase, direct-drive alternator.

Mayer, D. J. and Norton, J. H., Jr. (July 1981). *North Wind Power Company 2-Kilowatt High-Reliability Wind System; Phase I —Design and Analysis: Technical Report.* RFP-3310/2. Golden, CO: Rockwell International. 168 pp. Work performed by North Wind Power Company, Inc., Warren, VT. Available NTIS: Order No. DE82015124.

This report presents the results of a Phase I program to design a reliable 2-kW wind turbine for use in remote locations and harsh environments.

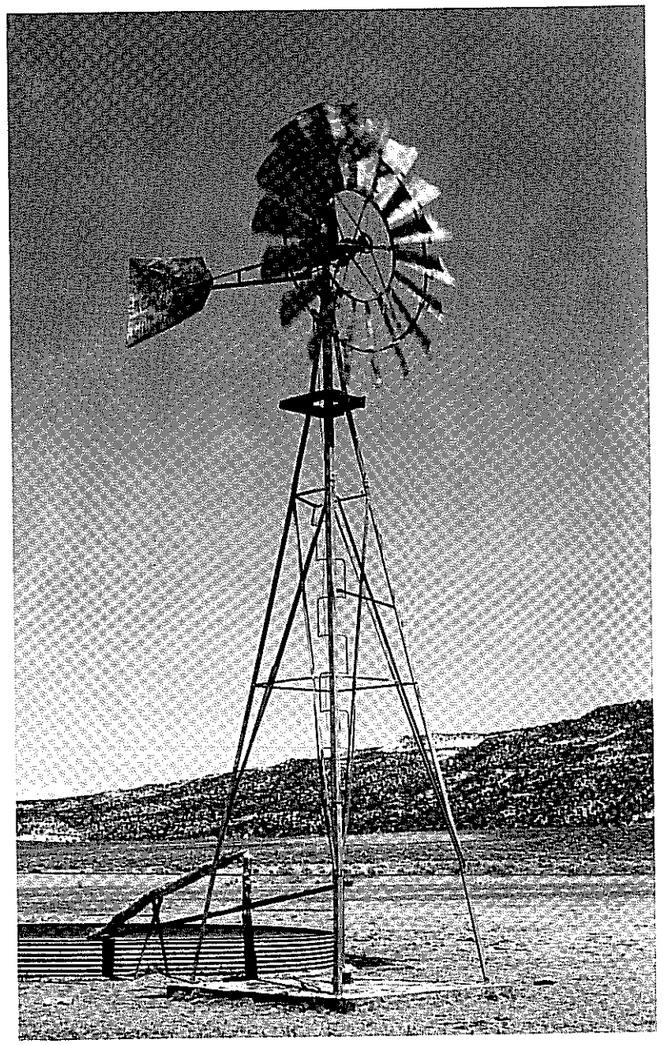
Mayer, Donald J. and Norton, John H., Jr. (June 1982). *North Wind 2 kW High-Reliability Wind System, Phase II: Fabrication and Test.* RFP-3426. Golden, CO: Wind Systems Program, Rockwell International Corporation; 43 pp. Work performed by North Wind Power Company, Inc., Warren, VT. Available from NTIS: Order No. DE83007196.

This report presents the results of a Phase II program to design, fabricate, and test a 2-kW wind system capable of unattended operation at remote sites.

Zickefoose, C. R. (December 1982). *Enertech 15 kW Wind System Development; Phase II Fabrication and Test.* RFP-3515. Golden, CO: Rocky Flats Wind Energy Research Center; 58 pp. Work performed by Enertech Corporation, Norwich, VT. Available NTIS: Order No. DE83017773.

Reducing costs and improving reliability are the main goals in current development of small wind turbines. Some of the improvements expected to help meet these goals include

- Development of components engineered specifically for wind turbine use
- More reliable transmissions and generators
- Increased rotor efficiency
- Lightweight, inexpensive, yet durable blades
- Flexible, lightweight towers designed specifically for wind turbines
- Large-scale production and assembly techniques.



Windmills pump water for livestock and crops throughout arid regions of the American West.

This Phase II report presents a description of hardware fabrication for the Enertech 15-kW prototype wind system.

Proceedings: Small Wind Turbine Systems 1981; Boulder, CO; 12-14 May 1981. (1981). SERI/CP-635-1212. Golden, CO: Solar Energy Research Institute; 355 pp.

Sponsored by the DOE Rocky Flats Wind Energy Research Center and the U.S. Department of Agriculture's Agricultural Wind Energy Research Program, the workshop presented overviews of federal programs as well as papers on the latest research in small wind energy conversion systems.

Bollmeier, W. S.; Butterfield, C. P.; Cingo, R. P.; Dodge, D. M.; Hansen, A. C.; Shepherd, D. C.; and Tangler, J. L. (February 1980). *Small Wind Systems Technology Assessment: State of the Art and Near Term Goals.* RFP-3136/3533/80/18. Golden, CO: Rockwell International; 85 pp.

Commercially available small wind energy conversion systems (SWECS), DOE-funded prototype SWECS, and possible second-generation advanced concepts are assessed from the standpoint of several key economic figures of merit, reliability, performance, and installation and maintenance costs.

Large-Scale. A large wind machine is one with a rated capacity of 100 kW or more. Much of WECS development has focused on machines capable of generating at least 1 MW of electric power. Currently, almost all large wind turbines are horizontal-axis designs. In terms of basic appearance and function, large and small turbines are similar. The blade diameter of very large machines exceeds the wingspan of a jumbo jet, and the latest computer technology is needed to control the angle of the blades and rotational speed. Made of steel, laminated wood, fiberglass, or a combination of these materials, the blades must withstand a variety of stresses and loads, including cyclical fatigue loads and random wind loads associated with turbulence. In addition to blade material, some of the technological issues currently under discussion include the prediction and reduction of dynamic and fatigue loads, the shape of the airfoil, how many blades a machine should have, the design of the transmission system, and whether towers should be rigid or flexible.

National research programs in Canada, Denmark, Italy, the Netherlands, Spain, Sweden, the United Kingdom, the U.S.S.R., and West Germany are working on machines that produce power ranging from 200 kW to several megawatts. In the United States, under DOE-sponsored programs, the NASA Lewis Research Center in Cleveland, Ohio, was the lead center for large wind turbine development. NASA work in this area was completed following the successful development of a series of large wind turbines.

Since 1974, NASA worked on a series of more advanced and progressively larger horizontal-axis turbines. The 100-kW MOD-0 research turbine was built in 1974-75. Four machines of the second design, the 200-kW MOD-0A, were placed at utility sites around the country between 1977 and 1980. The MOD-1 was the first megawatt-scale machine in the series; rated at 2 MW, it commenced operation in 1979. The 2.5-MW MOD-2 was the next machine in the series; three of these turbines began operating in the Goodnoe Hills area near Goldendale, Washington, in 1981. Testing has been successfully completed and these turbines have been decommissoned.

The last machine developed in this series was the MOD-5B, a 3.2-MW horizontal-axis turbine with a rotor diameter of 97.5 m. Now operating on the island of Oahu, Hawaii, the MOD-5B incorporates advanced features, including a variable-speed generating system and new aerodynamic systems and controls. Initial test phases, conducted with Hawaiian Electric Industries, were successfully completed in 1987; the machine performed better than expected, exceeding all design requirements. The MOD-5B was sold to Hawaiian Electric Renewable Systems, Inc., and began utility operation in January 1988.

Thresher, Robert W., ed. (1982). *Large Horizontal-Axis Wind Turbines; Cleveland, OH; 28-30 July 1981.* NASA CP-2230. Cleveland, OH: NASA Lewis Research Center; 838 pp.

Participants in this workshop discussed and documented progress in the development of propeller-type wind turbines designed to drive electric utility generators. Forty-one technical papers were contributed by manufacturers, government laboratories, electric utilities, and private research organizations. Papers covered current and advanced large wind turbine systems, rotor blade design and manufacture, electric utility activities, research and supporting technology, meteorological characteristics for design and operation, and wind resource assessments and siting.

Schefter, J. L. (1982). *Capturing Energy from the Wind.* NASA SP-455. Washington, DC: National Aeronautics and Space Administration; 84 pp.

This softcover booklet provides an informative, easy-to-read overview of today's wind energy research.

Anderson, T. S.; Bodenschatz, C. A.; Eggers, A. G.; Hughes, P. S.; Lampe, R. F.; Lipner, M. H.; and Schornhorst, J. R. (August 1980). *MOD-0A 200 kW Wind Turbine Generator Design and Analysis Report.* DOE/NASA/0163-2. Cleveland, OH: National Aeronautics and Space Administration; 393 pp. Work performed by Westinghouse Electric Corporation, Advanced Energy Systems Division, Pittsburgh, PA. Available NTIS: Order No. DE81027625.

This report documents the design, analysis, testing, installation, and initial operating performance of the 200-kW MOD-0A wind turbine. Topics include NASA project requirements and approach, system description, system design requirements, design and analysis, system tests and installation, safety considerations, failure modes and effects analysis, data acquisition, and initial operating performance.

Wilreker, V. F.; Stiller, P. H.; Scott, G. W.; Kruse, V. J.; and Smith, R. F. (February 1984). *Wind Turbine Generator Interaction with Conventional Diesel Generators on Block Island, Rhode Island. Vol. I. Executive Summary.* DOE/NASA/0354-1; 47 pp. Available NTIS: Order No. DE84015874. *Vol. II. Data Analysis.* DOE/NASA/0354-2; 138 pp. Available NTIS: Order No. DE84016961. Cleveland, OH: NASA Lewis Research Center.

To assess MOD-0A performance when connected to an isolated diesel utility, a comprehensive data measurement program was conducted on the Block Island Power Company's installation in Rhode Island. This report presents the results, focusing on the areas of fuel displacement (savings), dynamic interaction between the diesel utility and the wind turbine, and effects of three modes of wind turbine reactive power control. Even under severe, winter-time operating conditions, fuel savings for the utility were significant.

Collins, J. L.; Shaltens, R. K.; Poor, R. H.; and Barton, R. S. (April 1982). *Experience and Assessment of the DOE-NASA MOD-1 2000-Kilowatt Wind Turbine Generator at Boone, North Carolina.* DOE/NASA/20366-2. Cleveland, OH: NASA Lewis Research Center; 53 pp.

This report on the MOD-1 wind turbine provides information on configuration, performance, and utility interaction, as well as environmental impact and public reaction.

MOD-2 Wind Turbine System Development; Final Report. (September 1982). DOE/NASA-0002-821/1 and 2. Cleveland, OH: NASA Lewis Research Center; 2 Vols. Work performed by Boeing Engineering and Construction, Seattle, WA.

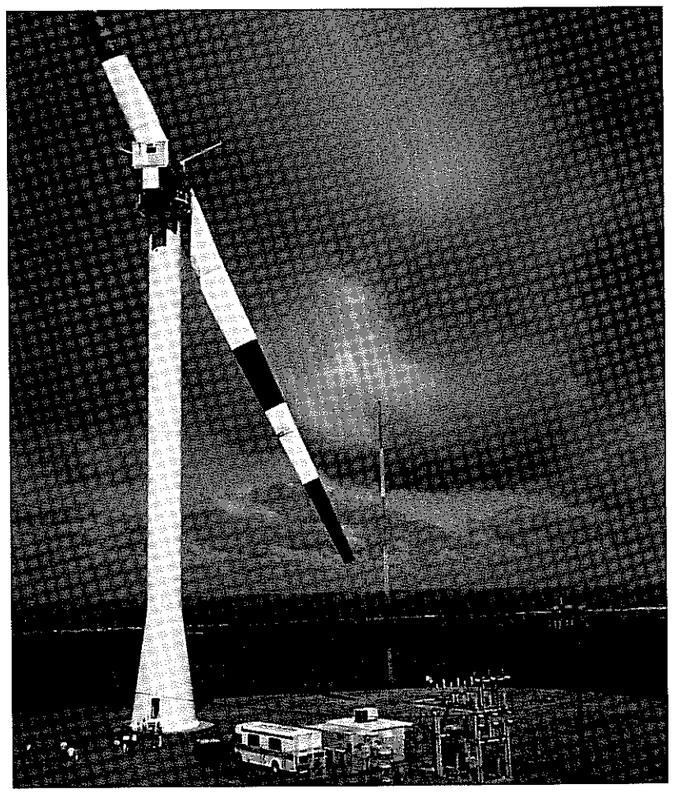
These reports document the development of the MOD-2 wind turbine from concept and preliminary design phases through acceptance testing and initial operational evaluation. The MOD-2 design was optimized for commercial production rates which, in multi-unit installations, could be integrated into a utility power grid to achieve energy costs of less than $0.04/kWh (1977 dollars). Information is provided on project background, system description, testing, initial operation, and conclusions and recommendations.

MOD-5A Wind Turbine Generator Program Design Report. (August 1984). Vol. I: Executive Summary. DOE/NASA/0153/1; 63 pp. *Vol. II: Conceptual and Preliminary Design, Books 1 and 2.* DOE/NASA/0153/2; 661 pp. *Vol. III: Final Design and System Description, Books 1 and 2.* DOE/NASA/0153/3; 1145 pp. *Vol. IV: Drawings and Specification Books 1-5.* DOE/NASA/0153-4; 2754 pp. Cleveland, OH: NASA Lewis Research Center. Work performed by the Advanced Energy Programs Department, General Electric Company, Philadelphia, PA.

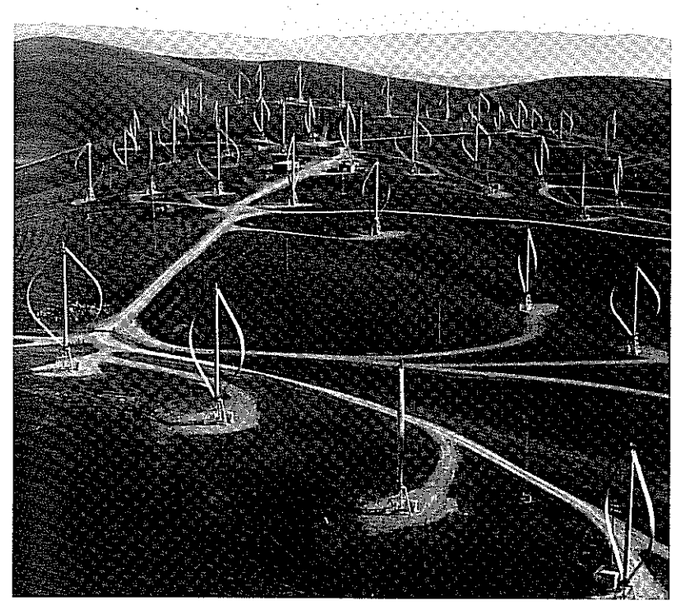
This comprehensive technical report details the design, development, and analysis of the 7.3-MW MOD-5A wind turbine from July 1980 to June 1984. Volume I summarizes all phases of the MOD-5A program, with information on performance and energy cost as well as descriptions of all major subsystems. Volume II discusses the conceptual and preliminary design phases. Volume III describes the final design of the MOD-5A, and Volume IV presents drawings and specifications for the final design.

MOD-5B Wind Turbine System Final Report. (March 1988). Vol. I: Executive Summary. DOE/NASA 0200-3. *Vol. II: Detailed Report.* DOE/NASA 0200-4. *Vol. III: Acceptance Testing.* DOE/NASA 0200-5. Cleveland, OH: NASA Lewis Research Center. Work performed by Boeing Aerospace Company, Seattle, WA.

This comprehensive technical report details the design, development, and acceptance testing of the 3.2-MW MOD-5B wind turbine now producing power for Hawaiian Electric Renewable Systems on Oahu, Hawaii.



The 3.2-MW MOD-5B wind turbine on Oahu, Hawaii.



FloWind's vertical-axis turbines, shown here at Altamont Pass, were developed with the aid of SNL research.

Vertical-Axis Systems

As with HAWTs, vertical-axis wind turbines (VAWTs) are propelled by either drag forces or aerodynamic lift forces. Drag-type VAWTs use plates or cups as the drag device. The most common configuration is the Savonius (S-shaped) rotor, which provides some lift force but is predominantly a drag device. These machines are useful for applications requiring relatively high starting torque, such as water pumping, but they have relatively low power output in proportion to rotor size, weight, and cost.

The Darrieus rotor, invented in the 1920s by G. J. M. Darrieus of France, is a lift device characterized by vertical blades that rotate into and out of the wind. Various configurations have been conceived, including those with straight or curved vertical blades. The most common Darrieus configuration has two or three curved blades with airfoil cross sections, which are attached to a central tower at the upper and lower ends. Considered to be the strongest potential competitor to the more widely commercialized HAWT designs, this VAWT configuration has been under extensive development since the early 1970s by DOE through Sandia National Laboratories in the United States and the National Research Council of Canada.

The Darrieus VAWT offers several potential advantages with respect to HAWTs. VAWTs need not be turned into or out of the wind as the wind direction changes, thus eliminating the need for a yawing nacelle with its associated yaw mechanism or vane. This also eliminates the need for a mechanism (such as slip-rings) that transfers power from the rotating nacelle to utility transmission lines. In addition, the VAWT offers easy service access because the drive-train components and controls are close to the ground at the base of the machine.

Design and Fabrication of a Low Cost Darrieus Vertical Axis Wind Turbine System, Phase II; (March 1983). Volume 1. Executive Summary. SAND82-7113/1; 51 pp. *Volume 2. Final Technical Report.* SAND82-7113/2; 235 pp. *Volume 3. Design, Fabrication and Site Drawing.* SAND82-7113/3; 121 pp. Albuquerque, NM: Sandia National Laboratories.

Johnston, S. F., ed. (August 1980). *Proceedings of the Vertical Axis Wind Turbines (VAWT) Design Technology Seminar for Industry; Albuquerque, NM; 1-3 April 1980.* SAND80-0984. Albuquerque, NM: Sandia National Laboratories; 339 pp.

The VAWT Design Technology Seminar for Industry allowed the exchange of information on current and future VAWT technology. Papers were presented on design characteristics of VAWT systems, as well as structural design, aerodynamic performance, engineering and economics, and measurement and instrumentation.

Ashwill, T. D. and Leonard, T. M. (September 1986). *Developments in Blade Shape Design for a Darrieus Vertical Axis Wind Turbine.* SAND86-1263. Albuquerque, NM: Sandia National Laboratories; 21 pp.

Describes the development of a computer code that allows the user to design the optimum blade shape for a Darrieus-type VAWT when large gravity effects and blade joints are present. Use of this code is shown to reduce the mean flatwise blade stresses on a large VAWT by a factor of two, resulting in an increase of blade fatigue life by a factor of two to four.

Darrieus blades are supported at both ends, alleviating structural problems associated with the cantilevered blades of some HAWTs. And in contrast to most HAWT blades, VAWT blades contain no twist.

VAWTs do require a guyed tower, and significant vertical preloading is necessary to achieve tower stability. As a result, the cost of placing VAWTs on higher platforms to take advantage of higher wind regimes is apt to be quite high. VAWTs do not have a self-starting capability and must be motored up to operating speed. In addition, they have low solidity and relatively low power output.

The Darrieus VAWT has undergone limited commercial development. About 550 commercial machines rated between 150 kW and 300 kW are now operating in the California windfarms of Tehachapi, Altamont Pass, and San Gorgonio; this compares to more than 14,000 HAWTs now producing power for utilities in the same areas.

Under a DOE program, Sandia National Laboratories recently built a 500-kW, variable-speed VAWT test bed on the Texas plains near Amarillo. This research-oriented machine will be used to validate current analytical codes and spur the development of new capabilities in aerodynamics, structural mechanics, and control systems.

Touryan, K. J.; Strickland, J. H.; and Berg, D. E. (November-December 1987). "Electric Power from Vertical-Axis Wind Turbines." *Journal of Propulsion and Power.* Vol. 3 (No. 6); pp. 481-493.

This survey article critically reviews the status of the Darrieus VAWT, with emphasis on aerodynamic, structural, and systems characteristics. In addition, the article briefly reviews some critical issues involved in making proper estimates for wind resources and their impact on predicting power production from VAWTs, with emphasis on micrositing and array-loss problems. An extensive bibliography is included.

Klimas, P. C. (November 1984). *Tailored Airfoils for Vertical Axis Wind Turbines.* SAND84-1062. Albuquerque, NM: Sandia National Laboratories; 12 pp.

The report describes the evolution of a family of airfoil sections designed to be used as VAWT blade elements. The computer simulations, wind tunnel testing, and field testing involved in this evolution reveal that significant reductions in system energy costs and increases in fatigue lifetime may be expected for VAWT systems using these blade elements.

Nellums, R. O. (February 1985). *Field Test Report of the Department of Energy's 100-kW Vertical Axis Wind Turbine.* SAND84-0941. Albuquerque, NM: Sandia National Laboratories; 60 pp.

Summarizes the field test results of three second-generation, Darrieus-type VAWTs built by DOE and installed in 1980-81. These turbines were heavily instrumented and had accumulated more than 9000 hours of operation at the time the report was written. Aerodynamic, structural, drive-train, and economic data are presented. The report closes with a review of potential design improvements.

Berg, D. E. (April 1985). *Structural Design of the Sandia 34-M Vertical Axis Wind Turbine.* SAND84-1287. Albuquerque, NM: Sandia National Laboratories; 23 pp.

This report describes the conceptual design phase for a 500-kW, research-oriented, variable-speed VAWT using VAWT-specific blade element sections and step-tapered blades.

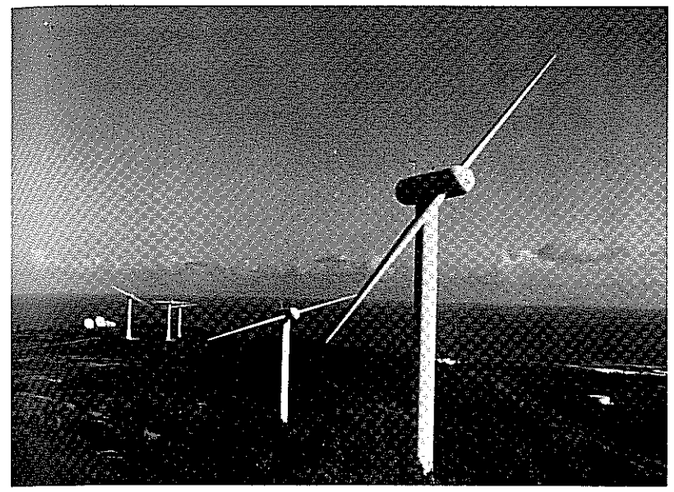
Windfarms

The modern windfarm is a group of wind turbines interconnected to a common utility through a system of transformers and transmissions lines and (usually) one substation. Operation, control, and maintenance functions are often centralized through a network of computerized monitoring systems, supplemented by visual inspection.

The concept of installing a group of large wind turbines in one place to provide electric power to a utility network is not a new one. Such installations of multimegawatt-scale machines were called "multi-unit" installations by the U.S. government when federally sponsored research began in 1973. However, the idea that a group of small or intermediate-scale machines installed in this manner could be economically worthwhile was originated around 1975. These multi-unit installations are called windfarms or wind plants.

Lissaman, Peter B. S.; Zalay, Andrew; and Gyatt, Graham. (April 1982). *Design of Optimal Wind Turbine Arrays.* AV-TP-82/528. Pasadena, CA: AeroVironment, Inc.; 10 pp. Available from the AeroVironment library.

General guidelines are provided for designing wind turbine arrays. These criteria are based on a revised wake interference model developed by AeroVironment under contract to DOE. Key factors for designing arrays include the wind and topographical conditions pertaining to the prospective site(s), along with economic considerations; tradeoffs between performance and economics are discussed. The publication also examines the economics of designing wind turbine arrays for projects financed either by utilities or by independent developers.



The fifteen 600-kW Westinghouse wind turbines in this windfarm generate electricity for Hawaiian Electric Renewable Energy Systems, Inc.

Since the late 1970s, a variety of other names have been used for similar installations, including "wind park," "wind turbine cluster," "wind turbine array," "wind power station," and others. The most commonly used term (and the one used in this document) is "windfarm." It is a useful name because "windfarm" is descriptive of the land area required to make the wind resource available and also links the resource to the variability of the natural environment and indicates that the land can also be used for agriculture or grazing.

California is the site of the most ambitious windfarm development efforts to date. Several of the state's large utility companies have signed contracts with independent wind-energy entrepreneurs to build windfarms. Pacific Gas and Electric, San Diego Gas and Electric, and Southern California Edison have contracted to buy significant amounts of wind power from private windfarm developers; today, more than 16,000 turbines represent about 3% of California's installed capacity for the generation of electricity. Windfarms have also been built (or are being planned) in Hawaii, Massachusetts, Oregon, Vermont, New Hampshire, and Montana.

Gipe, Paul. (February 1984). "Wind's Tough Dreamers." *Solar Age.* Vol. 9 (No. 2); pp. 36-43.

This article discusses the status of windfarm development in California. Machine size, installation, spacing, longevity, and performance are covered along with descriptions of the management and financial structures typical of many windfarm projects. Listings of projects, by location and power production, and windfarm suppliers are included.

Simon, R. L.; Matson, D. F.; and Fuchs, J. M. (September 1987). *Wake Effects in a Fayette 95-11S Wind Turbine Array.* SERI/STR-217-3186. Golden, CO: Solar Energy Research Institute; 75 pp. Work performed by Fayette Manufacturing Corporation, Tracy, CA. Available NTIS: Order No. DE88001103.

This report describes the investigation of 35 Fayette wind turbines in Altamont Pass, California, to quantify array wake effects and the factors influencing them. Approximately 65 hours of field measurement were made in 1986, with turbine energy production and wind velocity data recorded for various scenarios of array operation. Customized software and hardware were developed and installed by Fayette to facilitate these measurements. Although the results of this study apply only to this specific array and type of wind turbine, the methodology could be applied to study wake effects at other windfarms.

Pennell, W. T. (January 1983). *Siting Guidelines for Utility Application of Wind Turbines.* EPRI-AP-2795. Palo Alto, CA: Electric Power Research Institute; 266 pp. Work performed by Battelle Pacific Northwest Laboratories, Richland, WA.

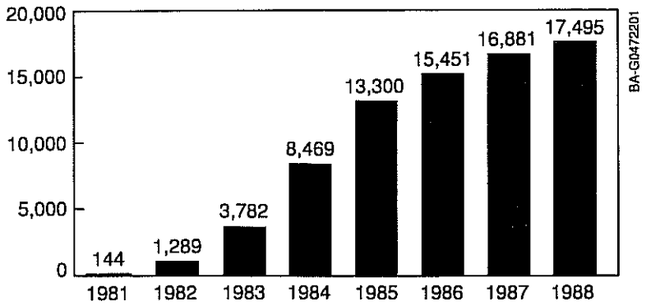
This report describes utility-oriented guidelines for identifying viable sites for wind turbines. Topics include a description of the DOE wind resource atlases; procedures for predicting wind turbine performance; methods for analyzing wind turbine economics; procedures for estimating installation and maintenance costs; methods for analyzing wind distribution; and instrumentation for documenting wind behavior.

Wegley, H. L. and Pennell, W. T. (March 1983). *Application Examples for Wind Turbine Siting Guidelines.* EPRI-AP-2906. Palo Alto, CA: Electric Power Research Institute; 124 pp. Work performed by Battelle, Pacific Northwest Laboratory, Richland, WA.

This report describes the trial application by two utilities of wind turbine cluster siting guidelines described in EPRI report AP-2795, *Siting Guidelines For Utility Application of Wind Turbines,* W. T. Pennell, October 1982. The activities of the two utilities are discussed, labor/time estimates are given for each stage of the siting guidelines, and baseline economic (as well as other) assumptions are provided for both utilities. In addition, the sensitivity of wind turbine economics to two types of wind turbine performance models is examined.

Hiester, T. R. and Pennell, W. T. (January 1981). *The Meteorological Aspects of Siting Large Wind Turbines.* PNL-2522. Richland, WA: Pacific Northwest Laboratory; 512 pp.

This report addresses the meteorological aspects of site selection as well as machine design and wind energy economic evaluation as related to



The number of wind turbines installed in California windfarms has risen dramatically since 1981. (Source: American Wind Energy Association)

Innovative Systems

In recent years, DOE has investigated many nonconventional ideas for producing electricity from the wind. These research efforts were supported by the Advanced and Innovative Wind Energy Concepts (AIWECS) program, whose purpose was to solicit, investigate, evaluate, and possibly develop more cost-effective methods for wind energy conversion. Management of the program was assigned to SERI in 1978 until the program was completed in 1983.

Advanced and innovative concepts for wind energy conversion usually involve some modification or augmentation to conventional HAWT or VAWT systems. Modifications investigated under the AIWECS program included different types of airfoil and rotor designs such as sailwings (HAWT airfoils made of cloth) and teetered rotors with stabilizing tailvanes. Flow augmentation concepts ranged from the highly unconventional "tornado tower"—a slotted, upright cylinder equipped with a vertically oriented turbine—to the addition of small airfoil sections to the tips of HAWT blades.

Devices investigated under the AIWECS program also included a number of theoretical concepts proposed to extract energy from drag forces imposed by the wind. For example, the electrofluid dynamic wind-driven generator was designed to extract energy from charged particles blown through an electric field. Oscillating systems would convert the kinetic energy of oscillating cables, vanes, or wings to electric power. Another unusual concept for wind energy conversion, called a humid air device, more closely resembles a heat engine that uses air as the working fluid.

While intriguing, and even theoretically possible, none of these concepts demonstrated the ability to compete with existing technology in terms of either performance or cost. However, the knowledge gathered during the AIWECS program is useful to innovators and inventors who wish to become familiar with prior research in nonconventional wind concepts.

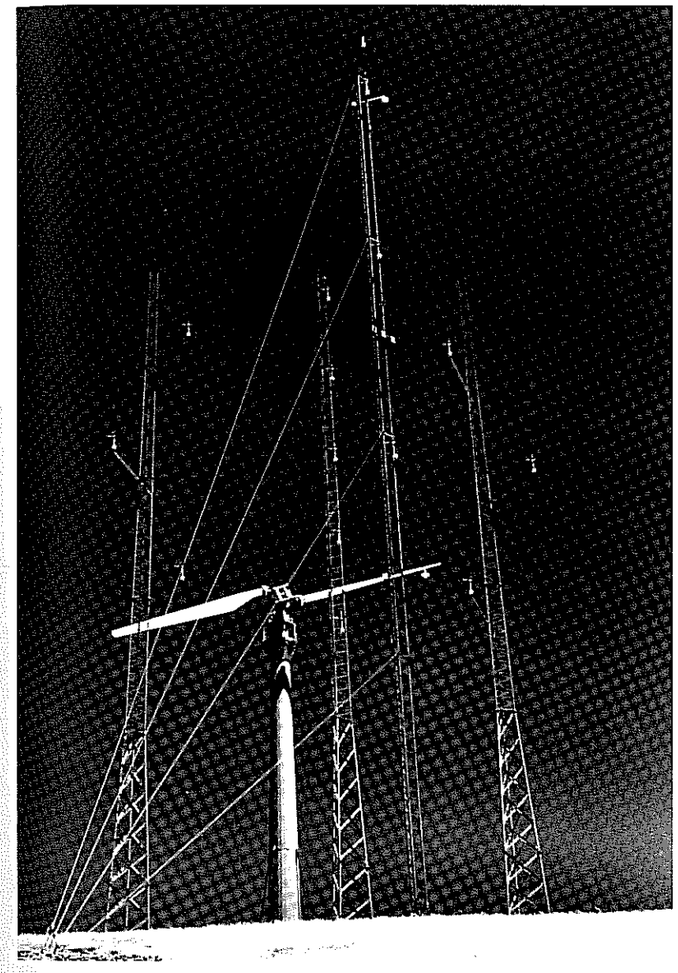
meteorological siting concerns. The report should enable potential users to assess the meteorological aspects of siting, determine ways to solve the problem, and integrate these solutions into the overall site selection program.

Jacobs, E. W. (1983). "Research Results for the Tornado Wind Energy-System: Analysis and Conclusions." *Solar Engineering -1983: Proceedings of the ASME Solar Energy Division Fifth Annual Conference; Orlando, Florida; 18-21 April 1983.* New York: American Society of Mechanical Engineers; pp. 606-617.

Numerous experimental and analytical research efforts have investigated the potential of the tornado wind energy device. This paper summarizes and analyzes much of the research to date. A simplified cost analysis incorporating these research results is included. Based on these analyses, the tornado device does not show promise for significant improvements of either the performance or the energy cost attainable by conventional WECS. The prospects for achieving either a system power coefficient above 0.20 or an energy cost of less than $0.50/kWh (1979 dollars) appear to be poor.

Jacobs, E. W. and Lasier, D. D. (January 1984). *A Theoretical Analysis of Solar-Driven Natural Convection Energy Conversion Systems.* SERI/TR-211-1950. Golden, CO: Solar Energy Research Institute; 37 pp.

A theoretical study of the performance of solar-powered natural convection towers. Both heated and cooled towers are analyzed; the latter uses evaporating water as the cooling mechanism. Results show that the ideal conversion efficiencies of both heated and cooled natural convection towers are linear functions of height. The performance of a heated tower in an adiabatic atmosphere ideally approaches the Carnot efficiency limit of ≈3.4%/km (1.0%/1000 ft). Including water pumping requirements, the ideal limit to cooled tower performance is ≈2.75%/km (0.85%/1000 ft).



As a part of DOE's Cooperative Research Program with industry, federal researchers studied the dynamic response of an innovative wind turbine built by Northern Power Systems.

Cooperative Research Program for Wind Energy Systems

Since 1985 DOE has had a program for performing important cooperative research projects with industry. These projects address critical issues related to wind turbine development. With technical support from SERI, SNL, and PNL, three wind turbine manufacturers (Atlantic Orient Corporation, Bergey Windpower Co., and Northern Power Systems) are participating in cost-shared studies of wind/diesel systems, small wind/electric pumping systems, and improved wind/diesel system architecture. Final reports on these projects will be available in 1989.

Simon, R. L.; Matson, D. F.; Fuchs, J. M. (September 1987). *Wake Effects in a Fayette 95-IIS Wind Turbine Array.* SERI/STR-217-3186. Golden, CO: Solar Energy Research Institute; 75 pp. Work performed by Fayette Manufacturing Corporation, Tracy, California.

A group of 35 Fayette Manufacturing Corporation 95-IIS wind turbines on the Castello Ranch in Altamont Pass, California, was investigated to quantify array wake effects (losses in energy production due to operation of upwind turbines) and the factors influencing them. Approximately 65 hours of field measurements were made in summer 1986, with turbine energy production and wind velocity data recorded for various scenarios of array operation. Customized software and hardware were

developed and installed by Fayette to facilitate these measurements.

Snow, A.L.; Heberling, C.F., III; Van Bibber, L. E. (March, 1989) *The Dynamic Response of a Westinghouse 600-kW Wind Turbine.* SERI/STR-217-3405. Golden, CO: Solar Energy Research Institute; 185 pp. Work performed by Westinghouse Electric Corporation, Pittsburgh, Pennsylvania.

This report is the seventh in a series of documents that present the findings of field tests conducted under the Deparment of Energy's Cooperative Field Test Program with the U.S. wind industry. In the field tests described in this report, a 600-kW Westinghouse wind turbine located on the north shore of the island of Oahu, Hawaii, was used to sample the loads and performance of an intermediate-size wind turbine. This report documents the instrumentation, data acquisition system, data-gathering periods, calibration, and the initial assessment of the data. These data can be used to validate aeroelastic design methods for predicting service loadings of intermediate-size, upwind, teetered-hub, horizontal-axis wind turbines.

Wehrey, M.; Redmond, I.; Anderson, C.; Jamieson, R. (February 1988). *Dynamic Response of a 330-kW Horizontal Axis Wind Turbine Generator.* SERI/STR-217-3203. Golden, CO: Solar Energy Research Institute; 103 pp. Work performed by Southern California Edison, Rosemead, California, and James Howden and Company Ltd., Glasgow, Scotland.

This report is the second in a series presenting the findings of field tests conducted under the Department of Energy's Cooperative Field Test Program with the U.S. wind industry. The report provides the results of a combined experimental and theoretical study of the dynamic response of a Howden 330/26 wind turbine generator. The work was undertaken by Southern California Edison with the aim of extending current knowledge on the dynamic loading of wind turbines.

Standards

The American Wind Energy Association (AWEA) is currently developing standards and recommended practices for WECS under a cooperative agreement with DOE. After each set of standards documents has passed internal and membership approval, it is sent to the American Society for Testing and Materials (ASTM) for approval and will eventually become national consensus ASTM standards.

AWEA subcommittees are working on standards in the following areas:

- Terminology: Standard definitions for terms commonly used in wind energy.
- Performance: Standard methods of rating wind machines, describing their performance, and testing them.
- Siting: Standard methods of collecting data on the wind resource and selecting a tower location and height at a specific site.
- Installation: Standards for electrical hookups, foundations, lightning protection, etc.
- Electrical Power Subsystems: Standards for generators, power conditioning, and utility grid interface.
- Safety: Standards for the safe design and use of WECS.

Standard Performance Testing of Wind Energy Conversion Systems. (1985). AWEA Standard: AWEA 1.1-1985. Alexandria, VA: American Wind Energy Association; 36 pp.

This standard is the first of a series prepared by AWEA to facilitate uniform practices and communication in wind energy technology. The document describes a standard method of determining and reporting primary performance characteristics. Included are definitions and units of measurement, a field test procedure used to determine power production performance, a field test procedure that determines noise levels associated with WECS operation, procedures for deriving WECS performance parameters, and a description of a proposed test report to be used as part of certification.

Recommended Practices for Wind Turbine Testing: 1. Power Performance Testing; 1 Edition 1982. (1982). Frandsen, Steve; Trenka, Andrew R.; and Pedersen, B., eds.; 17 pp. Submitted to the Executive Committee of the International Energy Agency Programme for Research and Development on Wind Energy Conversion Systems. Available NTIS: Order No. DE84901417.

This document describes the recommended practices for testing and reporting power performance characteristics of WECS, and a standard methodology for comparing energy production characteristics.

Recommended Practices for Wind Turbine Testing: 2. Estimation of Cost of Energy from Wind Energy Conversion Systems; 1. Edition 1983. (1983). Nitteberg, J.; deBoer, A. A.; and Simpson, P. B., eds.; 23 pp. Submitted to the Executive Committee of the International Energy Agency Programme for Research and Development on Wind Energy Conversion Systems. Available NTIS: Order No. DE84901132.

This document describes the recommended procedure for estimating energy costs from WECS, and a standard methodology for comparing energy costs from commercial WECS.

Recommended Practices for Wind Energy Conversion Systems Testing: 3. Fatigue Characteristics; 1. Edition 1984. (1984). Dekker, J. M. W.; Jensen, E.; Ottens, H. H.; Thor, S. E.; and Hassan, U., eds.; 19 pp. Submitted to the Executive Committee of the International Energy Agency Programme for Research and Development on Wind Energy Conversion Systems.

This document describes recommended practices for evaluating fatigue characteristics of WECS. The aim is to provide a standard method so the levels of fatigue damage from different modes of WECS operation can be determined.

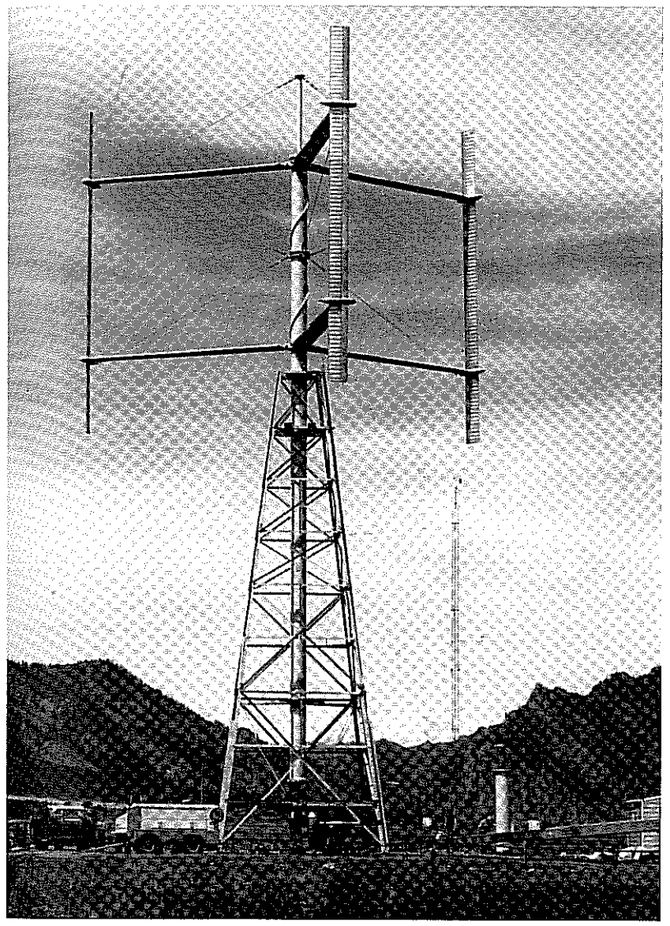
Recommended Practices for Wind Turbine Testing; 4. Acoustics. Measurement of Noise Emission from Wind Energy Conversion Systems (WECS); 2. Edition 1988. (1988) Ljunggren, S. and Gustafsson, A., eds.; 23 pp. Submitted to the Executive Committee of the International Energy Agency Programme for Research and Development for Wind Energy Conversion Systems.

This document describes the procedures to be used for the measurement and description of noise emission from wind energy systems.

Recommended Practices for Wind Turbine Testing and Evaluation; 5. Electromagnetic-Interference; Preparatory Information; Issue 1, February 1986. (1986). Chignell, R.J., ed.; 16 pp. Submitted to the Executive Committee of the International Energy Agency Programme for Research and Development on Wind Energy Conversion Systems.

The objective of this document is to present an indication of the mechanisms that have so far been identified as contributing to the interference, to report some of the undesirable effects that have been noted and to recommend appropriate remedial action, if any.

Recommended Practices for Wind Turbine Testing: 7. Quality of Power. Single Grid-Connected WECS; 1. Edition 1984. (1984). Ballard, L. J. and Sivansborough, R. H., eds.; 24 pp. Submitted to the Executive Committee of the International Energy Agency Programme for Research and Development on Wind Energy Conversion Systems.



Early DOE/SERI research included the investigation of advanced and innovative concepts such as the giromill.

- Design Criteria: Standards defining the environment, loads, and design criteria necessary to maintain the structural integrity and safe operation of a wind machine for a given lifetime.

Additional information can be obtained from

AWEA Standards Program
American Wind Energy Association
1730 North Lynn Street, Suite 610
Arlington, VA 22209

The International Energy Agency (IEA) is involved in developing internationally agreed-upon test and reporting practices for wind energy conversion systems. With Denmark assigned the role of Operating Agent, the following countries are involved: Belgium, Canada, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

Additional information can be obtained from

International Energy Agency
(Agence Internationale de l'Energie)
2, rue Andre Pascal
F-75775 Paris Cedex 16 France.

The American Society of Mechanical Engineers (ASME) published performance test codes for wind turbines. The code provides standard instructions for conducting performance tests of wind turbines. It is based on the use of accurate instrumentation and the best analytical and measurement methods and procedures available, and is intended to produce results of the highest accuracy consistent with good engineering practice.

ASME reports and publications may be obtained, for a fee, from

American Society of Mechanical Engineers
345 East 47th Street
New York, NY 10017
(212) 705-7722.

This document describes the recommended practices for determining the quality of power delivered by a single grid-connected WECS. It provides a methodology for obtaining power quality data that can be used to compare different WECS.

Recommended Practices for Wind Turbine Testing and Evaluation: 8. Glossary of Terms; Issue 1, March 1987. (March 1987). Elliot, G., ed.; 11 pp. Submitted to the Executive Committee of the International Energy Agency Programme for Research and Development on Wind Energy Conversion Systems.

This document provides a glossary of wind energy terms.

Wind Turbines: Performance Test Codes. (1989). ASME/ANSI PRC 42-1988. New York: The American Society of Mechanical Engineers; 61 pp.

The code compares the net amount of electrical energy produced by the wind turbine during a given period of time to the predicted test energy for the same period and the same wind speed histogram.

The code can be used to: compare the test power-versus-wind-speed curve to the reference power-versus-wind-speed curve; compare the annual energy output calculated using the test power-versus-wind-speed curve with that calculated using the reference power-versus-wind-speed curve, for the same annual wind speed histogram; determine the effects on wind turbine performance of changes to subsystems and components of the wind turbine or changes in the methods of operation for specified conditions at a given site; and compare the performance of the wind turbine with the established performance of other wind turbines at the same or different sites.

Chapter 4
Wind Energy Resources and Systems Performance

Resources and Siting

Wind Energy Meteorology. Meteorology is important in the exploratory, planning, and operational phases of work on wind energy conversion systems. Although this section discusses meteorology as it relates to wind energy, some aspects of meteorology that relate specifically to WECS design and performance were discussed in Chapter 2.

The exploratory phase involves wind prospecting for likely WECS sites and preliminary WECS design. Meteorological services of special interest in this phase include

- Information about available meteorological data, especially wind data
- Preparation of climatological analyses as a basis for wind energy prospecting
- Investigation of the probability of producing wind energy at a particular site
- Time-series analyses
- Application of atmospheric simulation models to WECS design models.

The planning phase involves detailed site evaluation and WECS design. The following services would be of use during this phase:

- Detailed information on site-specific wind and other environmental data
- Evaluation of data and effects of topography and geography on wind and other conditions
- Design of special measurement systems and collection of site-specific wind data
- Optimized grouping and array arrangements with the aid of climate-related analyses and knowledge of boundary-layer meteorology.

In the WECS operational phase, meteorological services of interest include forecasting wind energy production on different time scales and continuing evaluation of the system's performance and production.

Existing Resource Data. Pacific Northwest Laboratory (PNL), operated for DOE by Battelle, has been responsible for the atmospheric research element of the Federal Wind Energy Program. In 1979 and 1980, PNL compiled 12 atlases covering the United States and its territories. The atlases depict regional and statewide wind resources in graphic, tabular, and narrative form. Surface wind data used to compile the atlases were obtained from a number of sources, with the National Climatic Data Center (NCDC) providing the greatest amount of data. The regional editions of the atlases (along with their respective publication numbers and dates) are as follows:

- *Volume 1: Northwest Region (Idaho, Montana, Oregon, Washington, and Wyoming).* PNL-3195 WERA-1; April 1980.
- *Volume 2: North Central Region (Iowa, Minnesota, Nebraska, North Dakota, and South Dakota).* PNL-3195 WERA-2; February 1981.

Meteorological Aspects of the Utilization of Wind as an Energy Source. (1981). Technical Note 175. Geneva, Switzerland: World Meteorological Organization; 180 pp.

The report addresses the need for wind information as applied to wind energy generation, both for meteorologists and for engineers and others who plan, design, and operate wind energy systems. It includes information on the wind, especially atmospheric circulation systems; WECS technology, including different system types and their applications; and wind energy meteorology, its use in wind energy application and WECS development. The final chapter indicates the economic aspects to consider when establishing a wind energy system. Appendices provide detailed information on turbulence and the atmospheric boundary layer, wind-measurement instruments, computation of power output, and nomenclature.

Proceedings of the Conference and Workshop on Wind Energy Characteristics and Wind Energy Siting; Portland, OR; 19-21 June 1979. (1979). PNL-3214. Richland, WA: Pacific Northwest Laboratory; 471 pp.

Thirty-eight papers were presented at the conference. Subjects dealt with wind energy characteristics for operations, resource assessment, and siting methods. The main engineering disciplines involved are mechanical, aeronautical, electrical, and civil.

Changery, Michael J. (December 1978). *National Wind Data Index.* HCO/T1041-01. Asheville, NC: National Climatic Data Center; 245 pp.

This index is intended as a guide to the identification of all locations in the United States with original wind data, in any form, that have been archived at the National Climatic Data Center.

Changery, Michael J.; Hodge, W. T.; and Ramsdell, J. V. (September 1977). *Index—Summarized Wind Data.* BNWL-2220 WIND 11. Richland, WA: Battelle Pacific Northwest Laboratories; 151 pp.

This index provides a description of all wind summaries then available at the National Climatic Data Center.

- *Volume 3: Great Lakes Region (Illinois, Indiana, Michigan, Ohio, and Wisconsin).* PNL-3195 WERA-3; February 1981.
- *Volume 4: Northeast Region (Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont).* PNL-3195 WERA-4; September 1980.
- *Volume 5: East Central Region (Delaware, Kentucky, Maryland, North Carolina, Tennessee, Virginia, and West Virginia).* PNL-3195 WERA-5; November 1980.
- *Volume 6: Southeast Region (Alabama, Florida, Georgia, Mississippi, and South Carolina).* PNL-3195 WERA-6; January 1981.
- *Volume 7: South Central Region (Arkansas, Kansas, Louisiana, Missouri, Oklahoma, and Texas).* PNL-3195 WERA-7; March 1981.
- *Volume 8: Southern Rocky Mountain Region (Arizona, Colorado, New Mexico, and Utah).* PNL-3195 WERA-8; March 1981.
- *Volume 9: Southwest Region (California and Nevada).* PNL-3195 WERA-9; November 1980.
- *Volume 10: Alaska.* PNL-3195 WERA-10; December 1980.
- *Volume 11: Hawaii and U.S. Pacific Trust Territories.* PNL-3195 WERA-11; February 1981.
- *Volume 12: Puerto Rico and U.S. Virgin Islands.* PNL-3195 WERA-12; January 1981.

PNL also produced a more recent survey in a publication entitled *Wind Resource Atlas of the United States*. This survey was the result of a program initiated by DOE in 1983 and administered by PNL to identify and assimilate new site data that could be useful in verifying or updating the wind resource estimates in many areas of the United States. Data were evaluated from approximately 270 new sites. Approximately 200 of these new sites were instrumented specifically for wind energy assessment purposes. The new atlas, published in 1987, therefore contains revised maps for annual and seasonal average wind power, based largely on the examination and analysis of these new site data. Certainty ratings credited to the wind resource were also revised, and the areal distribution maps were updated to reflect changes in the wind resource estimates. However, the regional atlases are still useful for those requiring more detailed information in a specific area.

As mentioned above, much of the data for the regional atlases was provided by NCDC. NCDC collects and archives the data recorded by the National Weather Service and its predecessor agencies along with the weather services of the Air Force and Navy, the Federal Aviation Administration, the Coast Guard, and cooperative observers. Climatic summaries for major U.S. weather stations are available from the NCDC for the cost of reproduction. NCDC also makes available the data base used to produce the regional wind energy assessments. See the listing for the Wind Energy Resource Information System (WERIS) in Chapter 8 under Data Bases for more information about data available from NCDC.

Environmental Aspects of Design. The wind characteristics important for developing design criteria consist of either representative average conditions (e.g., mean wind distribution) or extreme conditions (e.g., gusts). As such, these criteria do not necessarily represent a set of wind conditions that would actually be encountered at any particular location. Since the use of wind characteristics for design is often closely related to performance and siting, resources listed in those sections also may be useful. PNL performs work in this area in addition to developing wind resource data.

Gipe, Paul. (May 1981). "Sources of Wind Data." *Solar Age.* (6:5); pp. 35-36.

Elliott, D. L.; Holladay, C. G.; Barchet, W. R.; Foote, H. P.; and Sandusky, W. F. (March 1987). *Wind Energy Resource Atlas of the United States.* DOE/CH 10093-4. Richland, WA: Pacific Northwest Laboratory; 210 pp. Available from the U.S. Government Printing Office or NTIS: Order No. DE86004442.

The atlas estimates the wind energy resource for the United States and its territories, and indicates general areas where a high wind resource may exist. The information allows wind energy developers and potential wind energy users to choose a general area of estimated high wind resource for more detailed examination. Chapter 2 presents national maps of the annual and seasonal average wind resource, certainty rating, and area distribution. Chapter 3 presents regional summaries of the wind resource estimates. Maps of the annual average wind resource are presented for each state in the region. The appendices provide information on synthesis of the regional assessments, the Wind Energy Resource Information System, annual and seasonal mean wind speed and power summaries for selected stations, evaluation of new site data for verifying or updating the wind resource estimates, and annual and seasonal mean wind speed and power summaries for 35 candidate wind turbine sites.

Frost, W.; Long, B. H.; and Turner, R. E. (December 1978). *Engineering Handbook on the Atmospheric Environmental Guidelines for Use in Wind Turbine Generator Development.* NASA-TP-1359. Huntsville, AL: National Aeronautics and Space Administration, Marshall Space Flight Center; 372 pp.

The guidelines in this report are in the form of design criteria relative to wind speed, wind shear, turbulence, wind direction, ice and snow loading, and other climatological factors. Design criteria are presented in an engineering format that can be used directly in wind turbine design computations.

Although wind is the most important environmental design parameter for WECS, other climatological factors are also important, especially when they represent hazardous conditions such as icing or atmospheric corrosion.

Resource Assessment. To determine if a specific site has sufficient wind to power a wind turbine or to find a good wind site by investigating several areas, it is necessary to evaluate the wind resource and related environmental factors. In most cases, on-site measurement is needed to verify the site's wind energy potential. However, prior to such measurement, various site-screening techniques may be used to determine if the site has sufficient wind energy potential to warrant further investigation. The site-screening process is sometimes referred to as wind prospecting.

Biological wind prospecting seeks indicators of high wind by using local vegetation. It is based on the fact that trees and plants can be greatly deformed (or "flagged") in a consistent way by the wind. Aeolian landforms can be another indicator of an area's wind conditions. Usually present in sparsely vegetated arid and semi-arid lands, aeolian surface features indicative of strong wind are sand dunes, playas, and scour features.

Meteorological and topographical features suggesting the presence of high wind energy include long, sloping valleys parallel to prevailing winds and areas of strong geostrophic winds that have land features such as high elevation plains, exposed ridge crests and mountain summits, and exposed coastal sites.

Physical and numerical modeling also can be used for wind prospecting. Numerical models provide a method for estimating effects of terrain on air flow, and for interpolating wind data from locations where wind observations exist to locations where there are none. Physical modeling simulates the flow over terrain by placing a scaled representation of the terrain in a suitably designed wind tunnel.

Doran, J. C. (August 1981). *Inherent Uncertainties in Meteorological Parameters for Wind Turbine Design.* PNL-SA-736. Richland, WA: Pacific Northwest Laboratory; 18 pp.

The narrow limits of variability often assumed for the values usually found in WECS design handbooks do not actually exist for many of the meteorological parameters relevant to WECS design. This paper identifies these uncertainties and discusses them for wind frequency distributions, vertical wind shear, and the representation of atmospheric turbulence.

Connell, J. R.; Morris, V. R.; Hinchee, M. E.; and Thresher, R. W. (1987). "Input Turbulence Features at a Megawatt-Size Wind Turbine, Medicine Bow, Wyoming." *Sixth ASME Wind Energy Symposium; The Tenth Annual Energy-Sources Technology Conference and Exhibition; Dallas, Texas; February 15-18, 1987.* SED-Vol. 3. New York: American Society of Mechanical Engineers; pp. 201-214.

The authors discuss measurements of turbulent wind velocity profiles made at the WTS-4 wind turbine site in Medicine Bow, Wyo., which were used to characterize the wind in terms of fixed-point, single-tower properties and to model wind properties as they would be experienced by points on rotating turbine blades.

Justus, C. G. (June 1980). "Wind Systems Siting and Performance." *Proceedings of the 1980 Annual Meeting of the American Section of the International Solar Energy Society; Phoenix, AZ; 2-6 June 1980.* Franta, G. E. and Glenn, B. H., eds. Newark, DE: AS of ISES; Vol. 3.2, pp. 1437-1441.

Site selection, screening, and validation criteria and guidelines are reviewed, especially from the larger scale viewpoint of regional and general site selection.

Wade, J. E. and Hewson, E. W. (October 1981). *A Guide to Biological Wind Prospecting.* DOE/ET/20316-80-2. Corvallis, OR: Oregon State University; 112 pp.

Marrs, R. W. and Gaylord, D. R. (April 1979). *A Guide to the Interpretation of Windflow Characteristics from Eolian Landforms.* RLO-2343-79/2. Laramie, WY: University of Wyoming; 39 pp.

Frost, Walter and Shieh, Chih-Fang. (December 1981). *Guidelines for Siting WECS Relative to Small-Scale Terrain Features.* DOE/ET/20242-78/1. Tullahoma, TN: FWG Associates, Inc.; 196 pp.

Corotis, Ross B. (May 1980). *Application of Statistical Techniques to Wind Characteristics at Potential Wind Energy Conversion Sites.* DOE/ET/20283-2. Evanston, IL: Northwestern University; 122 pp.

Wade, J. E.; Maule, P. A.; Bodvarsson, G.; Rosenfeld, C. L.; Woolley, S. G.; and McClenahan, M. R. (February 1983). *Remote Sensing for Wind Power Potential, A Prospector's Handbook.* DOE/ET 20316-81-1. Richland, WA: Pacific Northwest Laboratory; 308 pp. Work performed by Oregon State University, Corvallis, OR.

Siting Handbooks. Siting handbooks provide information on the actual techniques used to evaluate a particular site's wind resource and to select and place the WECS to best take advantage of the resource. An optimum site meets the following criteria:

- High mean wind speed
- Acceptable diurnal, seasonal, and interannual variations of the wind
- Acceptable extreme winds and turbulence levels and other environmental factors that affect structural integrity and system lifetime.

A number of other important variables affecting the ultimate site selection, such as local regulations or environmental impacts, are covered in Chapter 6 of this document. Several siting handbooks are profiled here.

This report combines several techniques described in the preceding documents into a method for quickly pinpointing promising wind power sites.

Standard Procedures for Meteorological Measurements at a Potential Wind Turbine Site. (1986). AWEA Standard AWEA 8.1-1986. Alexandria, VA: American Wind Energy Association; 18 pp.

Provides procedures and methods for obtaining meteorological measurements. Standards are provided for meteorological measurement systems as well as the installation, operation, and calibration of equipment. Guidelines for sampling strategies, data processing, and site evaluation practices are given in the appendices.

Standard Performance Testing of Wind Energy Conversion Systems. (1988). AWEA Standard AWEA 1.1-1988. Arlington, VA: American Wind Energy Association; 32 pp.

Describes a standard method for determining and reporting performance characteristics of wind turbines. Performance parameters that can be obtained and described by using this method include: power curve, AWEA estimated annual energy output, power form, cut-in wind speed, cut-out wind speed, maximum power, maximum wind speeds (design and tested), overspeed control, and rated rotor speed.

Wegley, Harry L.; Orgill, Montie M.; and Drake, Ron L. (March 1980). A Siting Handbook for Small Wind Energy Systems. PNL-2521 Rev. 1. Richland, WA: Pacific Northwest Laboratory; 132 pp.

This is a guide for individuals wishing to install small wind systems with rated capacity below 100 kW. The following topics are covered: siting in flat terrain, siting in nonflat terrain, methods of site analysis, wind measurements, and environmental hazards for WECS operations.

System Performance

Existing Performance Data. Performance is concerned with how much power can be extracted from the wind and the extraction capabilities of various rotor types. For an optimum system, the maximum percentage of wind power that can be extracted is derived by a formula developed by Carl Betz in 1927. The formula indicates that unaugmented wind system rotors can have a maximum power coefficient of 0.593, known as the Betz limit.

It is also important to understand the difference between lift-type and drag-type rotors because the matching of rotor to load is critical to the most efficient use of power output. Loads such as mechanical pumps, which require low speed and high torque, are best matched with drag-type rotors. Electric generators require higher speeds and are best matched with lift-type rotors, which can more closely approach the optimum power coefficient. More information on the relationship of aerodynamics to performance can be found under Aerodynamics in Chapter 2.

Performance data can help the WECS industry and potential users by identifying necessary modifications in machine design, demonstrating reliable operation, and providing information useful in the selection of a system to meet user needs. Such data usually include basic features such as design output, rotor configuration, and operating wind speeds; characteristics and problems of the machine in operation; and results of specific tests of machine capabilities.

Wind Turbine Performance Assessment: Technology Status Report No. 7. (April 1984). EPRI-AP-3447. Palo Alto, CA: Electric Power Research Institute; 146 pp. Work performed by Arthur D. Little, Inc., Cambridge, MA.

This report examines and interprets large wind turbine (rated power greater than 100 kW) test data, identifies trends, and facilitates the timely transfer of information from various test programs to the electric utility industry. Wind turbine programs in private industry and foreign countries are covered as well as DOE/NASA programs.

Wind Characteristics and Performance Evaluation. The single most important factor for design and performance is mean wind speed. The wind speed probability distribution is necessary for selecting the optimum design power coefficient and for assessing the power performance of a machine with previously specified operating characteristics. Seasonal and diurnal wind speed variations are also important, especially if load matching considerations are a factor in performance. Gustiness of the wind has an effect on the power output of a given machine design. The importance of wind speed variation with height makes it necessary to assess trade-offs of increased output power versus tower height. PNL is conducting work in this area of wind characteristics.

Justus, C. G. (1978). *Winds and Wind System Performance.* Philadelphia, PA: The Franklin Institute Press; 120 pp.

This book focuses primarily on the performance evaluation aspects of wind characteristics but also discusses those aspects of design, siting, and operations related to system performance.

Pennell, W. T. and Miller, A. H. (1981). *Procedures for Modeling Wind Turbine Performance from Site Wind Data.* 82-Pet-7. New York: The American Society of Mechanical Engineers; 10 pp. Available from Engineering Societies Library, 345 E. 47th Street, New York, NY 10017.

A key problem in wind turbine siting is estimating how a given wind turbine will perform at a given site. Solving this problem requires a model for converting wind information from a site into accurate simulations that show how a wind turbine installed at that site would perform. This paper reviews procedures for modeling wind-turbine energy production and discusses the strengths and weaknesses of each procedure.

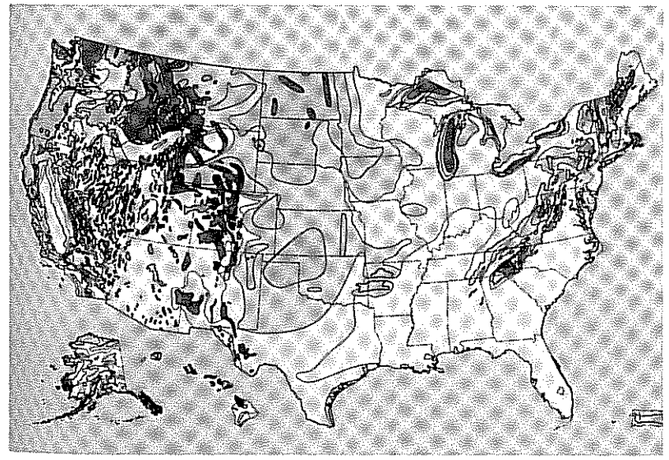
Prediction and Measurement of Performance. The performance of a wind turbine can be determined by actual power output measurements obtained through either long-term atmospheric testing or short-term wind-tunnel testing. Otherwise, performance can be estimated or predicted through the use of models, especially computer models (see Chapter 8). Equations and models used for wind performance calculations can be found in such books as Justus' *Wind and Wind System Performance*. The papers cited here review several methods of performance evaluation.

Viterna, L. A. and Janetzke, D. C. (September 1982). *Theoretical and Experimental Power from Large Horizontal-Axis Wind Turbines.* DOE/NASA/20320-41. Cleveland, OH: NASA Lewis Research Center; 18 pp.

The report describes a method for calculating power output from large horizontal-axis wind turbines and gives modifications to airfoil characteristics and the momentum portion of classical blade element-momentum theory.

Moment, R. L. (February 1983). *Performance and Size Estimating for Wind Systems.* RFP-3586. Golden, CO: Rocky Flats Plant Wind Energy Research Center; 63 pp.

The publication describes a method for estimating WECS performance, given wind speed, and annual energy production in common wind regimes (10-18 mph) for different rotor diameters ranging from 10 to 140 feet.



Wind resource sites of 13 mph and higher are found in wide areas of the United States.

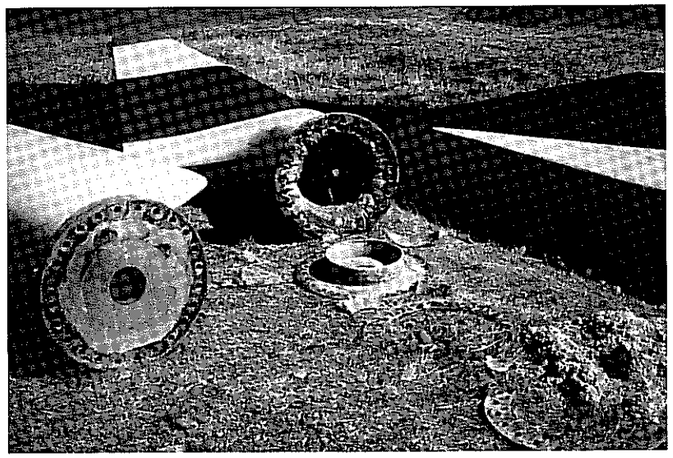
Tangler, J. L., ed. (February 1983). *Horizontal-Axis Wind System Rotor Performance Model Comparison—A Compendium.* RFP-3508. Golden, CO: Rocky Flats Wind Energy Research Center, 381 pp. Work performed by AeroVironment, Pasadena, CA; Oregon State University, Corvallis, OR; United Technologies Research Center, East Hartford, CT, and Aerospace Systems, Inc., Burlington, MA.

This compendium consists of four reports that evaluate performance prediction methods for smaller horizontal-axis wind turbines.

Waldon, C. A. (April 1980). *Wind Machine Fatigue Analysis and Life Prediction.* RFP-3135. Golden, CO: Rockwell International; 63 pp.

This report presents techniques for locating high-stress measuring points, obtaining data, using

Failure Analysis. Fatigue is the main cause of structural failure in wind machines, and its prediction is a difficult task for a designer. Fatigue of wind-machine components is usually caused by vibration.



Blade detachment resulting from structural failure on a Danish HAWT.

computer programs for calculating fatigue reduction, and predicting fatigue life. Techniques are developed for small wind energy systems and are intended for use by manufacturers.

Veers, Paul S. (October 1981). "Blade Fatigue Life Assessment with Application to VAWTs." *Fifth Biennial Wind Energy Conference and Workshop; Washington, DC; 5-7 October 1981.* SERI/CP-635-1340. Irwin E. Vas, ed. Golden, CO: Solar Energy Research Institute; pp. 597-610.

This paper relates vibratory stress to wind speed and discusses how to correlate these factors to produce fatigue life estimates.

Waldon, C. A. and Hansen, A. C. (June 1983). *Fatigue Modeling for Small Wind Systems: Basic Theory.* RFP-3564. Golden, CO: Rocky Flats Wind Energy Research Center; 56 pp. Available NTIS: Order No. DE84013191.

This report discusses the theory of fatigue as applied to horizontal-axis wind systems and reviews current techniques for predicting fatigue loads and fatigue life.

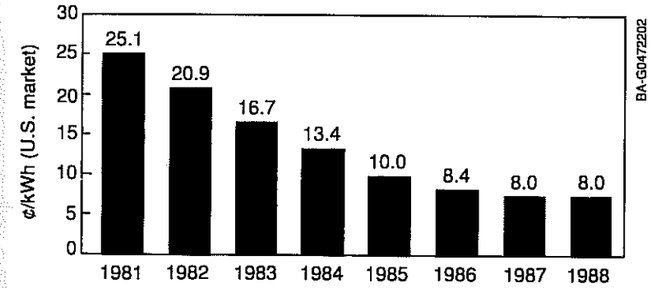
Chapter 5
Economics and Applications

Wind Energy Economics

The attractiveness of a wind energy system to a potential user depends to a great extent on the system's cost and economics when compared to conventional sources of energy. Typically, there are two economic considerations upon which consumers base their decisions: the initial cost of the system and the cost of the power it produces.

The initial (or production) cost includes all costs entailed in the design, materials, and manufacture of the wind system. It may also include the seller's profit, taxes and insurance, and operating and maintenance costs. Most of these costs represent initial expenses to the buyer and consequently are a major factor in the decision to purchase. However, although the major costs of a wind system occur early in its lifetime, the costs for utility-supplied electricity occur at different points in time and in differing amounts, making it difficult to compare ultimate user costs of wind systems and conventional sources.

One way to compare the economics of a wind system versus a more conventional power source is to measure the consumer costs of the power produced. This can be done with life-cycle costing—a method of considering total relevant costs over the lifetime of a system. The annualized energy cost available from the wind system is compared to the annualized energy cost available from the electric grid. It should be noted that life-cycle costing can give only an estimate of the WECS power cost. This is useful for making a purchase decision, but the actual cost will be influenced by the site's wind resource and other local factors.



Wind energy costs have been declining steadily.

Sullivan, R. L.; Flaim, Theresa; and Percival, David. (March 1982). *WECS Value Analysis: A Comparative Assessment of Four Methods.* SERI/TR-211-1563. Golden, CO: Solar Energy Research Institute; 51 pp.

This report compares four methods developed for conducting economic assessments of WECS in utility applications. The methods, developed by SERI, the Aerospace Corp., and the JBF Scientific Corp., were applied to two case-study utilities: Southern California Edison and Consumers Power Co. Results were compared for each step in the analysis, including WECS performance, load modification, production cost, capacity displacement, and break-even cost. The sources of discrepancies among the methods were identified, and changes were suggested to improve accuracy.

Britt, J. F.; Davey, H. L.; McCarroll, D. A.; and Wysocki, K. J. (December 1981). *Small Wind Turbine Production Evaluation and Cost Analysis.* SERI/TR-09049-1. Golden, CO: Solar Energy Research Institute; 2 Vols.

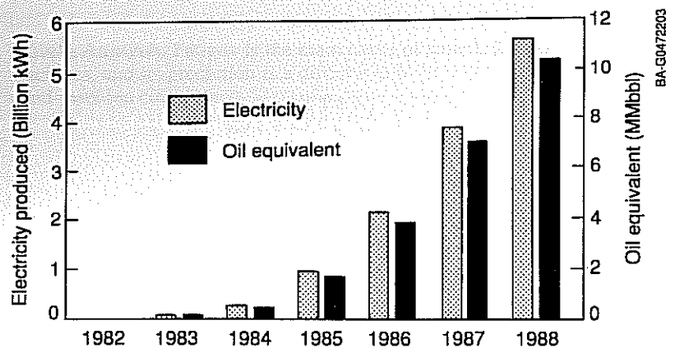
This study determined the suitability of a specific 10-kW horizontal-axis wind turbine design for manufacture. It also analyzed production at three different manufacturing rates and generated a cost analysis of the production processes. Manufacturing cost, which consisted of the sum of all costs necessary to place a finished product on the factory dock ready to ship, was developed for production rates of 1000, 10,000, and 100,000 turbines per year.

Moyle, R. A.; Chernoff, H.; Schweizer, T. C.; and Patton, J. B. (November 1982). *Assessment of Distributed Solar Power Systems: Issues and Impacts.* EPRI AP-2636. Palo Alto, CA: Electric Power Research Institute; 184 pp. Work performed by Science Applications, Inc., McLean, VA and by Systems Control, Inc., Palo Alto, CA. Available from EPRI, Research Reports Center, Palo Alto, CA.

Some of the technical and economic impacts of dispersed solar power systems are discussed. Among the economic issues are user purchase criteria, structures and installation costs, marketing and product distribution costs, and interconnect costs. In addition, the report describes the development of an interactive computer program that calculates allowable system prices and allowable generation equipment prices.

Krawiec, Stella. (April 1980). *Economics of Selected WECS Dispersed Applications.* SERI/TR-431-580. Golden, CO: Solar Energy Research Institute; 38 pp.

This report presents an economic analysis for distributed WECS covering the following areas: the cost of electricity generated by selected wind systems in residential and agricultural applications, break-even cost of wind systems able to compete economically with conventional power sources in



Energy production from California's windfarms has been increasing rapidly. (Source: American Wind Energy Association, 1988)

Financing and Financial Incentives. The major institutional obstacle to large-scale wind energy development is the availability of financing, with many of the companies and manufacturers in the field needing to raise capital for the operation and expansion of their businesses.

Because of the high front-end costs of wind machines, consumers often require some form of financial assistance to purchase wind systems. However, traditional financial institutions tend to be conservative in backing new technologies. To alleviate this problem, a number of incentives, along with some actual financial assistance, have been made available by the federal government and various state governments. Most of these focus on various forms of tax incentives usually available to individuals and businesses.

The Wind Industry. One good source of WECS information is the manufacturer or local dealer/distributor of the machine. A wind-machine distributor also may provide anemometers and other wind-measuring devices to assist in siting. The Yellow Pages section of the telephone book is a good place to begin looking for local dealers and distributors.

dispersed applications, and the impact of major economic factors on the cost-performance index.

Jaras, Thomas. (1987). *Wind Energy 1987: Wind Turbine Shipments and Applications.* Great Falls, VA: Stadia, Inc., Wind Data Center; 316 pp.

This book presents statistical information on world wide wind turbine manufacturing, installations and markets with specification data from 150 manufacturers. It includes data on applications such as water pumping and water heating as well as grid connected and isolated power generation.

Sullivan, W. N. (August 1979). *Economic Analysis of Darrieus Vertical Axis Wind Turbine Systems for the Generation of Utility Grid Electrical Power.* SAND78-0962. Albuquerque, NM: Sandia National Laboratories; 4 Vols.

This VAWT economic study attempts to accurately determine the profitable selling price of Darrieus vertical-axis systems produced by a typical manufacturing and marketing firm. This price can then be compared to the electric utility energy saved by the system, allowing potential users to assess the usefulness of the VAWT concept. The basic approach for assessing the selling price is a detailed economic analysis of six actual system designs ranging from 10 to 1600 kW.

Merrill, O.; Schweizer, T.; Chernoff, H.; Conopask, H.; Knowles, R.; and Moyle, R. (August 1985). *Early Market Potential for Utility Applications of Wind Turbines.* EPRI-AP-4077. Palo Alto, CA: Electric Power Research Institute; 200 pp. Work performed by Science Applications International Corporation, McLean, VA.

If installed prices for reliable turbines decline to $1,100/kW (1980 dollars), cumulative nationwide market potential exceeds 21,000 MW by 2000. This figure does not represent a forecast of development levels but rather the potential market under reasonable expectations of electric demand, coal prices, oil prices, and related factors. Extensive sensitivity analyses were conducted to investigate effects of uncertainties in these factors on wind turbine market potential.

Smeallie, Peter H. and Wolff, Benjamin. (May 1980). *Capital Formation for Small Wind Energy Conversion System Manufacturers: A Guide to Methods and Sources.* SERI/STR-98298-1. Golden, CO: Solar Energy Research Institute; 57 pp. Work performed by American Wind Energy Association, Washington, DC.

This report is intended to serve as an introductory resource for raising capital for current or potential SWECS manufacturers, primarily through conventional financial institutions and programs. The report includes an introduction to capital, a business plan, sources of capital, and four case histories.

Vosburgh, Paul N. (1983). *Commercial Applications of Wind Power.* New York: Van Nostrand Reinhold Co.; 279 pp.

This book discusses commercially promising WECS that can generate substantial quantities of electricity

Periodicals such as *Independent Power* and *Windpower Monthly News* are good sources of industry news. See Chapter 8 for a listing of periodicals concerned with wind energy.

Marketing information helps the manufacturers and distributors of wind machines by identifying

- Areas of the country with high WECS market potential
- Issues affecting WECS use
- Strategies to obtain financing
- Strategies to attain sales goals
- Optimum WECS capacity for a specific application.

In the past, the SERI Wind Energy Test Center and its contractors have performed studies and issued reports concerning commercialization and marketing. With the change in focus of the Federal Wind Energy Program, commercialization and marketing are no longer studied. However, there are several private companies listed in Chapter 8 that may provide this information.

Product Liability. Product reliability is an important concern for the wind industry because it can pose a considerable business risk. Manufacturers traditionally respond to liability risks by purchasing product liability insurance as a means of financial protection. Product liability insurance provides coverage to manufacturers for damages awarded to an injured party for personal injury or loss of property alleged to have been caused by a defective product.

For many manufacturers of small wind energy conversion systems, especially the modern units that use aerospace technology, obtaining this kind of insurance protection is difficult. Because the manufacture of modern wind systems is a relatively new field with a short history and little data

(20 kW or more). The growing wind industry is reviewed, and both bulk power and dispersed applications are discussed. WECS technology, including manufacturers, project planning, and development, are presented in enough detail to familiarize the reader with the practical aspects of wind energy systems. The appendices provide information on WECS history, acronyms and definitions, and sources of information.

Small Wind Systems Application Analysis. (June 1981). RFP-3147/2. Golden, CO: Rockwell International; 217 pp. Work performed by JBF Scientific Corp., Wilmington, MA.

The study estimates the potential market of SWECS (less than 100 kW) for farm residences, nonfarm residences, rural electric cooperatives, feed grinders, and remote communities. Specific objectives of the study were to provide assistance to DOE for planning R&D programs that would enable the wind industry to plan for effective growth of production capacity and development of marketable product lines, to identify marketing strategies to help the wind industry obtain financing and achieve sales goals, and to provide DOE with marketing data to help determine what actions should be taken to assist the wind industry.

Osborn, William C. and Downey, William T. (February 1981). *Near-Term High Potential Counties for SWECS.* SERI/TR-98282-11. Golden, CO: Solar Energy Research Institute; 2 Vols. Work performed by Arthur D. Little, Inc., Cambridge, MA.

The report provides market information to manufacturers of small wind energy conversion systems to assist them in developing marketing strategies for their products. The data have been arranged in a format that permits rapid identification of a particular location or market segment for further investigation. Extensive backup information is available by state and county in the appendix.

Hewett, R.; Buchanan, D.; Diksit, P.; Krawiec, S.; and Neybert, A. (September 1980). *Commercial Readiness Assessment of Wind Energy Conversion Systems.* SERI/TR-431-368. Golden, CO: Solar Energy Research Institute; 364 pp.

This report assesses the commercial readiness of four wind technology applications: central wind systems for large utilities, central wind systems for small utilities, distributive wind systems for agriculture, and distributive wind systems for residences.

Bass, L.; Wynholds, H.; Bloedorn, J.; Hodgson, F.; and Herzog, F. (November 1980). *Study of Product Liability Insurance Issues Related to Small Wind Energy Conversion Systems.* RFP-3178-80/21. Golden, CO: Rockwell International; 72 pp. Work performed by Hans W. Wynholds Company, Cupertino, CA.

This study determined that product liability insurance is available to all but the smallest and newest SWECS manufacturers; however, the costs vary considerably. The study was sponsored by DOE to analyze the particular product safety and liability status of the wind industry and to propose strategies for addressing its needs. Eight strategies were identified that would reduce the manufacturer's risk,

on accidents and safety, some insurers have previously been hesitant to provide coverage.

Utility Applications

Electric utilities are the largest potential market for wind machines, especially for those machines in the megawatt power range. However, the use of wind power poses a variety of problems for utilities, primarily because wind is highly variable and cannot be controlled. Determining the impact of intermittent technologies on electrical utilities involves three basic steps: (1) estimating WECS performance, (2) determining the correlation between the time profile of energy produced by the wind system and the time profile of the utility load, and (3) calculating the resulting change in the utility's production costs. Other considerations affecting utilities' use of wind power include terrain and availability of land to the utility, and the economic and technical constraints on wind machine size, rated capacity, and capacity factors.

redistribute the economic burden of product liability, and redefine the concept of acceptable risk.

Noun, Robert. (May/June 1980). "Product Liability and Wind System Manufacturers: Proposals for Protection." *Solar Law Reporter.* (2:1); pp. 73-107.

This overview of product liability law includes a summary of judicial direction in product liability law, the role of standards in assessing potential liability, and the impact of potential liability on wind system product liability insurance. Some potential solutions are suggested.

Wilreker, V. F.; Stiller, P. H.; Scott, G. W.; Kruse, V. J.; and Smith, R. F. (February 1984). *Wind Turbine Generator Interaction with Conventional Diesel Generators on Block Island, Rhode Island.* Volume 1. Executive Summary. DOE/NASA-0354-1. Cleveland, OH: NASA Lewis Research Center; 45 pp. Available NTIS: Order No. DE84015874.

This report summarizes the primary results of a three-part study of the effects of connecting a MOD-0A wind turbine generator to an isolated diesel power system owned and operated by the Block Island Power Company.

Reddoch, T. W. and Barnes, P. R. (July 1981). "Review of Utility Issues for the Integration of Wind Electric Generation." *Large Horizontal-Axis Wind Turbines; Cleveland, OH; 28-30 July 1981.* NASA CP-2230. Robert W. Thresher, ed. Cleveland, OH: NASA Lewis Research Center; pp. 773-781.

This paper reviews the issues and concerns of the electric utility industry regarding the integration of wind generators. The issues have been categorized into three major areas: planning, operations, and dynamic interaction.

Goldenblatt, M. K. and Wegley, H. L. (March 1983). *Analysis of the Effects of Integrating Wind Turbines into a Conventional Utility: A Case Study.* PNL-3962-Rev. Richland, WA: Pacific Northwest Laboratory; 66 pp. Work performed by JBF Scientific Corp., Wilmington, MA.

This report analyzes three aspects of integrating wind turbines into an existing utility generation system: the impact of wind speed sampling frequency, wind turbine model accuracy, and wind speed forecasting accuracy.

Marah, Frederic; Dlott, Edward H.; Korn, Donald H.; Madio, Frederick R.; McArthur, Robert C.; and Vachon, William A. (1982). *Wind Power for the Electric-Utility Industry.* Lexington, MA: D.C. Heath and Company, Lexington Books; 159 pp.

This book is based on a study of the economics of solar-electric/conservation technologies including wind as fuel-saving investments for electric utilities.

Noun, Robert J.; Lotker, Michael; and Friesema, H. Paul. (May 1981). *Utility Siting of WECS: A Preliminary Legal/Regulatory Assessment.* SERI/TR-744-778. Golden, CO: Solar Energy Research Institute; 105 pp.

This report discusses difficult legal and regulatory issues in siting WECS, including land use and environmental impact.

System Dynamics of Multi-Unit Wind Energy Conversion Systems Application. (February 1978). DSE-2332-T (1-3). Valley Forge, PA: General Electric Company; 3 Vols.

This study provides design information for the interface of wind machines with electric utility power systems.

Existing Projects. Although wind-generated electricity does not yet constitute a significant portion of our utility power, a number of utilities are becoming interested in wind energy systems and have sponsored various projects. These projects range from hosting DOE wind turbine field experiments (such as the 200-kW MOD 0A turbines by four utilities) to collecting data on the weather (such as the wind survey used to evaluate the wind resource potential for the Seattle Department of Lighting). For example, a study conducted by EPRI in 1980 found that 91 utilities were sponsoring 152 wind energy projects. A follow-up study conducted by EPRI the next year showed an increase in both the number of utilities involved and the number of projects. Additionally, the National Rural Electric Cooperative Association (NRECA) conducted two surveys in 1982 identifying 30 rural electric utilities that were sponsoring wind projects, along with 130 rural utilities that already have small wind generators interconnected to their grids.

Operational Impacts of Wind Arrays. Economies of scale and simplified logistics favor the use of windfarms or arrays (rather than dispersed individual turbines) for large utility applications. Such windfarms or arrays are connected to high voltage transmission lines in much the same way as conventional power plants, operating as part of the overall generation mix. However, unlike conventional generating sources, the wind is an intermittent resource. Such intermittency can cause the output of a windfarm or array to fluctuate (often by the minute), which in turn could adversely affect the operation of the grid. These adverse effects could be magnified if wind power comprises a large proportion of the system's generating capacity.

However, if the output fluctuations of a windfarm or array are limited or can be anticipated, or if the wind-generating plant is coupled with versatile generating sources, the adverse effects of wind power fluctuations on the grid could be reduced significantly.

McCabe, T.; Henry, G.; Tennis, M.; and Goldenblatt, M. (January 1984). *Early Utility Experience with Wind Power Generation.* EPRI AP-3233. Palo Alto, CA: Electric Power Research Institute; 3 Vols. Prepared by JBF Scientific Corp., Wilmington, MA.

This project helped improve the understanding of wind power generation, in particular the process a utility must undergo to initiate and carry out a wind turbine project. The report presents the experiences of two utilities, Pacific Gas and Electric Company and Bonneville Power Administration, with wind turbine projects at Ilano County, California, and Goodnoe Hills, Washington. Condensed descriptions of the projects, a comparison of the projects, and highlights of the utilities' experiences are presented.

Reddoch, T. W.; Barnes, P. R.; Lawler, J. S.; and Skroski, J. C. (May 1982). "Strategies for Minimizing Operational Impacts of Large Wind Turbine Arrays on Automatic Generation Control Systems." *Journal of Solar Energy Engineering.* (104:2); pp. 65-69.

The article considers several potential operating concepts that could improve the effectiveness of wind arrays in utility systems.

Chan, S. M.; Curtice, D.; and Chang, S.-K. (October 1983). *Methods for Wind Turbine Dynamic Analysis.* EPRI AP-3259. Palo Alto, CA: Electric Power Research Institute; 272 pp. Prepared by Systems Control, Inc., Palo Alto, CA.

The analytical tools needed to study the effects of wind turbines on utility networks and system operations were developed in this project. Methods for computing the additional costs are also identified.

Wind Power Generation Dynamic Impacts on Electric Utility Systems. (November 1980). EPRI/AP-1614. Palo Alto, CA: Electric Power Research Institute; 90 pp. Work performed by Zaninger Engineering Company, San Jose, CA.

This study assesses potential dynamic impacts on electric utility systems from integrating clusters of large wind turbines, including short-term transient stability; system frequency excursions; and minute-to-minute, unit-ramping limitations of conventional system generation.

Younkins, T. D. (April 1987). *Methodology for Control and Operation of Wind Arrays in Utility Systems: Final Report.* ORNL/Sub/81-7242/1. Oak Ridge, TN: Oak Ridge National Laboratory; 290 pp. Available NTIS:

Assessment Methods. Economic assessments of intermittent, grid-connected solar electric technologies help provide an understanding of what these technologies must cost to compete with conventional technologies. The assessments also offer techniques for performing sensitivity analyses of certain economic policy variables and indicate economic methods of displaying results in an understandable manner. In centralized utility applications, the time profiles of power produced from the solar plant and the utility's load will determine the extent to which a solar plant can displace conventional fuel and capacity costs. Because intermittent solar electric technologies generally have higher capital costs per kilowatt of capacity but lower operation costs per kilowatt-hour than conventional units, a utility would seek to minimize operating costs by using power from the solar plant whenever possible.

Various methods are used to determine the potential value of a wind system for a particular utility. In general, the WECS value is the amount a utility can afford to pay for a wind turbine based on its performance and the fuel cost savings if the wind system is installed. Because WECS provide intermittent power, they cannot be represented directly in utility planning models. Therefore the economic assessment often analyzes first a base case (without WECS) and then an alternative case that includes wind turbines.

Order No. DE87008546. Work performed by General Electric Company, Electric Utility Systems Engineering Department, Schenectady, NY.

The report describes a method by which utilities can determine whether control of wind turbine arrays is needed on an automatic generation control timescale (seconds to minutes). Limited simulations of three utility systems are also presented.

Flaim, Theresa and Hock, Susan. (May 1984). *Wind Energy Systems for Electric Utilities: A Synthesis of Value Studies.* SERI/TR-211-2318. Golden, CO: Solar Energy Research Institute; 112 pp.

This report normalizes and interprets the results from eight value analysis studies that estimate WECS value to utilities.

Kaupeng, B. M. (February 1983). *Assessment of Distributed Wind Power Systems.* EPRI AP-2882. Palo Alto, CA: Electric Power Research Institute; 364 pp. Work performed by General Electric Company, Schenectady, NY. Available from EPRI Research Reports Center, Palo Alto, CA.

This project developed and verified a method for assessing the potential impacts of connecting wind turbines to a utility system at distribution and subtransmission voltage levels.

Percival, David and Harper, James. (January 1982). *Electric Utility Value Determination for Wind Energy.* SERI/TR-732-604R. Golden, CO: Solar Energy Research Institute; 2 Vols.

This report describes a method that electric utilities can use to determine the value of wind energy systems. It is performed by a package of SERI computer models for use with most utility planning models.

Requirements Assessment of Wind Power Plants in Electric Utility Systems. (January 1979). EPRI/ER-978-SY. Palo Alto, CA: Electric Power Research Institute; 3 Vols. Work performed by General Electric Company, Schenectady, NY.

This report describes a method of assessing the prospects for wind generation in the service areas of individual electric utilities and an assessment of the interaction between wind generation and electric energy storage, development of preliminary penetration scenarios, and formulation of research and development recommendations.

Small-Scale Applications

System Selection. Applications for wind systems that produce less than 100 kW are oriented mainly toward residences and agriculture. Some of these applications include total or supplementary electrical supply for a home, farm, or small business; building heating; product processing and storage; hot water for residential and other uses; and pumping water or oil. Wind energy use in small producer-consumer units is likely to be more feasible if it can be coordinated with other energy sources and if it can be used to supply energy needs other than electrical.

Park, Jack. (1981). *The Wind Power Book.* Palo Alto, CA: Cheshire Books; 253 pp.

This book provides the potential small-scale wind system user with information about design and construction. Appendices contain detailed charts, tables, and diagrams that provide additional information on the book's topics.

To select the appropriate small wind system for a particular application, the user must determine power needs (otherwise known as load requirements) and estimate the wind system's power output at the selected site. This process of matching user requirements with the machine's capabilities is often referred to as sizing.

Moment, R. L. (February 1983). *Performance and Size Estimating for Wind Systems.* RFP-3586. Golden, CO: Rockwell International Corporation; 69 pp.

A method is described for estimating WECS performance given rated wind speed and annual energy production in common wind regimes (10 to 18 mph) for rotor diameters ranging from 10 to 140 ft. Curves are included for the various wind regimes and rotor sizes, allowing the reader to estimate performance for a given size machine or to select the rotor size required to produce a given amount of energy.

Wilson, J. E.; Schreibel, R. L.; Neal R.; Berube, N.; and Heffner, G. C. (August 1982). *Federal Applications for Wind Energy Systems.* SERI/STR-211-1707. Golden, CO: Solar Energy Research Institute; 138 pp. Work performed by JBF Scientific Corp., Wilmington, MA.

The report presents the results of a study that determined federal government sites at which wind systems are economically competitive with the marginal costs of new conventional energy sources.

Interconnection Issues. The most likely future application of small wind turbines is for a number of customer-owned machines, located on the owner's property, to be dispersed throughout the utility system. These will produce ac power, either directly or through dc power fed into an inverter. In this configuration, the wind turbines will not have on-site storage systems but will be interconnected to the utility so that when the wind is blowing, surplus power automatically flows back into the distribution system. This wind turbine system configuration offers many advantages of abundant power on demand but poses a number of potential technical problems for the wind turbine owner and the utility system. Principal among these problems are utility personnel safety and operational problems caused by a large number of widely distributed generation sources subject to rapid power output fluctuations, and by the utilities' lack of access to these generation sources.

Curtice, David and Patton, James. (March 1981). *Operation of Small Wind Turbines in a Distribution System.* RFP-3177-1 and 2. Golden, CO: Rockwell International; 2 Vols. Work performed by Systems Control Inc., Palo Alto, CA.

This study analyzes technical interconnection problems with dispersed wind turbine applications. Specific objectives include analysis of utility personnel safety, distribution system and wind turbine protection equipment, wind turbine effects on line losses and distribution feeder voltage and regulation equipment, and development of a method to analyze utility load-frequency control problems.

Tower and System Installation. The purpose of the supporting tower is to securely hold the wind device at the recommended height for the specific system. Towers must be designed to withstand the lateral thrusts produced by high winds acting on the blades; they must also be equipped with special top adaptors designed to fit the particular wind turbine to be installed. They should be equipped with lightning protection kits and anti-climb devices. In general, towers are made in two basic configurations: guy-wire supported or cantilever (freestanding). Most manufacturers guarantee their wind machines only if they are mounted on an approved tower.

Hunt, V. Daniel. (1981). "Towers and Systems Installation." *Windpower: A Handbook on Wind Energy Conversion Systems.* New York: Van Nostrand Reinhold Co.; pp. 131-146.

This chapter describes the requirements that a wind system tower must meet and discusses several types of acceptable and unacceptable towers. Detailed information is provided on two commercial towers and on considerations for siting and tower-height determination.

Installation of a power-producing wind system includes the following steps: tower raising, WECS raising, wiring, lightning protection, and installation of other equipment (such as switch gear or batteries). Proper installation and regular maintenance are necessary for the safe and efficient operation of the wind system.

Residential Installations. Most residential use of small wind turbines is for supplying part or all of the home's electrical needs. To determine the type and size of machine needed, the site's wind resource must be evaluated and the expected electric load estimated. Because the wind system cannot supply power all the time, the owner must plan to install other generating sources or interconnect with the utility. The second option has

Gipe, Paul. (1983). *Wind Energy: How to Use It.* Harrisburg, PA: Stackpole Books; 400 pp.

Park, J., Schwind, D. (September 1978). *Wind Power for Farms, Houses, and Small Industry.* RFP-2841/1270/78/4. Mountain View, CA: Nielsen Engineering and Research, Inc.; 229 pp.

become the most popular solution to the wind's intermittency, and most of today's small wind machines are designed for utility interconnection.

In addition to *The Wind Power Book* cited previously, several publications describe the use of wind systems for residential applications.

Agricultural Installations. Various stationary (nonvehicular) agricultural tasks could be adapted to use wind energy. Principal applications of wind energy for agriculture are general farmstead power (primarily electrical), building heating, irrigation pumping, product storage and processing, and hot water for residences and dairies. Most of these applications will require small wind systems ranging from 10 kW to 100 kW and perhaps even small windfarms. Field tests have indicated that, in general, the wind system must be used throughout the year to be economically viable. However, single applications that include a storage system also may be viable.

Since 1976 the Agriculture Research Service (USDA-ARS) of the U.S. Department of Agriculture has been conducting field experiments to identify, develop, and test applications of wind power in agriculture. Additional studies have been conducted on economics and load requirements for wind machines. Six field experiments were completed in 1980, two each in building heating, irrigation, and product storage and processing.

Information is presented concerning basic wind turbine energy conversion, wind behavior and site selection, power and energy requirements, components of a WECS, selecting a WECS, and system economics, and legal aspects.

Marjan, P. L., and Clark, R. Nolan. (November 1982). *Evaluation of Pumps for Wind-Driven Irrigation.* DOE/ARS-7315-20741/83/1; 174 pp. Work performed by Science Applications, Inc., Albuquerque, NM, and Agricultural Research Service, U.S. Department of Agriculture, Bushland, TX.

A survey of pumping equipment for wind power irrigation applications.

Gilley, J. R. (July 1985). "Potential Use of Wind Power for Pumping Irrigation Water." *Energy Agriculture.* (4:2); pp. 133-146.

The potential energy savings from three types of wind-powered irrigation pumping plants were determined for selected areas of the United States. The wind systems analyzed were wind-assist combustion engines; wind-assist electric motors, with and without the sale of surplus electricity; and a stand-alone turbine with a reservoir for water storage.

Hagen, L. J. and Sharif, M. (1981). *Darrieus Wind Turbine and Pump Performance for Low-Lift Irrigation Pumping.* DOE/ARS-3707-20741/81/1. Manhattan, KS: Kansas State University; 65 pp. Available NTIS: Order No. DE82016270.

Specific objectives of this investigation were to design, construct, and analyze the performance of a prototype wind-powered system for low-lift (less than 15 m head) irrigation pumping.

David, Milton L.; Buzenberg, Robert J.; Glynn, Earl F.; Johnson, Gary L.; Shultis, J. Kenneth; and Wagner, John P. (August 1979). *Wind Energy Applications in Agriculture, Final Report; Executive Summary.* DOE/SEA-1109-20401/79/2; 210 pp. Beltsville, MD: Science and Education Administration, U.S. Department of Agriculture. Work performed by Development Planning and Research Associates, Manhattan, KS.

The economics and market potential for wind turbine applications in U.S. agriculture are analyzed in this report.

Garling, W. S.; Haufer, M. R.; Merchant-Geuder, L.; and Welch, M. (March 1980). *Economic Analysis of Wind-Powered Refrigeration Cooling/Water Heating Systems in Food Processing.* DOE/SEA-1109-20401/81/1. 150 pp. Work performed by Tetra Tech, Inc., Arlington, VA.

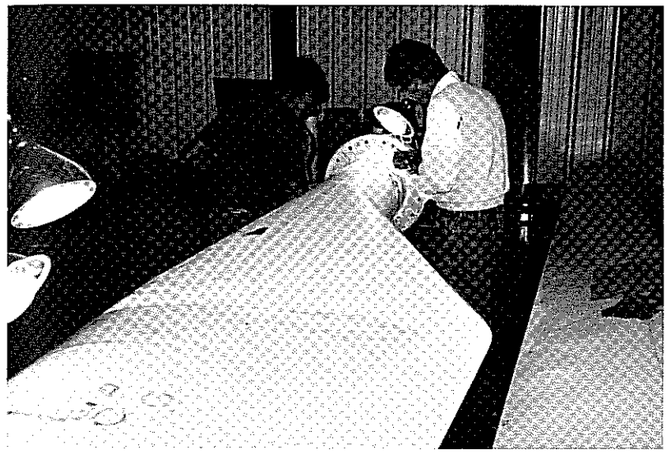
This study analyzed the economic feasibility of wind power in refrigeration cooling and water heating systems in food processing plants, including meat and poultry, dairy, fruit and vegetable, and aquaculture.

Gunkel, W. W.; Lacey, D. R.; Neyeloff, S.; and Porter, T. G. (May 1981). *Wind Energy for Direct Water Heating; Final Report.* DOE/SEA-3408-20691/81/2. 74 pp. Work performed by Cornell University, Ithaca, NY.

The report presents the results of the research project Wind Energy Substitution at Dairy Milking Centers, including the development of an energy conversion unit for direct conversion of shaft power to heat, results of a one-year field test, and mechanical repair and maintenance experience.

Stafford, R. W.; Greeb, F. J.; Smith, M. F.; Des Chenes, C.; and Weaver, N. L. (January 1981). *Economic Analysis of Wind-Powered Farmhouse and Farm Building Heating Systems; Final Report.* DOE/SEA-3408-20691/81/1. 360 pp. Work performed by Regional Systems Services Group, Inc., Englewood, CO.

The study evaluated the break-even values of wind energy for selected farmhouses and farm buildings, focusing on the effects of thermal storage on the use of WECS production and value.



An engineer from Northern Power Systems (left) and a researcher from Sandia National Laboratories (right) mount gauges on a blade used in fatigue and dynamic response tests.

Gilley, J. R. (April 1980). *On-Farm U.S. Irrigation Pumping Plants; Final Report.* DOE/SEA-7315-20741/18/1. 60 pp. Work performed by Southwest Research and Development Company, Las Cruces, NM.

The report presents the results of a USDA-funded study of water pumping equipment on U.S. farms. Distribution of these units by geographic regions and potential wind power zones is presented.

Clark, R. N.; Schneider, A. D.; Nelson, V.; Gilmore, E.; and Barieau, R. E. (January 1981). *Wind Energy for Irrigation—Wind-Assisted Pumping from Wells; Final Report.* DOE/SEA-7315-20741/81/3. 77 pp. Work performed by Science and Education Administration, U.S. Department of Agriculture, Bushland, TX, and Alternative Energy Institute, West Texas State University, Canyon, TX.

The report describes a USDA-funded study of water pumping using a vertical-axis turbine.

Lansford, R. R.; Supalla, R. J.; Gilley, J. R.; and Martin, D. L. (July 1980). *Economics of Wind Energy for Irrigation Pumping; Final Report.* DOE/SEA-7315-20741/81/2. 89 pp. Work performed by Southwest Research and Development Company, Las Cruces, NM.

This study addresses some of the economic questions associated with wind power as an energy source for irrigation under different situations in seven regions of the nation.

Stafford, R. W., and Soderholm, L. H. (March 1983). *Analysis of Problems of Interfacing Wind Systems to Rural Power—Distribution Systems; Final Report.* DOE/ARS-3408-20691/83/1. 216 pp. Work performed by Regional Systems Services Group, Inc., Englewood, CO, and Agricultural Research Service, U.S. Department of Agriculture, Ames, IA.

The report includes an updated survey and prioritization of interconnection problems and issues, a working guide that correlates WECS references with the interconnection concerns, a recommendation of WECS interconnection analyses; an analysis of potential harmonics and their effect on rural services, and a quantitative analysis of metering options.

Chapter 6
General Issues

Environmental Effects

Wind energy developers are in the unusual position of being able to determine potential environmental impacts prior to the expanded use of the resource. On a broad level, environmental effects can include aesthetic effects, TV interference, noise, safety factors, socioeconomic impacts, habitat impacts, effects on animal life, and effects on microclimate and vegetation.

Rogers, S. E.; Cornaby, B. W.; Redman, C. W.; Sticksel, P. R.; and Talle, D. A. (December 1977). *Environmental Studies Related to the Operation of Wind Energy Conversion Systems.* COO-0092-77/2. Columbus, OH: Battelle Columbus Laboratories; 108 pp.

This assessment explores the possible environmental impacts determined through field studies of a 100 kW experimental wind turbine at the NASA Lewis Research Center.

Phillips, Paul D. (May/June 1979). "NEPA and Alternative Energy: Wind as a Case Study." *Solar Law Reporter.* (1:1); pp. 29-54.

The report uses two WECS scenarios to illustrate the applications of the basic legal requirements of the National Environmental Policy Act (NEPA) of 1969, with its environmental impact statement requirement.

Medsker, Larry. (December 1982). "5. Wind Energy Conversion (WEC)." *Side Effects of Renewable Energy Sources.* EPRD Report #5. New York: National Audubon Society; pp. 36-39.

The chapter includes a two-page chart summarizing the ways to mitigate the environmental impact of a wind energy system on land, water, air, wildlife and flora.

Lawrence, Kathryn A. and Strojan, Carl L. (May 1980). *Environmental Effects of Small Wind Energy Conversion Systems (SWECS).* SERI/TP-743-628. Golden, CO: Solar Energy Research Institute; 16 pp.

This paper reviews the potential pollution releases and risks that might result from the manufacture, operation and maintenance, and decommission of small WECS (power ratings of 2, 8, and 50 kW).

Television Interference. An issue of particular concern for WECS located near human habitations is electromagnetic interference, especially with television signals. The rotating blades of a horizontal-axis wind turbine can distort the video portion of a television signal and thereby interfere with TV reception in the vicinity of the machine. Interference decreases with distance from the machine, but it can still affect the upper UHF channels at distances of several kilometers. Even when the blades are stationary, the scattered signal may appear on the TV screen as a ghost.

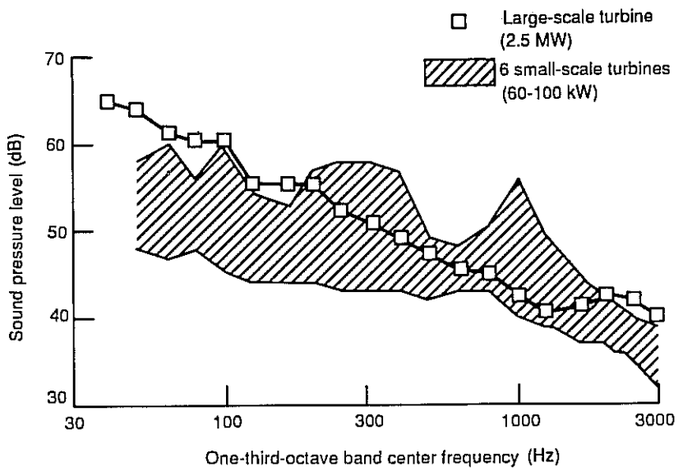
Senior, Thomas B. A. and Sengupta, Dipak L. (January 1983). *Large Wind Turbine Siting Handbook: Television Interference Assessment.* SERI/STR-215-1879. Golden, CO: Solar Energy Research Institute; 54 pp. Work performed by Radiation Laboratory, Department of Electrical and Computer Engineering, University of Michigan, Ann Arbor, MI.

This handbook describes the prediction of the region where a large horizontal-axis wind turbine can significantly affect the reception of television signals.

Sengupta, D. L.; Senior, T. B.; and Ferris, J. E. (January 1983). *Study of Television Interference by Small Wind Turbines.* SERI/STR-215-1880. Golden, CO: Solar Energy Research Institute; 43 pp. Work performed by University of Michigan, Ann Arbor, MI. Available NTIS.

Television signal interference by small wind turbines (rated at about 5 kW) was studied using scale

Noise. A wind turbine generator may produce noise with both impulsive ("thumping") and broadband ("swishing") characteristics. The low-frequency impulsive noise tends to be the most annoying because it dominates other sources and can cause structures to shake. However, not all types of machines produce this noise. The effects of wind turbine noise on the listener may be modified by factors such as the background noise level, location of the listener (indoors/outdoors), and the presence of any perceptible house vibrations induced by the noise. Any noise from a wind turbine tends to be masked by the noise of the wind itself, and of course, the machines do not run when the wind is still.



Noise spectra from large- and small-scale HAWTs with upwind rotors at a downwind distance of 2.5 rotor diameters.

Safety Concerns

One barrier to the widespread use of wind machines is concern about safety. Safety determination involves the acceptability of known risks. Although the risks presented by wind machines do not appear great, there are dangers posed during installation, operation, repair, and maintenance. Because there are few actual data on wind machine safety, safety engineering techniques are used to predict the ways in which a machine can fail and the likelihood and consequence of such failure.

models in conjunction with a microwave TV system inside an anechoic chamber. Two- and three-bladed windmills with metallized and wooden blades were investigated; results were extrapolated to give the interference effects of the full-scale machines.

Stephens, David G.; Shepherd, Kevin P.; Hubbard, Harvey H.; and Grosveld, Ferdinand W. (March 1982). *Guide to the Evaluation of Human Exposure to Noise from Large Wind Turbines.* NASA/TM-83288. Hampton, VA: NASA Langley Research Center; 70 pp.

This document will assist in designing and siting future large WECS as well as in assessing the noise environment of existing WECS. Guidance for evaluating human exposure to wind turbine noise is provided, including consideration of source characteristics, propagation to the listener's location, and exposure of the listener to the noise.

Viterna, L. A. (1982). *Method for Predicting Impulsive Noise Generated by Wind Turbine Rotors.* NASA TM-82794. Cleveland, OH: NASA Lewis Research Center; 4 pp. Presented at the 1982 International Conference on Noise Control Engineering; San Francisco, CA; 17-19 May 1982.

The report describes a method of calculating the impulsive noise generated when the wind turbine blade experiences air forces that are periodic functions of the rotational frequency. Results from this method are compared with measured sound spectra taken at locations of one to two rotor diameters from the DOE/NASA MOD-1 wind turbine.

Kelley, N. D.; McKenna, H. E.; Hemphill, R. R.; Etter, C. L.; Garrelts, R. L.; and Linn, N. C. (February 1985). *Acoustic Noise Associated with the MOD-1 Wind Turbine: Its Source, Impact, and Control.* SERI/TR-635-1166. Golden, CO: Solar Energy Research Institute; 232 pp.

This report summarizes extensive research conducted to establish the origin and possible amelioration of acoustic disturbances associated with the DOE/NASA MOD-1 wind turbine near Boone, N.C.

Bass, Lewis and Weis, Patricia. (September/October 1981). "Safety Standards Development for Small Wind Energy Conversion Systems." *Solar Law Reporter.* (3:3); pp. 453-476.

The article discusses safety concerns of consumers, building code officials, zoning commissions, and utilities as well as the importance of these groups for WECS acceptance. The kinds of safety standards that could be developed for small wind machines are summarized, and procedures for creation of either consensus or regulatory standards are explained.

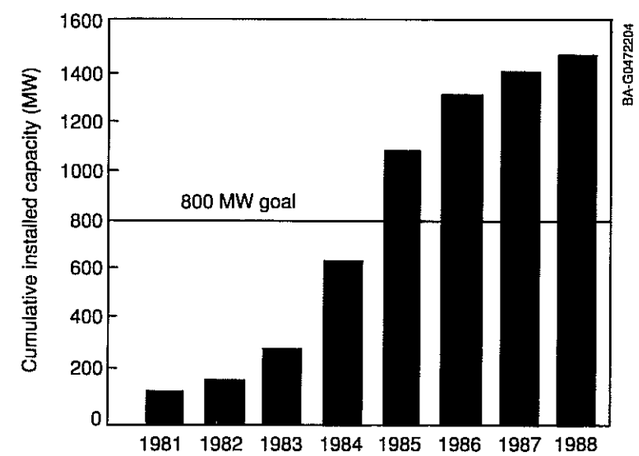
Legal-Institutional Implications of Wind Energy Conversion Systems (WECS); Executive Summary. NSF/RA-770203. *Final Report.* NSF/RA-770204; 332 pp. (September 1977). Work performed by the Program of Policy Studies in Science and Technology, George Washington University, Washington, DC.

The report discusses wind systems, their applications, and the interplay between technical, economic, social, and legal issues. Significant legal obstacles to the use of land-based WECS are described, as are existing legal features that may

Legal and Institutional Issues

Before the potential of wind energy can be realized, large-scale commercialization must occur. Such large-scale development may bring wind energy into conflict with a number of existing legal and institutional practices. Major considerations for siting wind machines are the effects of existing land-use policies and regulations, particularly zoning, and the need for new regulations, especially ones guaranteeing access to the wind. Legal considerations affecting WECS operation include building codes, safety regulations, and environmental regulations. The major institutional barrier to large-scale wind energy development is financing. Traditional financial institutions tend to be conservative in backing new technologies; therefore, financial incentives are useful for breaking down this prejudice.

These legal and institutional barriers can be changed by the pressure of public opinion. Public acceptance depends on the perception of wind as



The U.S. wind industry has exceeded the goal of 800-MW installed capacity set by the Wind Energy Systems Act of 1980.

facilitate use. A separate section is devoted to offshore wind systems.

Reilly, Dwight H. (June 1979). *Safety Considerations in the Design and Operation of Large Wind Turbines.* DOE/NASA/20305-79/3; NASA TM-79193. Cleveland, OH: NASA Lewis Research Center; 39 pp.

The report describes the process used to assure safety in the design and operation of the MOD-2 wind turbine, considered representative of large wind turbines.

Bankaitis, H. (1981). *Lightning Accommodation Systems for Wind Turbine Generator Safety.* NASA TM-82601. Cleveland, OH: NASA Lewis Research Center; 13 pp.

Several candidate methods of lightning accommodation for each blade were designed, analyzed, and tested by submitting sample blade sections to simulated lightning strikes. This activity was directed at defining design and procedural constraints, requirements for safety devices and warning methods, special procedures, protective equipment, and personnel training.

Coit, Lynde. (June 1979). *Wind Energy: Legal Issues and Institutional Barriers.* SERI/TR-62-241. Golden, CO: Solar Energy Research Institute; 28 pp.

This report discusses the implications of various institutional and legal barriers to the commercial development of wind energy systems, guaranteed access to the wind, environmental law issues, and the need for financial incentives.

Noun, Robert J. (September 1981). *Siting and Land-Use Considerations in Wind Energy Development.* SERI/TP-211-1410. Golden, CO: Solar Energy Research Institute; 8 pp.

This paper examines several methods for acquiring and preserving access to the wind resource and for dealing with related land-use issues.

Dodge, D. M. and Lawless-Butterfield, C. (May 1982). *Small Wind Systems Zoning Issues and Approaches.* RFP-3386. Golden, CO: Rocky Flats Wind Energy Research Center; 60 pp.

This report discusses the zoning requirements for siting wind turbines as well as common safety and environmental issues. The appendix consists of an annotated series of approaches to zoning issues, taken from ordinances proposed or enacted in various localities throughout the United States.

Public Reactions to Wind Energy Devices. (October 1977). NSF/RA 77-0026. Washington, DC: National Science Foundation; 215 pp. Work performed by Survey Research Laboratory, University of Illinois, Urbana, IL.

The objectives of this study are to provide information on public acceptance of different kinds of wind energy devices in different settings and to furnish a base for more intensive studies of public acceptance of such devices.

Federal Legislation

In the past decade, Congress has enacted a wide range of energy legislation with the dual goals of reducing the nation's dependence on imported oil and encouraging the development of domestically abundant or renewable energy technologies. Many of these laws affect directly or indirectly the development and use of WECS. Perhaps the most well known of the WECS-related legislation are the Public Utility Regulatory Policies Act of 1978 (PURPA) and the Wind Energy Systems Act of 1980 (WESA).

PURPA, which became federal law as part of the National Energy Act on November 9, 1978. (16 U.S.C. 2601 *et seq.*), encourages conservation and efficient use of energy resources by public utilities. One way to do this is to encourage cogeneration and small power production. Sections 201 and 210 of PURPA encourage these forms of electricity production by mandating that electric utilities purchase from and sell to cogeneration and small power producing facilities, and exempting these facilities from certain regulations. In early 1980 the Federal Energy Regulatory Commission (FERC) issued final regulations implementing sections 201 and 210, which required that state utility commissions and unregulated utilities must have begun implementing these regulations by March 20, 1981.

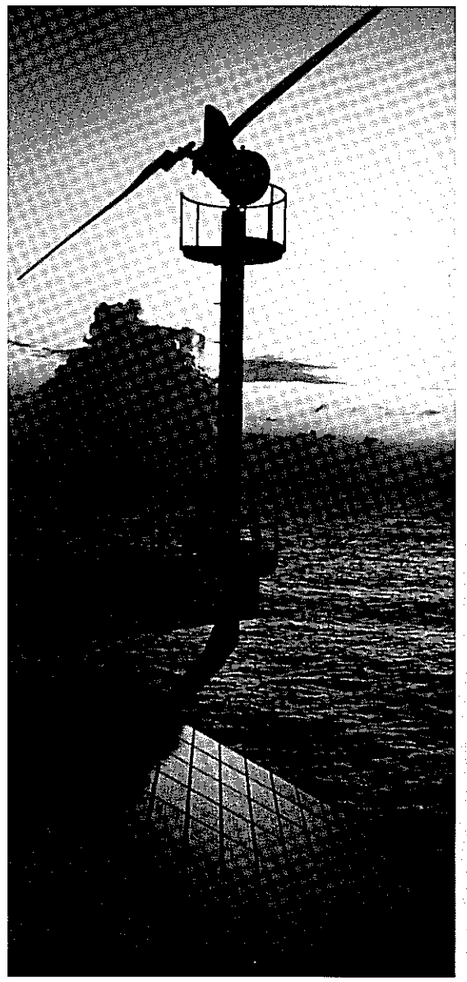
Implementation of this law has been slow as a result of two court challenges to PURPA. In February 1981, a Mississippi federal court declared Titles I, II, and Section 210 unconstitutional; however, this ruling was, in turn, struck down by the U.S. Supreme Court in June 1982. In another case, a U.S. Court of Appeals for the District of Columbia Circuit invalidated two provisions of Section 210 relating to the full avoided cost and interconnection rules. FERC appealed this ruling, and in May 1983, the U.S. Supreme Court reversed the decision of the U.S. Court of Appeals and upheld the PURPA rules on interconnection and avoided cost.

The Wind Energy Systems Act of 1980 (P.L. 96-345) was enacted by Congress on September 8, 1980. The Act set U.S. policy "to establish during the next eight years an aggressive research, development, demonstration and technology applications program for converting wind energy into electricity and mechanical energy." Three of the major goals identified in the Act were achieved before FY 1988, the target year.

- **Reduce the average cost of electricity.** The Act specified that the average cost of electricity produced by commercial WECS should be reduced to a level competitive with that of conventional energy sources. Today, the average cost of wind energy is as little as $0.08/kWh, making wind power competitive with nuclear power in some areas.
- **Reach a total installed capacity of at least 800 MW.** The Act specified that at least 800 MW of wind system capacity should be installed by the end of FY 1988. This goal was exceeded, with 1400 MW of installed capacity in California alone.
- **Accelerate the growth of a viable and competitive industry.** Although the number of wind turbine installations has declined each year since 1985, the wind industry has experienced steady growth in electricity production. New capacity in California decreased from 160 MW in 1987 to 67 MW in 1988. The total installed capacity dropped slightly because of the retirement of older machines, but the amount of electricity sold to California's utilities increased from about 1.7 billion kWh in 1987 to 1.8 billion kWh in 1988. This growth can be tied to the greater power output per unit of swept area of newer machines as well as better operating strategies and more effective maintenance techniques that lead to greater availability.

Lornell, Randi and Schaller, David A. (January 1982). *Small Power Production and Wind Energy: Regulatory Actions Under PURPA.* SERI/SP-635-794. Golden, CO: Solar Energy Research Institute; 64 pp.

This report provides electric utilities and their regulatory authorities with a clear perspective of section 201 and 210 rules under PURPA as they may affect decisions on the integration of small wind energy systems to electric distribution networks.



The Tactical Aircrew Combat Training System (TACTS) hybrid power system was designed by Northern Power Systems under contract to the U.S. Navy.

Chapter 7
Catalog of Current Research Centers

This chapter identifies organizations currently engaged in some form of wind energy research. During December 1987, SERI asked individuals from each organization to provide a description of their wind research activities and a list of information contacts. The entries were composed directly from the responses to this survey.

AeroVironment, Inc.

Performs studies for U.S. government agencies and for private U.S. and international organizations. Activities within the group include extensive work on wind energy resource assessment, development of commercial wind energy farms, and development of analytical models for wind-diesel systems. The company also develops and sells wind monitoring instruments internationally.

AeroVironment, Inc.
Wind Energy Group
145 Vista Avenue
Pasadena, CA 91107
(213) 449-4392

Key Personnel: Peter Lissaman, Vice President, Aeroscience, and Director, Wind Energy Group (aerodynamics, wind energy systems research, wind resource assessment, windfarms);Thomas Zambrano, Manager, Wind Resource Assessment.

Agricultural Research Service U.S. Department of Agriculture

See *U.S. Department of Agriculture, Agricultural Research Service*

Alternative Energy Institute West Texas State University

See *West Texas State University*

Arctic Environmental Information and Data Center University of Alaska

See *University of Alaska*

Associated Weather Services

Offers scientific consulting and research services to government, industry, and electric utilities. The organization is active in the fields of wind resource assessment, environmental impact, wind tunnel and numerical modeling, economic evaluation, and technology assessment.

For the past four years it has been conducting a wind energy feasibility study for the Niagara Mohawk Power Corporation and its 25,000-square-mile service territory. Five multilevel meteorological stations were operated for a year, complemented by tethered aerodynamically lifted anemometer (TALA) kite studies. The wind flow over a complex ridge line is being modeled in a wind tunnel. Wind turbine performance evaluations for numerous commercially available units have been modeled, and the feasibility study addressing as much as 100 MW of installed capacity has been completed.

Associated Weather Services
3 Computer Drive
Albany, NY 12205
(518) 458-2263

Key Personnel: Bruce H. Bailey, Project Manager, Wind Energy Studies (resource assessment, economic feasibility, technology assessment and application, environmental impact).

Another study focuses on the assessment of existing and emerging wind system technologies that offer the potential to generate economical electricity in New York State's moderate wind regime. This study is sponsored by the Empire State Electric Energy Research Corporation. The assessment includes the review of refinements to state-of-the-art technology as well as innovative concepts still in the development phase. The objective is to identify, through rigorous engineering and economic evaluation, the most promising concepts that New York's utilities should pursue. Research and testing plans will be developed for these concepts.

Battelle Pacific Northwest Laboratories

See *Pacific Northwest Laboratory (PNL)*

Bechtel Group, Inc.

Conducts wind energy activities such as engineering for a large windfarm project in Hawaii, planning a Caribbean windfarm demonstration and testing program for the European Development Fund, and evaluating wake effects on energy production in an Altamont Pass wind turbine array for Pacific Gas and Electric Company. Bechtel has also conducted EPRI-funded windfarm studies involving conceptual design, performance, and economic assessments for large horizontal-axis and intermediate vertical-axis wind turbines in a utility context. Company-funded conceptual designs of hybrid wind and photovoltaic power generation facilities have been conducted for use at isolated desert communities.

Bechtel Group, Inc.
Research and Engineering
P.O. Box 3965
San Francisco, CA 94119
(415) 768-1947

Key Personnel: Jack R. Darnell, Supervisor, Energy Program Department; Pascal DeLaquil, Supervisor, Renewable Energy Group; Robert Lessley, Program Manager, Wind Systems.

Bergey Windpower Co., Inc.

Works with all aspects of wind power, including research, design, manufacturing, and installation. Bergey conducts research in the general areas of wind power design, aerodynamics, and composite-material analysis and testing. Current and recent projects include direct electric water pumping (DOE), ultrasonic inspection of high strength composites (DOD), and wind power demonstration programs (U.S. Agency for International Development). The company also designs and manufactures a range of w ind power generators for both utility intertie and remote operations.

Bergey Windpower Co., Inc.
2001 Priestley Avenue
Norman, OK 73069
(405) 364-4212

Key Personnel: Karl H. Bergey, Chairman; Michael L. S. Bergey, President; (WECS design and system analysis, aerodynamic testing, nondestructive evaluation of composite materials).

Bertoia Studio, Ltd.

Designs wind systems. The company developed a 3-kW Aesthetic Energy Systems (AES) wind system for slow-wind performance and long life. The studio's goal is to sell two wind systems per year to increase the aesthetic, electrical, and environmental value per owner. Research involves observing the AES wind system perform without maintenance to determine endurance throughout all natural environment conditions.

Bertoia Studio, Ltd.
P.O. Box #383
Bally, PA 19503
(215) 845-7096

Key Personnel: Kylene Bertoia (system use, investment decisions); Val Bertoia (aesthetic appraisal, design standards).

Boeing Aerospace Company

Designed, tested, and fabricated the MOD-2 and MOD-5B wind turbines as a major participant in DOE's large-scale horizontal-axis wind program. Not currently involved in wind research.

Boeing Aerospace Company
Aerospace and Electronics Systems Operations
P.O. Box 3999
Seattle, WA 98124
(206) 393-3914

Bonneville Power Administration (BPA)

Markets electricity produced by federally owned dams to regional public and investor-owned utilities and to industrial direct-service customers. BPA's region includes Oregon, Washington, Idaho, western Montana, and parts of northern Nevada and northern California. As a result of reorganization, the responsibilities for wind programs now reside in the Office of Conservation and Power Resources, the Division of Resource Management, and the Division of Resource Planning.

BPA's wind technology activities are focused on technology tracking, resource assessment verification, and cooperative institutional and industry research and demonstration programs.

Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208
(503) 230-4523

Key Personnel: Doug Seely, Chief, Generation Engineering Branch, Division of Resource Engineering (siting, large-scale wind machines, utility integration, development of assessment instrumentation); Gary E. Stemler, Project Manager, Goodnoe Hills (electrical engineering, program management); Rodger B. Bennett, Site Manager, Goodnoe Hills (mechanical engineering, site activity coordination); Ronald H. Holeman, Project Engineer, Goodnoe Hills Generation Engineering Branch (electrical engineering, engineering coordination); Nick Butler, Lead Wind Technology Engineer, Generation Engineering Branch (siting, technology assessment); Mike Berger, Chief, Assessment Section, Division of Power Resource Planning (wind resource assessment).

Bureau of Reclamation, Department of the Interior

See *U.S. Department of the Interior, Bureau of Reclamation*

Carter Wind Systems, Inc. (CWS)

Develops wind energy systems, including windfarms, and manufactures small- and medium-scale wind turbines. CWS also licenses the manufacturing and sale of its wind turbines worldwide. The company is designing new components (such as larger diameter blades) for its existing wind turbines and developing a 1.5-MW machine for windfarm applications.

Carter Wind Systems, Inc.
Route 1, Box 405A
Burkburnett, Texas 76354
(817) 569-2238

Key Personnel: J. W. Carter, Sr., Chairman of the Board (fiberglass); J. W. Carter, Jr., President (mechanical and aerodynamic engineering).

Clean Energy Products

Develops reliable, efficient, and low-cost mechanical wind turbines for manufacture and application in developing nations. Clean Energy Products is refining a 5-m version of the 2.5-m machine that has been successfully introduced to Mexico and Panama.

Clean Energy Products
3534 Bagley Avenue North
Seattle, WA 98103
(206) 633-5505

Key Personnel: Ed Kennell, Mechanical Engineer; Lynn Wilcox, Millwright.

Colorado State University Department of Civil Engineering

Has performed studies for DOE on siting wind machines (especially large units), including topographical studies and the use of a wind tunnel to model terrain effects on the wind. A study for the Agricultural Research Service analyzed the effectiveness and economics of using a Darrieus wind turbine in a dairy to cool milk and heat water for sanitation. An ongoing project conducted for U.S. Windpower in Livermore, Calif., is investigating the aerodynamics of turbulence and wind flow around in situ wind turbine blades.

Colorado State University
Department of Civil Engineering
Fort Collins, CO 80523
(303) 491-5048

Key Personnel: Robert Meroney, Professor (wind characteristics, wind engineering); Virgil Sandborn, Professor (aeronautical engineering, flow distribution).

Cornell University

Studies agricultural applications for small wind units. Cornell researchers have completed a study on the direct power conversion of wind energy to heat water by mechanical agitation of the water itself and a feasibility study of powering a heat pump with a small wind machine to produce hot water and refrigeration. Studies in the university's Electrical Engineering Department deal with the problem of interconnecting wind systems to the utility grid.

Cornell University
Department of Agricultural Engineering
Ithaca, NY 14853
(607) 256-2270

Key Personnel: W. W. Gunkel, Professor (heating applications); Robert J. Thomas, Professor, Electrical Engineering (utility interconnection).

Electric Power Research Institute (EPRI)

Sponsors research on many topics related to electric power, including wind energy. Has published studies on siting, wind energy, wind energy markets, wind turbine performance, testing, and utility interface issues. EPRI is conducting a joint study with U.S. Windpower on advanced turbine designs.

Electric Power Research Institute
P.O. Box 10412
Palo Alto, CA 94303
(415) 855-2000

Key Personnel: Edgar DeMeo, Program Manager, Solar Power Systems; John Schaefer, Project Manager.

Engineering Research Institute Iowa State University

See *Iowa State University*

Environmental Research Laboratories

See *National Oceanic and Atmospheric Administration (NOAA), Environmental Research Laboratories*

Fayette Energy Corporation

Manufactures, operates, and maintains a windfarm of about 1600 turbines; also designs and manufactures composite wind turbine blades. The company maintains an Engineering/Research and Development Department. It has been actively engaged in the following aspects of wind energy research: resource assessment, wakes, wind flow modeling, WECS siting, turbine rotor aerodynamics, machine dynamics, and electrical studies. Fayette is a private corporation and wholly owned subsidiary of Wolverine Power Corporation, employing 150 people.

Fayette Energy Corporation
P.O. Box 1149
Tracy, CA 95378-1149
(209) 836-2260

Key Personnel: G. E. Berasi (automatic data acquisition and computer design); J. V. Frerotte (aerodynamics and composite structures); G. Johnson (electronic design, computer firmware); D. M. Shimmel (structural dynamics, materials); J. M. Fuchs (siting, resource assessment, wind variability); A. H. Miller (turbine dynamics, aerodynamics, operations, electrical problems); W. V. Thompson (turbine design, dynamics, operations).

Flow Industries, Inc.

Specializes in fluid dynamics research. The company has flow visualization techniques to study under a contract to Pacific Northwest Laboratory. The company has also reviewed state-of-the-art literature on wind turbine wakes.

Flow Industries, Inc.
21414 68th Avenue South
Kent, WA 98032
(206) 872-8500

Key Personnel: Y. H. (Michael) Pao, Chairman of the Board (fluid dynamics); John Cheung, President (solid mechanics); H. T. (Peter) Liu, Senior Research Scientist (wake analysis); Jim Riley, Consultant (wake analysis).

Flowpower, Inc.

Carries out wind resource assessments and siting studies (including computer simulations of wind machines based on site data) primarily for large-scale machines. The company has performed studies for utilities and for the state of New York. It is now carrying out computer simulations of wind characteristics for rugged terrain with simultaneous wind tunnel simulations of the same terrain.

Flowpower, Inc.
P.O. Box 963
Huntington, NY 11743
(516) 427-6388

Key Personnel: P. M. Sforza, President (wind resource assessment, siting).

Georgia Institute of Technology

Develops techniques to facilitate the interactions between the meteorological and wind energy technological communities. The institute monitors the effects of various wind characteristics on a small wind turbine. It has studied the development of large wind arrays with respect to wind characteristics and utility generation planning.

Georgia Institute of Technology
Geophysical Sciences Department
Atlanta, GA 30332
(404) 894-3890

Key Personnel: C. G. Justus, Professor, Geophysical Sciences (wind characteristics).

Gougeon Brothers, Inc.

Analyzes wind machine blade materials, particularly those factors relating to cost and fatigue. The company has produced a low-cost composite wood blade and has manufactured blades for both small and large wind turbines.

Gougeon Brothers, Inc.
706 Martin Street
Bay City, MI 48706
(517) 684-7286

Key Personnel: Meade Gougeon, President (blade development).

Hawaii Natural Energy Institute, University of Hawaii

See *University of Hawaii, Hawaii Natural Energy Institute*

Hawaiian Electric Renewable Systems, Inc.

Commercial windfarm providing power to Hawaii Electric Company using fifteen Westinghouse 600 kW wind turbines and the NASA MOD5-B 3.2 MW wind turbine.

Hawaiian Electric Renewable Systems, Inc.
P.O. Box 730
Honolulu, HI 96808
(808) 293-9255

Key Personnel: A.P. Manning, President; D.M. Suehiro, Vice President; M.W. Miller, Wind Farm Manager.

Iowa State University (ISU)

Performs continuing long-term tests of a utility-interactive wind turbine generator to evaluate the economic viability of such systems in central Iowa. The Engineering Research Institute of ISU is carrying out this testing in conjunction with Corn Belt Power (CBP) and Land O'Lakes Cooperative.

Iowa State University
Engineering Research Institute
104 Marston Hall
Ames, IA 50011
(515) 294-2336

Key Personnel: Al Potter, Professor, Electrical Engineering (agricultural applications, small-scale wind machines); Ken Kuyper, Transmission Supervisor, Corn Belt Power Cooperative; Paul Clayton, Manager, Land O'Lakes Answer Farm.

Kenneth E. Johnson Environmental and Energy Center

See *University of Alabama at Huntsville*

Johnson Energy Corporation

Conducts wind resource assessments and engineering studies for windfarms. The corporation currently is involved in research and development of a novel wind turbine suited for operation in low wind speeds.

Johnson Energy Corporation
1630 Osage Street
Manhattan, KS 66502
(913) 539-7088

Key Personnel: Gary L. Johnson, President (wind resource assessment, windfarms, low-wind-speed turbines).

R. Lynette & Associates, Inc.

Consultants for alternative energy systems, including finance, engineering, and systems analysis. The firm specializes in all phases of wind power research, development, and operations. Currently conducting analyses of wind energy research needs for SERI and EPRI and reviewing the past six years of experience in designing, installing, and operating commercial wind turbines. Also active in failure analyses, operations and maintenance, and wind power station financing.

R. Lynette & Associates, Inc.
15042 N.E. 40th Street
Suite 206
Redmond, WA 98052
(206) 885-0206

Key Personnel: Robert Lynette, President (machine reliability, costs, operation and maintenance); John Becker, Director, Engineering (structural dynamics, fatigue).

M & L Environmental Consultants

Works to develop wind energy, specializing in applying state-of-the-art technology and minimizing cost. M & L has expertise and specific interest in developing wind energy resources that are competitive when return-on-investment is critical. The firm integrates technology, use, and economics.

M & L Environmental Consultants
136 Brook Road
Sharon, MA 02067
(617) 784-7465

Key Personnel: F. J. Mogolesko, President (wind resource assessment, utilization); J. Laznow, Executive Vice President (wind resource identification, economics).

Massachusetts Institute of Technology (MIT) Department of Aeronautics and Astronautics

Researches free-wake analysis, rotor dynamics, dynamics of blade/tower interaction, and aeroelectic modeling. MIT has analyzed flutter and vibration of complete horizontal- or vertical-axis wind machines.

Massachusetts Institute of Technology
Department of Aeronautics and Astronautics
33-410
Cambridge, MA 02139
(617) 253-3400

Key Personnel: Norman Ham, Professor (wind machine vibration); Rene Miller, Professor (rotor acoustics, structural dynamics, wake analysis); John Dugundji, Professor (structural dynamics, aeroelastic modeling); Westley Harris, Professor (rotor acoustics).

Michigan State University Department of Electrical Engineering

Studies wind-electric planning, integration, and testing. Michigan State is a land-grant university that has had federal and utility support for these studies since 1974. Recent activities include measuring multiple-level short-term wind velocities at the former candidate wind turbine generator (WTG) site at Ludington, Mich.; evaluating the performance of alternating current pumps over wide ranges of voltage and frequency; evaluating improved dispatching models for utilities with high WTG penetration; and completing smaller WTG testing in Michigan.

Michigan State University
Department of Electrical Engineering
East Lansing, MI 48824-1226
(517) 355-5066

Key Personnel: Robert A. Schlueter, Professor (dispatching WTG arrays); Gerald L. Park, Professor (testing small WTG, evaluating interconnection effects); O. Krauss, Assistant Director, Engineering Research (wind measurement).

Minnesota Department of Public Service, Energy Division

Developing a statewide wind energy resource assessment program that will involve mounting anemometers on microwave towers at the 30-m level. The plan is a cooperative effort between public and private utilities and the state. The department plans to centralize information gathered from this project and other sources (such as airport records) into a common data base. Annual reports are available.

Minnesota Department of Public Service
Energy Division
900 American Center Building
150 East Kellogg Boulevard
St. Paul, MN 55101
(612) 296-5120

Key Personnel: John Dunlop, Program Manager; Paul Helgeson, Program Manager.

Murray & Trettel, Inc.

Develops forecasting techniques useful for wind energy prospecting. In a study for Pacific Northwest Laboratory, synoptic weather maps were used to predict wind speed, wind duration, and other variables that could be expected to occur under those patterns and to develop forecasting rules for that particular geographic area.

Murray & Trettel, Inc.
414 West Frontage Road
Northfield, IL 60093
(312) 446-7800

Key Personnel: John R. Murray, President (meteorology); Dennis W. Trettel, Executive Vice President (wind characteristics, forecasting techniques).

National Oceanic and Atmospheric Administration (NOAA) Atmospheric Turbulence and Diffusion Division

Serves as a meteorological authority to DOE's Oak Ridge Operations Office. Research is conducted in support of DOE and NOAA goals. The laboratory conducts research on atmospheric dispersion, of which wind field information is a basic component. Studies are conducted of flow over terrain of varying complexity; numerical models are constructed and tested.

National Oceanic and Atmospheric Administration
Atmospheric Turbulence and Diffusion Division
Air Resources Laboratory
456 South Illinois Avenue, P.O. Box 2456
Oak Ridge, TN 38730
(615) 576-1233

Key Personnel: Rayford P. Hosker, Jr. (flow over complex terrain, physical modeling); Carmen J. Nappo, K. Shankar Rao, Ronald J. Dobosy, Richard M. Eckman (complex terrain, strongly stratified flows).

National Oceanic and Atmospheric Administration (NOAA) Environmental Research Laboratories/ Wave Propagation Laboratory (WPL)

Performs selected studies of use in the wind energy field. The laboratory used its special 300-m tower to test two of Pacific Northwest Laboratory's gust models for wind turbine design. Another study used a laser anemometer to simulate the effects of wind on large turbine blades. Finally, a method for remote sensing of wind speed, potentially of use in wind turbine siting, is being tested.

WPL develops and applies new methods for remote measuring of atmospheric and oceanic properties. Many of the measurement techniques are useful for remote wind resource assessment.

National Oceanic and Atmospheric Administration
Environmental Research Laboratories/WPL
325 Broadway
Boulder, CO 80303
(303) 497-6000

Key Personnel: J. C. Kaimal, Chief, Atmospheric Studies (wind characteristics); Robert Hardesey, Scientist (wind characteristics); Richard Fritz, Physicist (wind resource assessment); Steven F. Clifford, Director (wind resource assessment).

NASA Langley Research Center

Investigates wind turbine acoustics and develops the technology required for designing and siting wind machines that will be acceptable to the public. Working in conjunction with NASA Lewis Research Center, Langley focuses its research on noise sources, propagation of noise from machine to residence, and the subjective responses of residents to the noise, both indoors and outdoors. Langley uses a series of laboratory tests and field

NASA Langley Research Center
Acoustics Division
MS/462
Hampton, VA 23665
(804) 865-3577

investigations involving both physical measurements and subjective assessments. Most large wind turbines in DOE's program have been investigated, as have some smaller machines on selected windfarms. Researchers plan to develop a criteria document to serve as a handbook for environmental assessments of wind turbine noise and wind turbine design.

Key Personnel: David G. Stephens, Assistant Chief, Acoustics Division (acoustics of wind turbines); Kevin P. Shepherd, researcher (acoustics of wind turbines); Harvey H. Hubbard, Researcher, PRC Kentron (acoustics of wind turbines); Ferdinand W. Grosveld, Researchers, PRC Kentron (acoustics of wind turbines).

Naval Civil Engineering Laboratory

See *U.S. Department of the Navy*

New Mexico Solar Energy Institute

Performs research and development in the areas of solar thermal energy, solar electric energy, wind energy, bioenergy, energy conservation, geothermal energy, small-scale hydro power, and information and education. The institute has initiated a variety of wind-related research and development projects since it was established in 1977 by the New Mexico State University Board of Regents. Wind energy activities include resource assessment studies, demonstration projects, technology transfer, testing, evaluation, and development. Five small wind machines (ranging from 2 to 25 kW) were tested and interconnected with the utility grid. The institute also offers workshops and seminars to the public on wind energy and publishes a fact sheet on wind energy.

New Mexico Solar Energy Institute
New Mexico State University
P.O. Box 3SOL
Las Cruces, NM 88003
(505) 646-1846

Key Personnel: Rudi Schoenmackers, Head, Wind Division (small-scale wind applications, resource assessment, testing, evaluation, research, development, and technology transfer).

Northern Power Systems (NPS)

Manufactures remote power systems based on renewable energy sources; applications range from telecommunications to village electrification and water pumping. As part of the DOE/SERI Cooperative Research Program, NPS is investigating the operational parameters of remote wind/diesel systems designed to power communications systems. Two wind/diesel systems are being used to collect field data and compare them with laboratory test data of similar equipment. In addition, NPS is developing wind/diesel architecture for remote communities as well as testing a scale-system model and evaluating the system's economics.

In another DOE/SERI cooperative project, NPS is participating in the dynamic and fatigue analysis of its North Wind 100 turbine. The project, run for the wind season of 1987 and 1988, resulted in extensive field data collection to evaluate operational loads and inflow characteristics for this turbine as it operates in a windfarm environment. The project focuses on evaluating the turbine's dynamic characteristics and documenting its fatigue-loading spectrum.

With Delta Energy Limited, NPS is evaluating the aerodynamic and control properties of the Delta 150/200 wind turbine generator being developed under license from NPS. Activities include load analysis, rotor control design, and electronic control design and production.

Northern Power Systems
One North Wind Road
Moretown, VT 05660
(802) 496-2955

Key Personnel: Clint (Jito) Coleman, Vice President, Engineering; Jonathan Lynch, Electrical Engineer; Paul vanLieshout, Design Engineer; Rob Rolland, Engineer.

Ohio State University (OSU) Aeronautical and Astronautical Engineering Department

Operates a dynamic test facility that simulates a wide range of both HAWT and VAWT operating conditions. The facility is used to test airfoil sections for the development of advanced airfoil designs, including cambered natural laminar flow airfoils. Recent work in conjunction with Sandia National Laboratories included the design of cambered airfoils that may reduce VAWT cyclic load variation. After suitable system and element design iterations are performed, blade elements will be fabricated and tested in a wind tunnel under dynamic conditions representative of VAWT operation. Feedback to element design will result in improved geometries, which will be tested on an experimental turbine at Sandia.

OSU researchers also have been engaged in research to measure lift and drag coefficients in stalled flow conditions. Samples of selected airfoils (both those in use and those still in the design stage) will be built and tested in the OSU blow-down tunnel. The resulting measurements of chordwise surface-pressure distribution will allow researchers to calculate lift, drag, and moment coefficients, which can be used to better predict rotor performance and aerodynamic blade forces.

Ohio State University
Aeronautical and Astronautical Engineering Dept.
Columbus, OH 43210
(614) 292-5531

Key Personnel: G. M. Gregorek, Professor, Aeronautical and Astronautical Engineering (airfoil design, steady and unsteady wind tunnel tests, vortex generators).

Oregon State University Mechanical Engineering Department

Studies the aerodynamics of both horizontal- and vertical-axis wind machines under subcontracts with Sandia National Laboratories and SERI. Contracts with SERI have included studies of the structural dynamics of wind machines.

Oregon State University
Mechanical Engineering Department
Corvallis, OR 97331
(503) 754-0123

Key Personnel: Robert Wilson, Professor (aerodynamics).

Pacific Gas and Electric Company (PG&E)

Owned and operated a Boeing MOD-2 and monitored its performance. PG&E also purchases power from three windfarms and has contracts with approximately 60 small wind machine owners, allowing them to interconnect with the utility grid.

Pacific Gas and Electric Company
77 Beale Street
San Francisco, CA 94106
(415) 781-4211 Ext. 2875

Key Personnel: Elmer E. Hall, Chief Generation Planning Engineer (utility applications, windfarms); Lesley Everett, Generation Planning Department (utility applications, windfarms); James Stearns, Manager, Commercial Department (utility interconnection, small wind machines).

Pacific Gas and Electric Company (PG&E) Department of Research, Development, and Demonstration

Acts as a support group to provide technical and environmental services and problem-solving research to other company managers. Some self-initiated projects focus on applied basic research. The department monitors and analyzes all available wind-related data, especially as they relate to the Altamont windfarms and PG&E's MOD-2. Wind resource studies, technology development projections, and economic analyses are also part of PG&E's wind program.

Pacific Gas and Electric Company
Department of Research, Development, and Demonstration
3400 Crow Canyon Road
San Ramon, CA 94583
(415) 820-2000

Key Personnel: M. A. Ilyin, Electrical Engineer; Joseph Iannucci, Program Manager, Wind; W. J. Steeley, Lead Engineer, Wind.

Pacific Northwest Laboratory (PNL)

Serves as the DOE Wind/Ocean Technologies Division's lead center for research on wind characteristics relevant to the cost-effective extraction of energy from the wind. Research during the past several years has focused on developing and testing improved models of turbulence

Pacific Northwest Laboratory
P.O. Box 999
Richland, WA 99352
(509) 376-6653

encountered by a wind turbine rotor; improved models of the flow over a site as it is affected by complex terrain; and models of wind turbine wakes and their effects on the flow encountered by downwind turbines. Field experiments involving wind measurements of rotor-scale turbulence have provided the data and insight to test and improve these models. Most field experiments are conducted in cooperation with SERI, Sandia, or wind industry participants through the Cooperative Research Program. An upgraded national version of the regional U.S. wind resource assessment was prepared by PNL and published through SERI. Wind resource assessments also have been performed to upgrade the worldwide assessment in selected areas, with the potential to become markets for U.S. wind turbine manufacturers. PNL is operated for DOE by Battelle Memorial Institute.

Key Personnel: Larry Wendell, Program Manager (flow variability); Jim Connell, Project Leader (turbulence analyses for aerodynamic effects and structural loads); Dennis Elliott (wake analyses); James Barnard (flow modeling); Carl Aspliden (eddy structure).

Pacific Wind Energy, Inc.

Consults on wind site selection, instrumentation, meteorological site evaluation, wind turbine performance evaluation and analysis of wind turbine spacing, forecasting, and wake interaction.

Pacific Wind Energy, Inc.
P.O. Box 1671
Corvallis, OR 97339
(503) 753-3139

Key Personnel: John Wade (wind resource assessment, siting); Stel Walker, Ph.D. (wind resource assessment, siting, performance evaluation).

Pennsylvania State University Department of Meteorology

Focuses much of its research on the environmental impact of wind machines (especially noise propagation). Under contract to SERI, the department assessed and evaluated both audible and subaudible noise produced by large wind machines. Other studies have measured boundary layer turbulence and estimated the effect of complex terrain on local and regional winds.

Pennsylvania State University
Department of Meteorology
University Park, PA 16802
(814) 863-1585

Key Personnel: Dennis Thomson, Professor (noise propagation, atmospheric surface and boundary layer measurements, structure and processes, micrometeorology).

Polytechnic University Department of Aerospace Engineering

Focuses on experimental design and development of wind machines, including field studies. Basic studies are conducted on three-dimensional flows related to rotating machines. Under contract to SERI, the department developed an innovative wind machine using the vortex augmentor concept.

Polytechnic University
Department of Aerospace Engineering
Route 110
Farmingdale, NY 11735
(516) 454-5120

Key Personnel: P. M. Sforza, Professor (innovative wind machines).

Portland General Electric Company (PGE)

Interconnects with a series of residential and commercial small power production projects (new and retrofit). Services are limited to the PGE service area. PGE will buy back electricity at the highest end-block retail rate as long as the customer interconnects safely.

Portland General Electric Company
Renewable Resources
121 S.W. Salmon Street, TB-6
Portland, OR 97204
(503) 226-8478

Key Personnel: Doug Boleyn, Specialist, Energy Management; Roy Josi, Manager, Renewable Resources.

Power Technologies, Inc.

Studies wind system dynamics (specifically, the interaction between large wind machines and the electric utility). Short-term dynamics such as wind gusts, operational impacts, and long-term economics of wind power are all examined as they relate to use in utility systems.

Power Technologies, Inc.
P.O. Box 1058
Schenectady, NY 12301
(518) 374-1220

Key Personnel: Eric N. Hinrichsen, Senior Engineer (utility applications); F. P. DeMello, Principal Engineer (utility applications).

Rensselaer Polytechnic Institute Department of Mechanical and Aeronautical Engineering

Studies the innovative Toroidal Accelerator Rotor Platform (TARP) wind turbine, under the sponsorship of the New York State Energy Research and Development Administration (ERDA). The TARP is in the final design stages and has undergone wind tunnel testing. A prototype will be developed.

Rensselaer Polytechnic Institute
Department of Mechanical and Aeronautical Engineering
J.E.C. 5020
Troy, NY 12181
(518) 276-6260

Key Personnel: R. E. Duffy, Professor (innovative wind machines).

Sandia National Laboratories

Serves as the DOE Wind/Ocean Technologies Division's lead center for research on Darrieus VAWTs and certain basic science research areas, including fatigue and unsteady viscous flow. Research areas involve the entire engineering system, from aerodynamic loads caused by turbulent winds to the resulting structural responses (turbine stresses) and the prediction of component fatigue life. Two primary research VAWTs are used to test these aspects of machine performance: a 17-m machine in Albuquerque, New Mexico, and a new 34-m, variable speed, 500-kW test bed located at the USDA facility in Bushland, Texas. Various industry and university research contracts exist to support all of the above research efforts. In addition, technology exchange arrangements are in place with the wind industry, including participation in the DOE Cooperative Research Program.

Sandia National Laboratories
Wind Energy Research Division
Division 6225
Albuquerque, NM 87185
(505) 844-5253

Key Personnel: Henry M. Dodd, Supervisor (systems engineering); Paul C. Klimas, Project Leader (aerodynamics, VAWT test bed); Dale E. Berg, Project Leader (structural dynamics); Dan D. Reda (unsteady viscous flow); Herbert J. Sutherland (fatigue).

Science Applications International Corporation (SAIC)

Assists both government and commercial clients in numerous research, development, systems optimization, and institutional problem areas. SAIC's technical and engineering support services in the area of wind energy research include research, development and demonstration, program planning, resource assessment and site selection, system performance evaluation and modeling, technical and economic feasibility studies, and market analysis.

Science Applications International Corporation
P.O. Box 1303
McLean, Virginia 22102
(703) 998-0931

Key Personnel: Thomas C. Schweizer, Manager, Energy and Environmental Technologies Division (technology assessment, market analysis, policy analysis); Joseph M. Cohen, Analyst (technology assessment, market analysis, policy analysis).

Solar Energy Research Institute (SERI) Wind Research Program

Conducts research and testing of HAWTs for the DOE Wind/Ocean Technologies Division. Primary research efforts involve improving rotor performance, improving load and aeroacoustic prediction techniques, and providing useful analytical and design tools for understanding complex dynamic response and fatigue phenomena. Researchers also develop advanced components, such as special-purpose airfoils and advanced rotors, and study advanced horizontal-axis configurations with the potential to reduce wind energy costs. Supporting research involves investigat-

Solar Energy Research Institute
Wind Research Program
1617 Cole Boulevard
Golden, CO 80401
(303) 231-7199

Key Personnel: Robert W. Thresher, Program Manager.

ing wind-diesel system requirements, studying the effects of interactions between utility systems and wind turbine clusters, providing support to industry standards development, and developing innovative instrumentation and data analysis systems. SERI participates in cooperative research and testing projects with private industry, and makes its Wind Energy Test Center available to industry for atmospheric, dynamometer, vibration, and acoustic tests and measurements.

Simpson Weather Associates

Deals with fundamental and applied problems in meteorology. The company has expanded to include services in environmental areas, such as ground water and water quality, coastal environments, air quality, and specialized measurements and instrumentation. Specializes in wind resource assessments, with studies conducted over large areas as well as site-specific studies, and in three-dimensional measurements and modeling. Simpson conducted a study of three sites for the state of Maryland to determine the feasibility of locating windfarms. In another project, it participated in measuring turbine wakes from the MOD-2 machines at Goodnoe Hills, Washington.

Simpson Weather Associates, Inc.
809 East Jefferson Street
Charlottesville, VA 22902
(804) 979-3571

Key Personnel: Michael Garstang, Executive Vice President (wind resource assessment, windfarms); G. David Emmitt, Vice President (wind resource assessment).

Stadia, Inc.

Collects and publishes market data for the wind energy industry. Stadia's Wind Data Center tracks worldwide wind turbine shipments and applications using an annual survey of manufacturers. All types of turbines (design, prototype and commercial machines) are documented.

Stadia, Inc.
Wind Data Center
P.O. Box 442
Great Falls, VA 22066
(703) 759-6520

Key Personnel: Thomas F. Jaras, Director (market research).

Stevens Institute of Technology

Continues analytical and experimental research on an oscillating cascade wind energy converter (i.e., nonrotating) under internal sponsorship. Formerly sponsored by DOE. In addition, Stevens is studying a self-rectifying turbine of 90° stagger angle (the Wells turbine) for both wind and hydro power.

Stevens Institute of Technology
Mechanical Engineering Department
Hoboken, NJ 07030
(212) 732-8237

Key Personnel: F. Sisto, Professor (innovative wind machines).

Thermax Corporation

Manufactures small wind generators and power systems rated at less than 1 kW. Also a representative for MBB large-scale wind generators with ratings between 25 kW and 3 MW. Research efforts include the patented Helius vertical-axis rotor for applications requiring low rpm, high constant torque, and low cost; a synchronator variable-speed synchronous alternator; and a hydrogen closed-cycle storage technique for large-scale dispatchable electricity generated by wind systems.

Thermax Corporation
Box 3128
Burlington, VT 05401-3128
(802) 658-1098

Key Personnel: Colin C. Kerr, Vice President, Engineering

Towson State University Communications Department

Focuses on public relations research, including the study of messages and their impact on attitude formation and subsequent behaviors. Wind energy research examines perceptions, attitudes, and behaviors of salient industry publics. Both qualitative and quantitative research activities are undertaken to determine the effectiveness of current wind industry practices and communications. Applies public relations theories and strategies to the wind energy program.

Towson State University
Communications Department
Towson, MD 21204
(301) 321-2887

Key Personnel: Phyllis B. Bosley, Associate Professor (public relations, research and evaluation, program planning, interpersonal and mediated communications, issues management, governmental relations, environmental relations).

TurboAir, Inc.

Develops and manufactures small VAWTs. Extensive research has been undertaken on the Savonius rotor, including the fabrication and testing of welded aluminum rotors ranging in size from 30 to 108 square feet. TurboAir is a privately owned corporation.

TurboAir, Inc.
2142 Maple Road
Grafton, WI 53024
(414) 377-3206

Key Personnel: Lowell Liebenstein, President (water pumping and air pumping for lake and pond aeration).

United Technologies Corporation

Conducts research, design, development, and engineering activities for large-scale wind turbines. United Technologies has been involved in these activities since 1973. The company has installed a 3-MW machine (the WTS-3) in Sweden and a 4-MW machine (the WTS-4) for the U.S. Bureau of Reclamation at a site near Medicine Bow, Wyoming.

United Technologies Corporation
Hamilton Standard Division
Windsor Locks, CT 06096
(203) 623-1621

Key Personnel: Robert P. Gregoire, Manager, Business Development and Marketing (large wind machines, marketing); Robert Bussolari, Engineering Manager, Wind Energy Systems (large wind machines).

U.S. Department of Agriculture (USDA) Agricultural Research Service

Conducts research in the Wind Erosion Research Unit on wind erosion from agricultural lands, including measurement, prediction, and control studies. The current objective is to develop a computer model to predict wind erosion in the United States. This effort includes developing a wind speed and direction simulator as well as the statistical data base necessary to operate the simulator. The Agricultural Research Service has been conducting field experiments since 1976 on water pumping applications of wind power. Work at the USDA Conservation and Production Research Laboratory in Bushland, Texas, has centered on irrigation pumping systems 10 to 500 kW in size. Stand-alone electrical and mechanical water pumping systems also have been developed for use in remote locations. The Sandia/DOE/USDA 34-m vertical-axis wind turbine test bed is located at Bushland.

U.S. Department of Agriculture
Agricultural Research Service
Wind Erosion Research Unit
Room 105-B, East Waters Hall
Kansas State University
Manhattan, KS 66506
(913) 532-6495

U.S. Department of Agriculture
Agriculture Research Service
Conservation and Production Research Laboratory
P.O. Drawer 10
Bushland, TX 79012
(806) 378-5734

Key Personnel: L. J. Hagen, Agricultural Engineer/Research Leader; E. L. Skidmore, Soil Scientist; G. W. Cole, Agricultural Engineer; D. V. Armbrust, Soil Scientist; R. Nolan Clark, Agricultural Engineer; Ronald G. Davis, Agricultural Engineer.

U.S. Department of Energy (DOE)

DOE's Wind/Ocean Technologies Division is responsible for managing the Federal Wind Energy Program. In addition to policy management, the division coordinates wind research and development activities at several federally funded laboratories, including Sandia National Laboratories, the Wind Energy Test Center at the Solar Energy Research Institute, and Pacific Northwest Laboratory. The goal of these research activities is to establish wind energy technology as a viable energy supply option, primarily by improving the technology base and by supporting industry in its effort to develop safer, more reliable, and more cost-effective wind systems.

U.S. Department of Energy
Office of Solar Electric Technologies
Wind/Ocean Technologies Division
CE-351
Washington, DC 20585
(202) 586-5630

Key Personnel: Louis Divone, Director, Office of Solar Electric Technologies; Leonard Rogers, Director, Wind/Ocean Technologies Division; Daniel Ancona III, John Cadogan, Oree Dyes, Peter Goldman, Jeffrey Rumbaugh, Program Managers.

U.S. Department of the Interior, Bureau of Reclamation

Through its Advanced Energy Applications Office, studies and tests wind energy systems for use at Bureau facilities. Test facilities include

U.S. Department of the Interior
Engineering and Research Center
Bureau of Reclamation,

the large wind turbine project at Medicine Bow, Wyoming, which consists of a 2.5-MW MOD-2 and a 4-MW WTS-4, and three smaller kilowatt-size installations—one near Ogden, Utah, and the other two near Amarillo, Texas.

Advanced Energy Applications Office
Denver Federal Center
Denver, CO 80225
(303) 234-3251, 234-4345

Key Personnel: Stanley Hightower, Coordinator, Advanced Energy Applications.

U.S. Department of the Navy

Using venture capital, pursues implementation of windfarm efforts at San Clemente Island, California. This is the Navy's response to interest by third parties to finance, own, operate, and maintain windfarms at military installations. The site has a remote isolated diesel electric power grid. Wind generation at the site would save fuel, resulting in substantial cost savings. The Navy also contracted Northern Power Systems of Vermont to develop a prototype hybrid power system consisting of two 10-kW wind turbines, one 5-kW photovoltaic array, and a 138-kW battery bank. This system will be used to operate TACTS flight monitoring systems on offshore platforms.

U.S. Department of the Navy
Naval Weapons Center
Code: 2603 Building: 981
China Lake, CA 93555
(619) 939-3411

Key Personnel: Rick Roberts.

U.S. Department of Navy, Naval Civil Engineering Laboratory (NCEL)

Monitors small (1- to 20-kW) wind energy systems under field conditions at remote, unmanned sites. These wind systems are not interconnected with a utility grid; instead, they use batteries to store power. NCEL is also assessing the wind resource at 10 potential wind system sites.

As the lead laboratory for the Navy's Wind Energy Program involving shore facilities, NCEL is investigating the use of WECS in the 1- to 100-kW range for generating electricity at Navy shore installations. The primary program objectives include

- Site-selection procedures to determine annual average wind speed, minimum electromagnetic interference, and special environmental conditions at Navy installations
- WECS size-selection guidance to meet the power load requirements based on site wind characteristics
- Collection and analysis of reliability, availability, and maintainability data on generic types and sizes of WECS
- Collection and analysis of performance and operational data to evaluate WECS design characteristics
- Collection of operating and maintenance cost data to determine the logistic support requirements for WECS at Navy bases
- Technical consultation and guidance to naval activities in development of third-party financed, owned, operated, and maintained windfarms.

U.S. Department of the Navy
Naval Civil Engineering Laboratory
Port Hueneme, CA 93045
(805) 982-5085

Key Personnel: Dharam Pal, Principal Investigator, Wind Energy Program (wind energy conversion systems).

University of Alabama at Huntsville Kenneth E. Johnson Research Center

Maintains records of wind speed measurements at first-class National Weather Service weather stations. Also maintains some special data sets. Previous activities have included monitoring a Savonius wind machine and providing wind data and support to wind machine dealers.

University of Alabama at Huntsville
Kenneth E. Johnson Research Center
Huntsville, AL 35899
(205) 895-6257

Key Personnel: Richard T. McNider, State Climatologist; Bernard M. Levine, Specialist (public information).

University of Alaska Arctic Environmental Information and Data Center

Collects wind data as part of its normal operations. The university also participated in Pacific Northwest Laboratory's wind resource assessment of Alaska.

University of Alaska
Arctic Environmental Information and Data Center
707 A Street
Anchorage, AK 99501
(907) 279-4523, 257-2737

Key Personnel: James Wise, State Climatologist (wind resource assessment).

University of Arizona Aerospace and Mechanical Engineering Department

Performs wind energy research in feasibility assessment for remote sites (McMurdo Station, Antarctica) and wind turbine blade optimization, using numerical penalty function codes. The department, which is accredited by the Accreditation Board for Engineering and Technology, offers B.S., M.S., and Ph.D. degrees in Aerospace Engineering and Mechanical Engineering. Goals in the wind energy area are teaching (one undergraduate elective course) and computer-aided design (CAD).

University of Arizona
Aerospace and Mechanical Engineering Department
Building 16
Tucson, AZ 85721
(602) 621-2235

Key Personnel: L. B. Scott, Jr., Professor (renewable energy wind tunnel testing, CAD).

University of California Electrical Engineering and Computer Sciences Department

Designs low-technology, utility-interface wind turbine generator systems, using computer optimization of design and cost.

University of California
Electrical Engineering and Computer Sciences Department
Berkeley, CA 94720
(415) 642-7591

Key Personnel: Otto J. M. Smith, Ph.D., Professor, Electrical Engineering and Computer Sciences (control, optimization, design).

University of Detroit Department of Electrical Engineering

Researches the electromagnetic interference effects of wind turbines. Wrote Chapter 7 (with Prof. T. B. A. Senior, see University of Michigan) of *Wind Turbine Technology*, a book to be published by DOE and the American Society of Mechanical Engineers (ASME).

University of Detroit
Department of Electrical Engineering
4001 West McNichols Road
Detroit, MI 48221
(313) 927-1365

Key Personnel: D. L. Sengupta, Professor, Electrical Engineering (electromagnetics, antenna theory electromagnetic interference).

University of Hawaii Hawaii Natural Energy Institute (HNEI)

Monitors wind energy activities (including windfarm development) in Hawaii. There are now four windfarms in Hawaii, plus the largest wind turbine in the world (the 3.2-MW MOD-5B) and many small wind machines throughout the state; most produce electricity and are interconnected with the utility grid. HNEI owns and operates 12 wind machines as well as a Wind Energy Storage Test (WEST) facility, which is the focus of its wind energy research on utility interface and energy storage, and hybrid energy systems programs. HNEI has contracts with SERI on the wind energy utility interface program and with Sandia National Laboratories on battery storage. Plans include research in wind forecasting,

University of Hawaii
Hawaii Natural Energy Institute
2540 Dole Street
Honolulu, HI 96822
(808) 948-8788

Key Personnel: Dick Neill, Program Administrator, Renewable Energy; Bernard Holst, Manager, WEST Facility.

invariable-speed induction generators, pumped-storage hydroelectric storage, and other energy storage technologies.

University of Michigan
Department of Electrical and Computer Engineering

Studies the electromagnetic wave interference caused by large and small wind turbines, including television, FM, microwave link, and navigation systems. The Radiation Laboratory has 10 staff members and more than 30 graduate students; it carries out theoretical and experimental research in all areas of electromagnetics, particularly scattering, remote sensing, antennas and interference. A complete range of experimental facilities is available, and the work is supported through contracts and grants from government agencies and industry. Involvement in wind energy research began in 1976 and has been concerned with the interference of wind turbines with the electromagnetic environment, particularly the interference with TV reception and microwave systems. Theories predicting interference have been developed for all existing large HAWTs and VAWTs, and have been verified with on-site measurements. These have also been used in preparing environmental impact statements for large installations.

University of Michigan
Department of Electrical and Computer Engineering
Radiation Laboratory
4072 East Engineering
Ann Arbor, MI 48109
(313) 764-0500

Key Personnel: T. B. A. Senior, Director and Professor, Electrical and Computer Engineering (electromagnetic interference).

University of New Mexico
New Mexico Engineering Research Institute (NMERI)

Provides technical services to both government and private enterprise in wind turbine system and component design. NMERI specializes in stress analysis and fatigue research, data acquisition and analysis system design, code development, control system design, research planning, and program management support. NMERI also maintains an extensive wind energy research library for DOE.

University of New Mexico
New Mexico Engineering Research Institute
Campus Box 25
Albuquerque, NM 87131
(505) 768-7524

Key Personnel: W. Reed Edgel, Supervisor (system design); Walter Jackson, staff (technology research); Dan Burwinkle, staff (data systems); Douglas Vetter, staff (fatigue).

University of Utah
Mechanical Engineering Department

Analyzes the aerodynamics and dynamics of wind turbines. Current research involves developing design methods and guidelines for yaw control systems. Extensive test data analysis capabilities also have been developed. The department's goal is to educate wind energy engineers.

University of Utah
Mechanical Engineering Department
Salt Lake City, UT 84112
(801) 581-6441

Key Personnel: A. Craig Hansen, Associate Professor (aerodynamics, dynamics, data analysis).

W. A. Vachon & Associates, Inc.

Consults on wind energy research and development to support the technical needs of the wind energy community. The company carries out system analysis, cost analyses, feasibility studies, and evaluations. Research activities include analysis of wind turbine loads, fatigue life, energy production, evaluation of wind energy projects, economics, competitiveness, and research plans. Clients include government research and development organizations, private developers, investors, and insurers.

W. A. Vachon & Associates, Inc.
P.O. Box 149
Manchester, MA 01944
(617) 526-4315

Key Personnel: William A. Vachon, President (wind research, technical evaluations, siting, feasibility studies, economics).

Virginia Power
Corporate Technical Assessment

Provides the senior management of Virginia Power with information, analysis, and assessment capabilities for scientific, technological, and environmental programs that may influence the company's operation. Virginia Power is the 15th largest investor-owned electric company in the United States and provides electricity for nearly 4 million people in a 32,000-square-mile area spanning Virginia and northeast North Carolina. Wind energy research within Virginia Power, either contracted or performed in house, includes: general overview of past, present, and future wind technology; evaluation of the wind resource within the company's service territory or on company-owned property; detailed evaluation of the wind resource near the Mt. Storm Power Station; and evaluation of the feasibility of operating a wind turbine in the Mt. Storm environment.

Virginia Power
Corporate Technical Assessment
Innsbrook Technical Center
5000 Dominion Boulevard
Glen Allen, VA 23060
(804) 273-2983

Key Personnel: Frederick P. (Ted) Heller, Project Engineer, Wind Energy Research; Timothy A. Bernadowski, Supervisor, Energy Assessments.

West Texas State University
Alternative Energy Institute

Evaluates wind turbines at the Wind Test Center. The institute measured wind resources at 10 sites around the state, taking data at 20- and 50-m heights. Other activities include R&D contracts, consulting, education and training, and information dissemination on wind energy and wind turbines.

West Texas State University
Alternative Energy Institute
P.O. Box 248
Canyon, TX 79016
(806) 656-2295

Key Personnel: Vaughn Nelson, Director (wind resource assessment); Earl Gilmore, Research Professor (wind resource assessment, technology assessment); Forrest Stoddard, Adjunct Research Professor (wind turbine design).

Westinghouse Electric Corporation

Designs, manufactures, installs, and operates 600-kW wind turbines. Fifteen turbines are now operating at Kahuku Point, Hawaii. The company fabricated and installed DOE's MOD-0A machines and developed a cycloconverter-based, variable-speed generating system under a DOE contract.

Westinghouse developed a retrofit design for the Enertech 40-kW and 60-kW turbines; these retrofits are now being performed on 60-kW turbines. Other studies have investigated the feasibility of off-shore wind energy systems and methods to determine the potential value of alternative energy systems for utilities. In addition, wind turbine performance analysis capability is available.

Westinghouse Electric Corporation
P.O. Box 10864
Pittsburgh, PA 15236
(412) 382-7000

Key Personnel: Peter Hughes, Manager, Energy Programs Marketing; Larry Van Bibber, Manager, Wind Energy Project; Tom Crouse, Manager, Commercial Wind Systems.

WestWind Industries, Inc.

Designs, manufactures, installs, tests, operates, and maintains wind systems. WestWind is a diversified engineering and manufacturing company specializing in wind energy conversion systems. It is now developing a family of wind turbine blades using advanced airfoils, improved aerodynamic overspeed devices, and root attachment fittings. WestWind is also conducting applied research related to compliant yaw systems and comprehensive load estimation methods for propeller-type wind turbines. Much effort continues on retrofit of distressed turbines.

WestWind Industries, Inc.
P.O. Box 1705
Davis, CA 95617
(916) 756-2222

Key Personnel: Kevin Jackson, Director, Mechanical Engineering (advanced blade design, loads estimation); Rus Couper, Director, Electrical Engineering (electrical/control systems); Paul Migliori, Vice President, Research and Development (configuration development).

WhirlWind Power Company

Conducts research to make small wind generators more cost-effective through optimal matching of propeller, generator, control, and loads. Also conducts new technology development and assessment for wind powered water pumping and operates the WhirlWind Test Site in Duluth, Minnesota. At the test site, WhirlWind is evaluating reduced cut-in wind-speed design, airfoils for improved efficiency at high tip-speed ratio, and a multipurpose wind generator (water pumping, heating and battery charging).

WhirlWind Power Company
207 1/2 East Superior Street
Duluth, MN 55802
(218) 722-1492

Key Personnel: Elliott Bayly, President (wind energy research); Scott Brainard, electronics (linear and digital electronics, wind generator controls).

Wichita State University (WSU) Center for Energy Studies

Conducts energy research, with special emphasis on applications to the state of Kansas. The investigators in the center, which was chartered by the Kansas Board of Regents, include faculty, staff, and graduate and undergraduate students. At the present time all center personnel are in the College of Engineering at WSU. Previous wind energy research projects have included an investigation of using small wind generators in a Kansas electric utility, a site evaluation of six potential windfarms in Kansas, evaluation of aileron and spoiler control sections for large wind machines, design of new airfoil sections for large wind machines, analysis of the Kansas wind resource, a feasibility study of the use of wind power for oil pumping in Kansas, development of a Kansas wind energy handbook, and demonstration of a wind generator.

Wichita State University
Center for Energy Studies
Campus Box 44
Wichita, KS 67208
(316) 689-3139

Key Personnel: Robert Egbert, Associate Professor, Electrical Engineering (power systems); Mark Jong, Professor, Electrical Engineering (power systems); Ward Jewell, Assistant Professor, Electrical Engineering (power systems).

Wind Data Center

See *Stadia, Inc.*

Wind Systems, Inc.

Conducts research on high-efficiency induction generators and designs low-technology utility interface wind turbine generator systems. Wind Systems uses computer optimization of design and cost.

Wind Systems, Inc.
612 Euclid Avenue
Berkeley, CA 94708
(415) 525-9126

Key Personnel: Otto J. M. Smith, Ph.D., Professor, Electrical Engineering and Computer Sciences (control, optimization, design); Phyllis S. Smith, President (writer, historian, lecturer).

Worldwatch Institute

Studies technical and political developments in wind energy at the national and international level.

Worldwatch Institute
1776 Massachusetts Avenue, N.W.
Washington, DC 20036
(202) 452-1999

Key Personnel: Christopher Flavin, Senior Researcher (international applications).

Chapter 8
Information Sources

This chapter lists the major sources of technical information on wind energy that are accessible to the public. This list is not intended to be exhaustive, but to concentrate on organizations or publications that can supply significant information on wind energy. The chapter is organized alphabetically by the following types of information sources:

- Associations
- Bibliographies
- Data Bases
- Directories
- Periodicals
- Software.

Associations

This section lists membership organizations with an interest in wind energy. Often, these organizations are sponsors of the major publications, conferences, and research activities in their area. The listing is based on information from the *Encyclopedia of Associations* and SERI's survey. Each entry includes the organization's name, mailing address, chief official, and description. The description might also include information on types of members, purpose, activities, awards, publications, products, and affiliations.

Alternative Energy Resources Organization (AERO)

Founded: 1974. Encourages energy efficiency and the transition from conventional to renewable energy sources (including solar, wind, wood, biomass, microhydro, and geothermal energies). AERO promotes renewable energy development, sustainable agriculture, and sustainable economic development through research, public education outreach (community education and organizing), and citizen representation. It also sponsors hands-on workshops and seminars and maintains a library and information center. Interested in general policy regarding wind energy, mostly brokering information among members. **Committees:** Agriculture, Economic Development, Education, Sustainable Agriculture, Technical. **Publications:** *AERO Sun-Times*, quarterly. Also publishes *Get Your Hands on Energy* (Vols. 1-2), *Sustainable Agriculture Resource Book*, energy activity books for children, and curriculum guides for elementary teachers.

Contact:
Al Kurki, Executive Director
Alternative Energy Resources Organization
44 North Last Chance Gulch, #9
Helena, MT 59601
(406) 443-7272

Alternative Sources of Energy (ASE)

Founded: 1971. Seeks to publicize and disseminate information on the practical applications of alternative technologies for the independent power production industry. As a scientific and educational organization, ASE's particular emphasis is on alternative environmental technologies in cogeneration, biomass, wind power, hydro power, and photovoltaics. **Publications:** *Independent Power* (formerly *ASE Magazine*), monthly. Also publishes a technical paper series.

Contact:
Donald Marier, Director
Alternative Sources of Energy
107 South Central Avenue
Milaca, MN 56353
(612) 983-6892

American Society of Mechanical Engineers (ASME), Wind Energy Committee

Founded: 1880. Wind Energy Committee founded 1981. The committee focuses on areas of wind energy that can increase the effective and efficient use of wind power. One of the committee's major efforts is organizing annual wind energy symposia. Each winter the Wind Energy Symposium is held in conjunction with the ASME Energy-Sources Technology Conference and Exhibition.

Contact:
Robert W. Thresher, Chairman, Wind Energy Committee
American Society of Mechanical Engineers
c/o Solar Energy Research Institute
Wind Research Branch
1617 Cole Boulevard
Golden, CO 80401
(303) 231-1897

American Solar Energy Society (ASES)

Founded: 1970. Provides leadership and education in all aspects of solar technology, applications, and research to speed the transition to widespread use of solar energy. ASES, formerly known as the American Section of the International Solar Energy Society (AS/ISES), is one of the oldest and largest national sections of ISES. Ten topical divisions encourage activity in specific technical disciplines. The wind energy division includes the areas of meteorology, climatology, aerodynamics, and ocean waves, as well as the engineering and application of wind power and ocean wave systems. ASES has 29 regional chapters and more than 2000 members. The society maintains a library of 3000 volumes. **Publications**: *Solar Today*, bimonthly. **Affiliated with**: International Solar Energy Society (parent). **Formerly**: American Section of the International Solar Energy Society (1982).

Contact:
Larry Sherwood, Executive Director
American Solar Energy Society
2400 Central Avenue
Unit B-1
Boulder, CO 80301
(303) 443-3130

American Wind Energy Association (AWEA)

Founded: 1974. Seeks to advance the art and science of using energy from the wind. As a nonprofit organization, AWEA's goals include assisting members in the commercial development of their businesses; providing industry representation to the various governmental agencies and other institutions involved in energy-source regulation and use; and disseminating information to the users of wind energy regarding sources of equipment, technical information, and standards. There are three categories of membership: industry (corporations, associations, groups, and individuals—members are eligible to vote); associate (dealers, educational institutions, and nonprofit organizations); and individual. **Publications**: *Windletter* (eight times per year), *Wind Energy Weekly* (weekly), conference proceedings, and special reports. AWEA's West Coast office acts as a liaison with the California wind industry, performing media relations, overseeing regulatory affairs, disseminating public information, tracking performance, and providing referrals.

Contact:
Tom Gray, Executive Director
American Wind Energy Association
1730 North Lynn Street, Suite 610
Arlington, VA 22209
(703) 276-8334
Fax: (703) 527-2833
Telex: (650) 330-4640 MCI UW

Paul Gipe, West Coast Representative
American Wind Energy Association, West Coast Office
P.O. Box 277
Tehachapi, CA 93561
(805) 822-7956
Fax: (805) 822-8452
Telex: 650-306-2869 MCI UW

Association of Energy Engineers (AEE)

Founded: 1977. Promotes the advancement of the profession and contributes to the professional development of members, who are engineers, architects, manufacturers, and other industry professionals with an interest in energy management and cogeneration. Awards scholarships to outstanding students in energy engineering, conducts seminars, and sponsors The Cogeneration Institute, a division of 1400 cogeneration professionals. **Committees**: Education, Energy Consultants, Energy Engineers in Government, Plant and Building Energy Management, Solar, Wind Power. **Councils**: National Energy Policy. **Publications**: *Strategic Planning and Energy Management Journal*, *Energy User News Magazine*, *Energy Insight Newsletter*, *Energy Engineering Journal*. **Absorbed**: National Association of Professionals in Energy Conservation, Total Energy Management Professionals (1984), Energy Management and Controls Society (1986).

Contact:
Wendy Wheeler
Association of Energy Engineers
4025 Pleasantdale Road, Suite 420
Atlanta, GA 30340
(404) 447-5083

Edison Electric Institute (EEI)

Founded: 1933. Provides the principal forum for electric utility representatives to exchange current information and to establish liaison nationally with customers, various interest groups, regulatory bodies, other national-level representative groups, and the federal government. EEI is the association of America's investor-owned electric utility companies. Its members provide approximately 75% of the country's electricity, serving about 75% of all electric customers in the United States. As a source of information for the electric utility industry, EEI monitors developments in all aspects of energy-related technology. **Publications**: *Electric Perspectives*; special reports on a wide range of utility topics. **Absorbed**: Electric Energy Association (1975), National Association of Electric Companies (1978).

Contact:
Justin Karp, Vice President
Engineering and Systems Operations Division
Edison Electric Institute
1111 Nineteenth Street, N.W.
Washington, DC 20036-3691
(202) 778-6968

Electric Power Research Institute (EPRI)

Founded: 1972. Manages a broad-based research, development, and demonstration program in areas of importance to electric power in the United States. EPRI is a nonprofit research institute funded by and operated for the U.S. electric utility industry. It maintains a data base containing summaries of ongoing and completed research in the electric power industry. EPRI has conducted extensive research in the application of wind energy to utility power generation. **Publications**: *EPRI Journal*, eight times per year; and *EPRI Guide*, three per year.

Contact:
Richard Balzhiser, President
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94304
(415) 855-2000

International Energy Agency (IEA)

Founded: 1974. A multinational organization of 21 industrialized, oil-consuming countries that carries out an international energy program designed to build and sustain strong energy economies. Objectives are to improve energy supply and demand balance, develop oil-alternative energy sources, coordinate international oil market information, maintain an emergency oil-sharing system. Compiles statistics. **Publications:** *Oil Market Report*, monthly; *Energy Policies and Programmes of IEA Countries*, annual. Also publishes energy statistics and reviews of coal and other energy sources.

Contact:
Helga Steeg, Executive Director
International Energy Agency
2, rue Andre Pascal
F-75775 Paris Cedex 16, France
1 45248200

Interstate Solar Coordination Council (ISCC)

Founded: 1980. Provides a national forum for developing compatibility, coordination, uniformity, and efficiency among state renewable energy programs. ISCC is a consortium of state renewable energy program managers. In addition to wind energy programs, ISCC has worked with such issues as Federal Energy Regulatory Commission (FERC) guidelines, incorporating renewable energy options in utility least-cost planning, codes and standards, and advertising guidelines. An ISCC newsletter column will be included in alternating issues of *Solar Today*.

Contact:
John R. Dunlop, Chairman
Interstate Solar Coordination Council
c/o Minnesota Department of Public Service
900 American Center Building
150 East Kellogg Boulevard
St. Paul, MN 55101
(612) 296-4737

Kern Wind Energy Association

Acts as liaison with the wind industry in Tehachapi, California, performing media relations, overseeing regulatory affairs, disseminating public information, tracking performance, and providing referrals. Serves the needs of the local wind industry and holds regular meetings to discuss topics of common interest.

Contact:
Paul Gipe, Executive Director
Kern Wind Energy Association
P.O. Box 277
Tehachapi, CA 93561
(805) 822-7956
Fax: (805) 822-8452
Telex: 650-306-2869 MCI UW

National Appropriate Technology Assistance Service (NATAS)

See *NATAS* in the Preface

See also *National Center for Appropriate Technology*

National Center for Appropriate Technology (NCAT)

Founded: 1976. Seeks to develop, apply, research, and transfer technologies appropriate to the energy-related needs of individuals; organizations; communities; and, particularly, low-income individuals. As a contractor to DOE and USDA, NCAT conducts research in the areas of renewable energy sources, resource conservation, reuse and recovery, housing and community facilities, integrated community development, and policy development and analysis. The center publishes and disseminates information and provides training and technical assistance for appropriate technology projects. It also maintains a library of 4000 volumes and 200 periodicals and publishes bibliographies, monographs, consumer booklets, and research reports. NCAT has contracted with DOE to operate NATAS, which provides information on energy conservation and renewable energy systems, including wind.

Contact:
Charles W. Greene, Vice President, Operations
National Center for Appropriate Technology
P.O. Box 3838
Butte, MT 59701
(406) 494-4572

National Association of Regulatory Utility Commissioners (NARUC)

Founded: 1889. Serves consumers by improving the quality and effectiveness of public regulation in the United States. As a nonprofit organization, NARUC is composed of government agencies engaged in the regulation of public utilities and carriers. **Publications:** *The Bulletin*, weekly; *The Annual Proceedings*; *The Annual Report on Utility and Carrier Regulation*. **Formerly:** National Association of Railway Commissioners (1918), National Association of Railway and Utilities Commissioners (1923).

Contact:
Paul Rodgers, General Counsel
National Association of Regulatory Utility Commissioners
1102 Interstate Commerce Commission Building
12th Street and Constitution Avenue, N.W.
Washington, DC 20044
(202) 898-2200

National Climatic Data Center (NCDC)

Founded: 1951. NCDC is the national collection center and custodian of U.S. weather records. Data are gathered from the National Weather Service operated by the National Oceanic and Atmospheric Administration (NOAA) as well as the weather services of the Air Force, the Navy, the Federal Aviation Administration, the Coast Guard, and other cooperative observers on land, at sea, and in the air. The center also uses cloud photography and other data obtained from environmental satellites. NCDC provides centralized data services for the U.S. community in addition to some services for the international community. Principal areas of research include climate, including temperature, pressure, precipitation, and wind; meteorology; solar radiation; and other atmospheric phenomena. **Publications:** *Local Climatological Data*, monthly; *Storm Data*, monthly; *Cooperative Data*, monthly; *Hourly Precipitation Data*, monthly; *Comparative Climatic Data*, annually; and the *Historical Climatological Series*. NCDC maintains a library in meteorology.

Contact:
Dr. Kenneth C. Hadeen, Director
National Climatic Data Center
Federal Building
Asheville, NC 28801
(704) 259-0682

North Dakota Renewable Energy Association

Founded: 1981. Sponsors meetings to educate the public about renewable energy and lobbies in support of state legislation favorable to alternative energy development in the state. In 1983 the wind energy association expanded its scope and became the North Dakota Renewable Energy Association. **Formerly:** North Dakota Wind Energy Association.

Contact:
Russell McKeeff, President
North Dakota Renewable Energy Association
R.R.1, Box 10
Mercer, ND 58559
(701) 447-2467

Renew America Project

Founded: 1978. Works to ensure that renewable energy technologies such as solar, wind, geothermal, biomass, ocean thermal, photovoltaic, and hydro have an equal chance to compete with traditional and subsidized forms of energy. Represents consumer interests in obtaining low-cost energy and securing a safe and sustainable energy future. Lobbies Congress and the executive branches of the federal government to encourage legislation on the development of renewable and solar energy. Provides members with voting records on wind energy issues. **Publications**: *Renew America*, bimonthly; *FREE Report* (newsletter), quarterly; *FREE Market Bright Ideas* (catalog), semiannual; *State of States* (report), annual; *Alternative Energy: A Guide to Free Information to Educators*; *Electricity: New Consumer Choices*; *The Hidden Cost of Energy*. **Formerly**: Fund for Renewable Energy and the Environment (FREE).

Contact:
Ric Barrick, Associate Director
Renew America Project
1001 Connecticut Avenue, N.W., Suite 719
Washington, DC 20036
(202) 466-6880

Bibliographies

This section lists bibliographies that focus on wind energy or contain sections on wind energy. Although these sources represent a comprehensive listing of wind energy publications, computerized data bases are often the best way to find recent publications. Each entry contains a bibliographic citation and an abstract.

ASSET: Abstracts of Selected Solar Energy Technology

Contains abstracts of recent books, articles, reports, and conference papers concerning solar, bioconversion, and wind energy technologies and the socioeconomic aspects of their use. Care is taken to include all available information that applies to rural communities in developing countries. Issues contain abstracts of recent publications balanced with those from the extensive older literature. Each issue also includes at least one complete reprinted paper.

Shearer, W., ed. (1985). *ASSET: Abstracts of Selected Solar Energy Technology*. Volume 7, No. 1. NRAS-70/UNUP-556. Tokyo, Japan: United Nations University; 31 pp. Available NTIS: Order No. DE85901708.

Bibliography: Wind Power

Lists wind periodicals with a brief description of their contents. The reference materials section contains bibliographic citations and descriptors. The citations are organized in the following categories: general reference; siting information; utility application information; legal, institutional, and environmental issues; magazine articles; and directories and bibliographies. Sources for this bibliography include industry, federal and state agencies, periodicals, and reference materials.

Bibliography: Wind Power. (1983). DOE/CS/69104-4. Lansing, MI: Michigan Department of Commerce; 30 pp. Available NTIS: Order No. DE84010426.

Energy Costs and Costing: A Selected, Annotated Bibliography

Lists books, reports, and journal articles on energy costs and costing. Entries in the wind energy section are annotated and listed under the subject headings of costs and statistics. The bibliography also includes a name index and a subject index.

Ocran, E. B. (1983). *Energy Costs and Costing: A Selected, Annotated Bibliography.* Metuchen, NJ: The Scarecrow Press, Inc.; 205 pp.

Energy from the Wind

Includes author, subject, report number, and conference proceeding indexes developed under DOE sponsorship. The third supplement covers books, reports, conference proceedings, journal articles, and patents. It adds 2455 references to the 3381 collected in the previous three volumes (*Basic Volume*, 1975; *First Supplement*, 1977; *Second Supplement*, 1979). A volume of cumulative indexes covering all four volumes is available separately.

Burke, Barbara L. and Meroney, Robert N. (1982). *Energy from the Wind: Annotated Bibliography—Third Supplement.* Fort Collins, CO: Colorado State University; var. pp.

EPRI Guide: Technical Reports

Compiles reports on EPRI's research projects into a bibliography. Each citation is listed with an abstract. The guide is published in January, May, and September each year and includes a subject index, an EPRI project number index, and an EPRI report number index. Topics in the subject index include wind, wind power, wind power generation, wind power plants, and wind turbines.

EPRI Guide: Technical Reports. Palo Alto, CA: EPRI Research Reports Center. Available from EPRI, Box 50490, Palo Alto, CA 94303, (415) 855-2411.

A Field Guide to American Windmills

See *Directories*

Quick Bibliography Series: Wind Energy for Agriculture, 1981-1983

Lists 77 wind energy citations compiled from an on-line search of the AGRICOLA data base. Also includes an author index and a list of land-grant university libraries that provide USDA's document service.

Quick Bibliography Series: Wind Energy for Agriculture, 1981-1983. (February 1984). Beltsville, MD: National Agricultural Library; 13 pp. Available from the USDA, National Agricultural Library, Reference Section, Room 111, Beltsville, MD 20705.

Sail-Type Wind-Turbines: A Review and Annotated Bibliography

Provides a comprehensive introduction for engineers who wish to gain an understanding of the design, construction, and performance of windwheels with flexible sails. The bibliography is a compilation of abstracts, which are the compilers' interpretations of the contents of each paper. The abstracts are classified into nine groups. The first six are concerned with the history, development, and use of sail-type wind turbines. The seventh group refers to possible refinements of low-speed, horizontal-axis, Cretan-type turbines. The eighth section outlines vertical-axis sail turbines, and the final group introduces two books, which deal primarily with small-scale harnessing of wind power.

Fleming, P. D. and Probert, S. D. (April 1982). "Sail-Type Wind-Turbines: A Review and Annotated Bibliography." *Applied Energy* (10:4), pp. 273-286.

Solar Power Generation: A Bibliography with Abstracts Quarterly Update, October-December 1982

Contains one chapter devoted to wind energy. Citations include the reference title, author, corporate affiliation, reference source, and abstract. The publication includes an index of authors and a list of abbreviations and acronyms.

Solar Power Generation: A Bibliography with Abstracts Quarterly Update, October-December. (April 1983). TAC-SPG-82 0014. Albuquerque, NM: University of New Mexico; 148 pp. Available NTIS: Order No. DE83901745.

SYNERJY, A Directory of Energy Alternatives

See *Directories*

Wind Energy: Bibliography with Abstracts and Keywords

Includes approximately 1000 citations covering the period from about 1900 to 1975. The citations and abstracts are written in English, but the language of the document itself is noted. The bibliography focuses on wind machines, although related areas such as meteorology, wind measurement, electronics, and energy storage are addressed briefly. Access is provided alphabetically by author (or by title for those citations without author), keyword, and country.

van Steyn, René (July 1975). *Wind Energy: Bibliography with Abstracts and Keywords.* Eindhoven, The Netherlands: Eindhoven University of Technology; 2 Vols.

Wind Energy 1975-1985: A Bibliography

Covers wind energy research and development around the world. The citations are organized in the following categories: resource assessment and site selection, design of wind energy conversion systems, institutional incentives and controls on wind energy conversion systems, applications of wind energy conversion systems, and bibliographies. An author index is provided.

Farmer, P. (1986). *Wind Energy 1975-1985: A Bibliography.* New York: Springer-Verlag; 167 pp.

Wind Energy Abstracts

Issues international wind power abstracts monthly in a looseleaf format. First published in 1983. The abstracts are grouped under subject headings such as aerodynamics and aeroelastics; wind measurement methodologies; construction, operation, and maintenance; national and regional programs; and policies. Upcoming wind energy meetings are announced. Some of the reports listed may be ordered from Wind Books.

Wind Energy Abstracts. St. Johnsbury, VT: Wind Books. Available from Wind Books, P.O. Box 4008, St. Johnsbury, VT 05819, (802) 748-2425.

Wind Energy Directories

Lists 76 directory-type publications with abstracts. The publications include newsletter and periodical lists, compilation of plans, bibliographies of audiovisual materials, summaries of design competitions, catalogs, manufacturer lists, and directories of government agencies.

Frankena, F. (May 1984). *Wind Energy Directories.* No. P1446. Monticello, IL: Vance Bibliographies; 20 pp. Available from Vance Bibliographies, P.O. Box 229, Monticello, IL 61856.

Wind Energy Technical Reading List

Cites technical publications produced by DOE's national laboratories and their subcontractors in the area of wind energy research and development. The reading list includes journal articles, conference papers, and technical reports. Publications are grouped in the following categories: general, international, aerodynamics, structural dynamics, controls and support systems, design and testing, environmental compatibility and

Wind Energy Technical Reading List. (1988). SERI/SP-273-2911. Golden, CO: Solar Energy Research Institute; 20 pp. Available NTIS: Order No. DE86010704.

safety, resource assessment and siting, applications and systems analysis, and economics.

Wind Energy Technology (WET)

Provides current information available worldwide on wind turbine concepts and design, including the basic science of wind turbine dynamics; advanced components and systems research; wind turbine performance; ancillary wind turbine equipment, including system protection and interconnection devices; wind resource identification; wind turbine project planning and development; legal and institutional implications of wind energy conversion systems; and environmental aspects of wind turbines. Published bimonthly, WET contains DOE report abstracts, journal articles, conference papers, patents, theses, and monographs added to the Energy Data Base (EDB) during the preceding two months. The digests in WET and other citations to information on wind energy back to 1974 are available for on-line searching and retrieval on EDB. The entire EDB is available on commercial on-line retrieval systems.

Wind Energy Technology. U.S. Department of Energy. Available from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831.

Wind Energy Utilization: A Bibliography with Abstracts

Contains cumulative citations from 1944-1974 on the following areas: wind energy utilization, wind power plants, wind power generators, wind machines, wind data and properties, energy storage, and related design topics. The citations are also indexed by author, corporate source, title, and keyword.

Wind Energy Utilization: A Bibliography with Abstracts. (April 1975). DOE/NASA/ 1010-77/4. Cleveland, OH: NASA Lewis Research Center; 496 pp. Work performed by Technology Applications Center, University of New Mexico, Albuquerque, NM.

Wind Turbine Acoustics Research—Bibliography with Selected Annotation

Contains a selected bibliography, with some annotations, of research papers on wind turbine acoustics. Citations are organized into the following sections: general publications; noise generation, prediction, and measurements; noise propagation; effects of wind turbine noise on people and communities; effects of wind turbine noise on buildings; and noise measurement technology. For those sections relating to propagation, measurement, and the effects of noise, some generally relevant papers are also included. In each section, certain key documents are listed with abstracts. Other documents are then listed in chronological order without annotations.

Wind Turbine Acoustics Research—Bibliography with Selected Annotation. (January 1988). NASA Technical Memorandum 100528. Hampton, VA: NASA Langley Research Center; 33 pp.

Data Bases

This section describes bibliographic and numeric data bases that are available to the public and are significant sources of wind energy information. Bibliographic data bases provide an efficient method of finding recent publications. They also make it easier to locate a specific type of publication or publications from a specific source. Numeric data bases provide access to data compilations and facilitate analysis of the data. Most of the data bases are available from commercial vendors. A list of these vendors appears at the end of this section. Libraries or other organizations subscribing to these vendors offer data-base search services, often on a recharge basis. In addition, several of the data-base publishers provide in-house search services. Publications produced from the data base and the magnetic tapes themselves might also be available. Data-base entries include the name, address, and telephone number of the sponsoring organization; a description of the data base's coverage; approximate size; services; ancillary publications; and availability.

Aerospace Data Base

Coverage: 1962 to present. Provides references, abstracts, and controlled-vocabulary indexing of key scientific and technical documents, as well as books, reports, and conferences, covering aerospace research and development in more than 40 countries, including Japan and Communist-bloc nations. This data base supports basic and applied research in aeronautics, astronautics, and space sciences, as well as technology development and applications in complementary and supporting fields such as chemistry, geosciences, physics, communications, and electronics. In one data base, the Aerospace Data Base combines two publications: *Scientific and Technical Aerospace Reports (STAR)*, produced by the National Aeronautics and Space Administration (NASA), and *International Aerospace Abstracts (IAA)*, produced by the American Institute of Aeronautics and Astronautics (AIAA) under contract to NASA. The file contains more than 1.5 millon citations and is updated two times per month. Available on line from DIALOG Information Retrieval Service.

Producer:
American Institute of Aeronautics and Astronautics
Technical Information Service
555 West 57th Street
New York, NY 10019
(212) 247-6500

COMPENDEX

Coverage: 1970 to present. Stands for the COMPuterized ENgineering inDEX (COMPENDEX) data base. Engineering Information, Inc. (EI), is a nonprofit organization that abstracts and indexes the world's engineering literature. EI maintains COMPENDEX, which contains abstracts and extensive indexing. All engineering fields, including related areas of applied science, management, and energy, are within the scope of COMPENDEX. The EI collection contains more than 2 million bibliographic references and abstracts gathered since 1884. About 1.7 million citations with abstracts are available on COMPENDEX. Abstracts are added to the file at a rate of more than 100,000 per year. EI makes information from COMPENDEX available in hard copy, microform, and computer-readable forms. Its major publication is *Engineering Index Monthly* Also published from the data base are *Energy Abstracts and Bioengineering Abstracts*. COMPENDEX is widely distributed on line through North American and European vendors, including DIALOG Information Services, Inc.; ORBIT Search Service; Bibliographic Retrieval Services (BRS); ESA-QUEST (European Space Agency); STN International; and DATA-STAR. EI also provides search services and magnetic tape subscriptions from the data base.

Producer:
Engineering Information, Inc.
345 East 47th Street
New York, NY 10017
(212) 705-7600

DOE Energy Data Base (EDB)

Coverage: 1974 to present. Covers journal articles, report literature, conference papers, books, patents, dissertations, and translations. The following energy topics are included: nuclear, wind, fossil, geothermal, tidal, and solar. Related topics such as environment, energy policy, and conservation also are included. To maintain EDB, the Office of Scientific and Technical Information (OSTI) collects, evaluates, analyzes, stores, and disseminates energy information resulting from DOE-funded research and development programs as well as other relevant technical literature produced worldwide. EDB is one of the world's largest computerized sources of literature references on all aspects of energy and related topics. Evolving from and expanding the scope of the Nuclear Science Abstracts (NSA) data base previously maintained by the Technical Information Center (OSTI's predecessor), EDB is the basis for OSTI products and services, including abstracts, journals, current awareness bulletins, and bibliographies. EDB is commercially available, holds more than 1.7 million literature references, and is updated biweekly. About 160,000 new items are recorded in EDB each year. EDB is available for on-line searching through DIALOG (as DOE Energy), ORBIT Search

Producer:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831
(615) 576-1188

Service, and STN International. It is also available by subscription on biweekly magnetic tapes, which average 12,000 to 15,000 items per month. The NSA file, which contains almost 1 million references to reports of the U.S. Atomic Energy Commission, the U.S. Energy Research and Development Administration, and other organizations, and covers the period from 1948 to 1976, is also now available from DIALOG Information Services, Inc. The current year of EDB and the Research in Progress (RIP) file are directly available from OSTI. RIP contains about 16,000 records on energy-related research projects sponsored by DOE.

Energy Bibliography and Index (EBIB)

Coverage: 1919 to present. Covers worldwide literature on energy from the Texas A&M library collection. Subjects include the production, use, and conservation of all types of fuels (e.g., fossil fuels, synthetic fuels, hydrogen, nuclear, energy storage and conversion, energy policy, alternative energy sources, power plants, and transmission systems) and the economic, political, environmental, and statistical aspects of energy-related issues and activities. A special feature of this file is its coverage of German World War II documents on synthetic fuel technology. EBIB also includes citations from the Energy and Agriculture Data Base project, which covered the conservation, use, and creation of energy in the agricultural community. The Energy and Agriculture Data Base was formerly known as the Energy for Agriculture Bibliography, which was compiled by Michigan State University's Department of Agricultural Engineering. *Energy Bibliography and Index* is produced from the data base. Approximately 14,000 citations are in the data base, principally from 1919 to the present, but some material dates to the late 19th century. This service is available on line from ORBIT Search Service.

Producer:
Texas A&M University
Sterling C. Evans Library
Reference Division
College Station, TX 77843
(409) 845-5741

Electric Power Database

Coverage: 1972 to present. Includes references to research and development projects of interest to the electric power industry. It corresponds to the printed work *Digest of Research in the Electric Utility Industry*. The data base covers U.S. and Canadian research related to issues in electric power, including hydroelectric power, fossil fuels, nuclear power, solar power, customer use, transmission distribution economics, advanced power systems, and environmental assessment. The records provide work descriptions, start and completion dates, dollars allocated, results, project reports, publications, and contact persons. Such projects are conducted largely by companies under contract to EPRI or to other utilities, as well as by EPRI itself. Research from other corporate and utility sources is also covered. The data base has more than 15,000 records and is updated monthly. The service is available on line from DIALOG Information Services, Inc.

Producer:
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94303
(415) 855-2000

Electric Power Industry Abstracts

Coverage: 1975 to present. Provides access to literature on electric power plants and related facilities. Topics include environmental effects of electric power plants and associated transmission lines, power plant siting methodologies, fuel transportation, storage and use, licensing and permit data, energy resources, monitoring programs, safety and risk management, uranium enrichment, coastal zone management plans, waste disposal facilities, and land-use studies. Source documents include technical reports and studies prepared by the electric utilities and their consultants, reports from federal and state agencies, siting commissions, and control boards, and selected journal articles, conference proceedings, and testimony from Congressional hearings. The file contains more than 25,000 records and is updated five times a year. Available on line from ORBIT Search Service.

Producer:
Edison Electric Institute
1111 Nineteenth Street, N.W.
Washington, DC 20036-3691
(202) 828-7400

ENERGYLINE®

Coverage: 1971 to present. ENERGYLINE is a primary source for information relating specifically to energy. Its data are drawn from many conventional discipline-oriented fields, such as chemistry or engineering, but are incorporated in ENERGYLINE only as they relate to energy issues and problems. Coverage includes books, journals, congressional committee prints, conference proceedings, speeches, and statistics. The data base, updated monthly, contains more than 80,000 records, including 8000 energy- and environment-related records from the *The Energy Index*, dating to 1971. ENERGYLINE is the on-line version of *Energy Information Abstracts*. EIC/Intelligence, Inc., provides a microfiche service for the full-text articles cited in ENERGYLINE. It is accessible on line through DIALOG Information Services, Inc.; ESA-QUEST (European Space Agency); and ORBIT Search Service. Magnetic tape copies of ENERGYLINE are available from EIC.

Producer:
EIC/Intelligence, Inc.
48 West 38th Street
New York, NY 10018
(212) 944-8500

NTIS

Coverage: 1964 to present. Contains approximately 1.2 million citations, most with abstracts, to unrestricted technical reports from U.S. and non-U.S. government-sponsored research, development, and engineering analyses. The U.S. reports are prepared by federal, state, and local agencies, and their contractors or grantees. Major subject areas include the biological, social, and physical sciences; mathematics; engineering; and business. NTIS includes announcements of computer-readable software and data files, U.S.-government-owned inventions, selected reprints, federally sponsored translations, and some non-English-language reports. The data base corresponds to the biweekly publication *Government Reports Announcements & Index* and in part to the weekly *Abstract Newsletters*. The service is available on line from BRS/Search Service; DATA-STAR; DIALOG Information Services, Inc.; ORBIT Search Service; and STN International.

Producer:
National Technical Information Service
Office of Product Management
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4929
Telex 899405

POWER

Coverage: 1970 to present. Consists of catalog records for books, monographs, proceedings, and other materials in the book collection of the DOE Energy Library. The collection is particularly strong in general works on energy, physical, and environmental sciences; technology; economics; renewable energy resources; and water resources. The library brings together several significant government agency collections, including those of the Atomic Energy Commission, the Energy Research and Development Administration, the Federal Power Commission, and the Federal Energy Administration. Although most of the citations date from the 1970s and 1980s, Federal Power Commission items published in the early twentieth century and AEC library material from the 1960s also are included. Records include complete Library of Congress cataloging information. The data base contains more than 35,000 records and is updated every two months. It is available on line from ORBIT Search Service.

Producer:
U.S. Department of Energy
Energy Library
Room G-042 GTN
Washington, DC 20545
(301) 353-4166

Wind Data Center Data Base

Coverage: 1981 to present. Contains data on world shipments, applications, wind turbine manufacturers, and wind turbine descriptions, compiled by the Wind Data Center. The center specializes in the systematic collection and analysis of wind industry statistics. Information is continually updated and expanded, and manufacturers are surveyed annually. The center provides special data runs and analysis tailored to individual needs. The following are basic information areas in the data base:

- Annual information since 1981
- Product characteristics (rotor diameter, wind turbine type, blade composition, other)
- Market data (units, MW, FOB value; region, country, territory; wind turbine characteristics; other)
- Manufacturing, import, and export data (units, MW, FOB value; region, country, territory; wind turbine characteristics; other)
- Wind turbine manufacturers (products; company size; region, country, territory; aggregated shipments; other)
- Applications data for eight application types (units, MW, FOB value; region, country, territory; wind turbine characteristics; other).

Aggregated statistics and analysis are published annually. Other services include market forecasting, market analysis, and in-country market assessment.

Producer:
Thomas F. Jaras
Wind Data Center
Stadia, Inc.
P.O. Box 442
Great Falls, VA 22066
(703) 759-6520

Wind Energy Resource Information System (WERIS)

Includes data and atlas maps from the 12 regional wind energy resource assessments produced for DOE (cited in Chapter 4). The following data files make up the data base: station descriptions, means and frequency distributions, intra- and inter-annual mean and standard deviations, climatic means and weather events, persistence of speed and direction, and wind data grid. Much of the data came from a Pacific Northwest Laboratory (PNL) analysis of 973 stations in the National Climatic Data Center (NCDC) TD1440 tape set. Data contained in the data base are available on microfiche and magnetic tape from NCDC. The WERIS user's manual, TD-9793, is also available.

Producer:
National Climatic Data Center
Information Services Division
Federal Building
Asheville, NC 28801-2696
(704) 259-0682

Data-Base Vendors

The following vendors provide direct on-line access to the listed data bases.

BRS/Search Service
BRS Information Technologies
1200 Route 7
Latham, NY 12110
(800) 345-4277

DATA-STAR
D-S Marketing Ltd.
Plaza Suite
114, Jermyn Street
London SW1Y 6HJ England
44 (1) 930-5503

DIALOG Information Retrieval Service
DIALOG Information Services, Inc.
Marketing Department
3460 Hillview Avenue
Palo Alto, CA 94304
(800) 334-2564

ESA-QUEST
European Space Agency
Information Retrieval Service
C.P. 64
Via Galileo Galelei
00044 Frascati
Italy
39 (6) 940 11
Telex 610637 ESRIN I

ORBIT Search Service
System Development Corporation (SDC)
2525 Colorado Avenue
Santa Monica, CA 90406
(800) 352-6689 (California)
(800) 421-7229 (outside California)

Pergamon InfoLine Service
Pergamon International Information Corporation
1340 Old Chain Bridge Road
McLean, VA 22101
(800) 442-0900 (Virginia)
(800) 336-7575 (outside Virginia)

STN International
c/o Chemical Abstracts Service
2540 Olentangy River Road
P.O. Box 3012
Columbus, OH 43210
(800) 848-6533
(800) 848-6538

Directories

This section lists directories and similar reference publications that can direct inquirers to wind energy information, products, services, and organizations (for a list of software directories, see the section entitled **Software**). Each entry includes a bibliographic citation and an abstract.

California Wind Atlas

Summarizes all available wind data in the state since 1930. The purpose of the atlas is to provide wind energy developers with an up-to-date reference on wind potential in California. Data are presented in charts, maps, graphs, and statistical summaries. The atlas contains tables summarizing the wind station locations; mean hourly, monthly, and annual wind speeds; peak wind gusts; mean wind power; year-to-year and vertical wind variations; and developable wind resource potential. Folded maps are included to show the location of wind measurement sites, wind resource potential, and the electric transmission system. Other sections describe the history of wind measurements in California and summarize the California Energy Commission's wind resource assessment studies.

California Wind Atlas. (April 1985). Sacramento, CA: California Energy Commission; 210 pp. Work performed by California Department of Water Resources, Sacramento, CA. Available from California Energy Commission, Publication Unit, 1516 Ninth Street, MS-15, Sacramento, CA 95814.

Current Alternative Energy Research and Development in Illinois, December 1986

Inventories recent research, development, and demonstration projects of nonfossil and nonnuclear energy sources. Projects were either completed after December 1985 or underway in October 1986. The reports on 56 alternative energy projects fall into eight major categories. The topics with actual numbers of reports are bioenergy (24); solar heating and cooling (18); solar photovoltaics (8); geothermal and ocean thermal (2); wind energy (3); and waste heat and materials recovery (1).

Current Alternative Energy Research and Development in Illinois, December 1986. (January 1987). PB-87-166187/XAB. Springfield, IL: Illinois Department of Energy and Natural Resources; 133 pp. Available NTIS: Order No. PB87-166187.

Directory of Information Centres in the World: Statistical Publications of Energy by International Organizations

Lists 400 entries from 69 countries. National and international organizations able to supply energy information are identified by country. The directory is published in English and French and includes information on fields covered, nature of available documents, offered services, and access to information networks.

Francais de L'Energie. (1983). *Directory of Energy Information Centres in the World: Statistical Publications of Energy by International Organizations.* Paris: Editions Europennes Thermique et Industrie; 278 pp.

Energy Directory

Covers more than 3000 agencies, organizations, and companies active in the energy field. The listings are divided into chapters entitled Federal Executive Establishment, Congressional Establishment, State Energy Officials, Energy Associations, Energy Companies, and Cumulative Index. Entries include organization name, personnel, address, telephone number, programs, projects, publications, and information services. The directory is indexed by organization name, keyword, subject, and personnel names. It was formerly called the *Energy Directory Update Service*. See ENERGYLINE® in Chapter 5.

Pronin, M., ed. *Energy Directory.* (1983). New York: Environment Information Center, Inc.; 600 pp.

Lists energy personnel at federal agencies and offices (primarily in DOE but also in other federal agencies) by subject area. Entries include name, title, abbreviated office address, DOE routing symbol, telephone number, and description of program or services related to energy concerns. An index of building locations provides complete addresses. The directory supersedes and enlarges the *Conservation and Renewable Energy Resource Directory*. Appendices list state energy offices, DOE research and development field facilities, and state energy extension service contacts. Subject and name indexes are also included.

Energy Information Directory. (June 1987). DOE/EIA-0205(87/2). Washington, DC: National Energy Information Center, U.S. Department of Energy; 84 pp. Available NTIS: Order No. DE87013214.

A Field Guide to American Windmills

Provides both a general history of turbine-wheel mills and an identification guide to the 112 most common models. The identification sections include illustrations. Appendices identify all the known windmill manufacturers in the United States, Canada, and Mexico and all the known windmill models from the 1850s to 1985. The comprehensive bibliography lists source materials on the history of wind power use. The bibliography is organized by the following sections: archival materials, interviews, books, articles, trade literature, advertisements, business directories, farm implement and industrial directories, and U.S. government documents.

Baker, T. Lindsay. (1985). *A Field Guide to American Windmills.* Norman, OK: University of Oklahoma Press; 516 pp.

International Directory of New and Renewable Energy Information Sources and Research Centers

This edition contains a total of 3596 entries representing 156 countries. National, regional, and international organizations and publications are included, covering governmental, private, or academic affiliations. For the purpose of the directory, new and renewable energy interest areas are identified as follows: biomass (includes biomass, bioconversion, alcohol fuels, and biomass applications); solar (includes active and passive solar heating and cooling, solar thermal, and photovoltaics); wind energy; hydropower; geothermal; other energy technologies (includes energy conservation, integrated energy systems, and ocean energy); and geographic descriptors. Only major organizations or publications are included. The directory comprises five sections: listings by country, organization index, subject index, publication index, and acronym list. In addition, there are two appendices; one details the numbers and type of entries for each country, and the other lists the references used by Unesco.

International Directory of New and Renewable Energy Information Sources and Research Centers, Second Edition. (1986). Paris: United Nations Educational, Scientific and Cultural Organization; 661 pp. Available from the United Nations Education, Scientific and Cultural Organization, Energy Information Section, 7 place de Fontenay, 75700 Paris.

Public Power Innovation

Lists innovative projects implemented by public utilities in the United States during 1983 to conserve energy and demonstrate advanced technologies. Summarizes nearly 1000 projects in 360 communities, covering 46 states. Twenty projects are listed in the area of wind energy.

"Public Power Innovation." (November-December 1983). *Public Power* (41:6).

Resource Directory of DOE Information Organizations

Covers nearly 200 major information analysis centers, libraries, and information offices operated by DOE or its contractors. Entries include the center name; address; telephone number; name of director; and annotation covering scope, sponsors, services, and qualified users. Entries are arranged by organization, and organization and personal name indexes are included. The directory was formerly called *Directory of Libraries and Information Specialists in DOE and Its Contractor Organizations*. It supersedes *Directory of ERDA Information Centers*.

Resource Directory of DOE Information Organizations. (January 1987). DOE/TIC-4616-Rev. 3. Washington, DC: U.S. Department of Energy, Office of Scientific and Technical Information; 184 pp. Available NTIS: Order No. DE87003393.

Status of Commercial Wind Power: 1986 Survey

Describes the results of this survey of commercial wind power stations, the data gathered on wind turbine manufacturers, and the products those manufacturers were offering for sale in the United States in 1986. This survey is the third sponsored by EPRI. The data have been examined for trends relative to earlier surveys. The survey collected both technical and business-related information from 54 wind power station developers and 25 wind turbine manufacturers. Only those wind power stations were included that were already on line by December 31, 1985. Only those wind turbine manufacturers were included that offered wind turbines for sale in the United States as of early 1986. Descriptions of 122 wind power stations established by 54 developers are included.

Steele, R. V. and McKellar, M. F. (March 1987). *Status of Commercial Wind Power: 1986 Survey.* EPRI AP-5084. Palo Alto, CA: Electric Power Research Institute; 308 pp. Work performed by Strategies Unlimited, Mountain View,CA. Available from EPRI Research Reports Center, Box 50490, Palo Alto, CA 94303.

SYNERJY, A Directory of Energy Alternatives

Contains information about renewable energy and energy storage presented in U.S. and foreign sources, including publications, major articles (in English), conferences, research associations, manufacturers, and facilities. Technologies covered include solar energy, biomass fuels, hydrogen fuels, geothermal energy, water power, wind power, electric energy use, and energy transfer and storage. Under the wind power heading, books,

Twine, J. M., ed. (Semiannual, January and July; July issue, cumulative). *SYNERJY/A Directory of Energy Alternatives.* New York: SYNERJY.

patents, government publications, articles, manufacturers' research organizations, and wind turbine facilities are listed. SYNERJY is updated semiannually; summer/fall issues are cumulative for one year only.

Who's Who in Civil Engineering Earth Sciences & Energy

Includes biographies selected because of the individual's outstanding contributions to the advancement of science, engineering, or technology. Biographical information for each person includes the name, current business position and affiliation, career history, education, publications, patents, major technical achievements, organization memberships, honors and awards, principal expertise, and personal information. The biographies are grouped by technical discipline, one of which is energy technology. An index of expertise provides more detailed subject access. An index of names is also provided.

Who's Who in Civil Engineering Earth Sciences & Energy. (1986). Woodbridge, CT: Research Publications; 718 pp.

ASE Wind Industry Directory

Consists of two main sections. Section I is alphabetized and lists all companies in the field, regardless of technology. Section II is organized by technology and lists company names in the appropriate subsection. The wind power section lists company names in the following categories: developers, owners, and operators; manufacturers; services; and other. The category of manufacturers is further divided: equipment, which includes wind turbines (WECS); small wind turbines (SWECS less than 25 kW); mechanical water pumpers, bearings, brakes, gearboxes, nacelles, rotors/blades, safety equipment, and towers; and instruments/controls, which includes controls, measuring instruments, and monitoring. The services category headings include: consultants, including computer services, environmental, feasibility, marketing, measurements, meterology, regulatory/licensing, research, and testing; engineering/construction (design, operation, maintenance, project management, and repair); and financial/legal (finance, insurance, and legal). The directory also lists trade groups and federal and state agencies, and includes a professional directory and an advertiser's index. Published annually by the nonprofit organization called Alternative Sources of Energy.

"1988 Industry Directory." (December 1987). *Alternative Sources of Energy.* (96). 96 pp.

Wind Energy Resource Atlas of the United States

Presents detailed estimates of the wind resource for the United States and its territories and indicates the general areas where high wind resources may exist. The atlas also presents a summary of the U.S. wind energy resource on a region-by-region basis including the Northwest, North Central, Great Lakes, Northeast, East Central, Southeast, South Central, Southern Rocky Mountains, Southwest, Alaska, Hawaii and the Pacific Islands, and Puerto Rico and the Virgin Islands. Each region is subdivided into annual average wind power by state and by area within the state. The appendices contain data analysis and assessment methods, a discussion of the Wind Energy Resource Information System model, annual and seasonal mean wind speed and power summaries for selected stations in the United States and its territories, evaluation of new site data for verifying or updating wind resource estimates, and wind power summaries for 35 wind turbine sites.

Elliott, D. L.; Holladay, C. G.; Barchet, W. R.; Foote, H. P.; and Sandusky, W. F. (March 1987). *Wind Energy Resource Atlas of the United States.* DOE/CH 10093-4. Washington, DC: U.S. Department of Energy; 210 pp. Work performed by Pacific Northwest Laboratory, Richland, WA. Available from GPO: Stock No. 061-000-00679-6 and NTIS: Order No. DE86004442.

Wind Power Instrumentation Directory

Defines and discusses wind resource characteristics and wind turbine performance parameters. Presents product descriptions for commercially available instruments to measure these characteristics and parameters. In addition to listing the suppliers' names, addresses, and telephone numbers, the product descriptions contain a brief summary of the electrical and physical characteristics of the instruments, data storage and data reduction capabilities, and mid-1985 prices. Indexes provide the reader with quick access to the individual product description sheets. Includes a glossary and a bibliography (which is oriented toward wind resource and wind turbine performance testing).

R. Lynette & Associates, Inc. (May 1986). *Wind Power Instrumentation Directory.* EPRI AP-4586. Palo Alto, CA: Electric Power Research Institute; 84 pp. Available from EPRI Research Reports Center, Box 50490, Palo Alto, CA 94303.

Wind Sourcelist

This two-page directory lists company name and mailing address for U.S. wind manufacturers. There are 53 entries under wind generator manufacturers; 17 for tower manufacturers; 17 for inverter manufacturers; and 19 for wind instrument manufacturers.

"Wind Sourcelist." (May/June 1983). *Alternative Sources of Energy.* (61); pp. 18-19.

World Directory of Energy Information

Covers national and international organizations concerned with energy use and conservation, energy research and development, and alternative sources of energy. Volume 1 covers 400 organizations and 300 publication sources in 17 Western European countries. Volume 2 covers 489 organizations in the Middle East, Africa, and the Asia/Pacific area. Volume 3 covers 473 organizations in the Americas. Each volume is divided into four parts. Part 1 provides an overview of the main features of energy in the region, with appropriate maps and tables. Part 2 looks in detail at individual countries in a standard sequence; key energy indicators are followed by sections dealing with energy market trends, the supply industries, energy trade, and energy policies. Part 3 contains profiles of organizations involved in the exploration, production, transmission, and distribution of energy as well as relevant official bodies. Part 4 is a bibliography of publications on energy matters at either the national or transnational level. Organizations are arranged by country or internationally. Publications are arranged alphabetically and cross-referenced by subject and country.

World Directory of Energy Information, 3 vols. (1984). New York: Facts on File, Inc.; Hampshire, UK: Gower Publishing Co. Ltd.

World Energy Directory: A Guide to Organizations and Research Activities in Non-Atomic Energy

Lists about 2500 industrial, official, academic, and independent organizations and laboratories throughout the world that conduct or promote R&D in nonnuclear energy. Subjects include the efficient use of nonrenewable resources; the harnessing of renewable sources such as wave, tidal, hydroelectric, wind, geothermal, and solar energy; fuel production from vegetable matter; energy storage; energy handling equipment; and different variables in energy supply and demand. The directory is arranged geographically by country with an alphabetic listing of organizations within individual entries. Entries include title, English translation, full postal address, and telephone and telex numbers; affiliation; names of director and senior staff; number of R&D staff; annual R&D expenditure activities; and publications and organizations for whom work is carried out. Organization and subject indexes provide additional access.

Smith, W. M., ed. (1985). *World Energy Directory: A Guide To Organizations and Research Activities in Non-Atomic Energy.* Essex, UK: Longman Group Ltd.; 582 pp.

Periodicals

This section lists currently available periodicals that are devoted to wind energy or that regularly feature wind energy articles. These periodicals are a primary source of current topical news and state-of-the-art developments in wind energy. Each entry provides title; frequency of publication; publisher name, address, and telephone number; and a description. The description includes information on the year first published, purpose or audience, topics covered, types of feature articles and departments, availability of microform or reprints, indexing and abstracting services, and variant titles.

AWEA Wind Energy Weekly

Frequency: Weekly. First published in 1982. Newsletter format presents wind technology developments, news items, government research and development funding, and windfarm performance. **Formerly:** *AWEA Update.*

AWEA Wind Energy Weekly
American Wind Energy Association
1730 North Lynn Street, Suite 610
Arlington, VA 22209
(703) 276-8334

Boundary-Layer Meteorology

Frequency: Monthly with double issues in January, April, July, and October. First published in 1970. An interdisciplinary journal concerned with the physical and biological processes in the lowest 1000 m of the atmosphere. It is an important medium for publishing theoretical, numerical, and experimental studies of the surface and planetary boundary layers. Occasional special issues are published. Subject areas covered in the journal include agriculture and forestry; air pollution; hydrology; micrometeorological instruments; planetary and surface boundary layers; mesometeorology; numerical modeling of boundary layers; remote sensing; urban meteorology. Microfilm available from University Microfilms International.

Indexed by: *Applied Mechanics Review; Biological Abstracts; Current Contents; Excerpta Medica; Geographical Abstracts; Oceanic Abstracts; Pollution Abstracts; Science Abstracts; Science Citation Index; Current Titles in Ocean, Coastal, Lake & Waterway Sciences; Fluidex; Environmental Periodicals Bibliography; Forestry Abstracts; Bibliography and Index of Geology; Herbage Abstracts; International Aerospace Abstracts; Index to Scientific Reviews; Meteorological and Geoastrophysical Abstracts; Physics Briefs;* and *Soils and Fertilizers.*

Boundary-Layer Meteorology
D. Reidel Publishing Company
P.O. Box 17
3300 AA Dordrecht, Holland

IEEE Transactions on Energy Conversion

Frequency: Quarterly. First published in 1986. Replaces *IEEE Transactions on Power Apparatus and Systems.* Three new transactions focus on energy conversion, power delivery, and power systems. *Transactions on Energy Conversion* covers virtually all aspects of the research, development, design, application, construction, installation, and operation of electric power generating facilities. Papers dealing with wind energy appear regularly. In general, papers are preprinted and presented at a technical meeting of the institute before being published in the appropriate transactions. Discussions by qualified specialists are sought and published along with a closure by the author. All contributions are reviewed by an appropriate technical committee of the Power Engineering Society.

IEEE Transactions on Energy Conversion
345 E. 47th Street
New York, NY 10017

Independent Power

Frequency: 10 per year. First published in 1971 as *Alternative Sources of Energy.* A nonprofit, tax-exempt, science and education organization for those persons concerned with the development and use of renewable forms of electric power generation. As the voice of the independent power production industry, *Independent Power* features articles and news items grouped into four sections: hydro power, cogeneration, photovoltaics, and wind power. Within these sections, information regularly appears on products and services, people in the industry, FERC certification applications, industry news, and conference reports. Regular departments include events calendar; editorial; investor information; classified advertisements; and legislative, regulatory, and association updates. Directories to manufacturers and products in one of the target areas are listed once each year.

Indexed by: *Alternative Press Index, Applied Science and Technology Index, Science Abstracts, Energy Index, Fuel & Energy Abstract, Gas Abstract, and Index to Scientific Reviews.*

Independent Power
Alternative Sources of Energy, Inc.
107 South Central Avenue
Milaca, MN 56353
(612) 983-6892

International Journal of Ambient Energy

Frequency: Quarterly. First published in 1980. Serves as a forum for the worldwide dissemination of new information on self-regenerating sources of energy and their potential use in serving the needs of humanity. Research on, and its application to, solar, wind, wave, tidal, and geothermal energies are documented by the journal. The largest single use of energy in many countries is for environmental control in buildings, and the application of ambient energy for this purpose receives particular emphasis. The design and construction of buildings and complexes to use natural energy sources, as well as technical information on design and performance of heating, hot water, and air-conditioning systems, is covered. Papers include original research, development of new technology and practical applications of ambient energy, case studies, and state-of-the-art reviews. A book review section examines new books from all parts of the world.

Indexed by: *Excerpta Medica, Science Abstracts, Fluidex,* and *International Aerospace Abstracts.*

International Journal of Ambient Energy
Ambient Press Ltd.
P.O. Box 25
Loughborough, Leics LE11 0GP, England

International Journal of Energy Research

Frequency: Quarterly. First published in 1977. Deals with the development and exploitation of both traditional and new fuels and other sources of energy. An interdisciplinary approach to this subject is encouraged. Topics have included solar power, nuclear power, heat pumps, buildings, wave power, transport, industrial, storage, wind, conservation, synthetic fuels, and district heating. Original material in either the area of scientific and technological development or feasibility, whether economic, environmental, or technological, is accepted. Other features are reviews on important development areas, letters, book reviews, and a conference diary. **Reprints available from:** University Microfilms International and Institute for Scientific Information.

Indexed by: *Chemical Abstracts, Current Contents, Science Abstracts, Science Citation Index, Fluidex, Geographical Abstracts,* and *International Aerospace Abstracts.*

International Journal of Energy Research
John Wiley & Sons Ltd.
Baffins Lane
Chichester, Sussex PO19 1UD, England

International Journal of Solar Energy

Frequency: 24 per year. First published in 1982. Publishes experimental, theoretical, and applied results in both the science and engineering of solar energy (e.g., photovoltaic power, wind generators, biofuels, solar heating, thermal power plants, and radiation data). The journal provides up-to-date information from Europe, North America, Japan, and the developing nations. Papers on development achievements and original research are published, as are review articles, news items, and technical notes.

Indexed by: *Chemical Abstracts, Science Abstracts,* and *International Aerospace Abstracts.*

International Journal of Solar Energy
Harwood Academic Publishers
50 West 23rd Street
New York, NY 10010

International Solar Energy Intelligence Report

Frequency: Weekly. First published in 1975. Reports news and developments for all aspects of solar energy technology, legislation, budget, and business. Feature stories and short news items make up the body of the periodical. Each issue also lists publications available from NTIS. Includes *Solar Industry Bulletin, World Solar Markets, Solar Energy Digest, Practical Solar, Solar Energy Business & Marketing Report, Solar Outlook, Solar Energy Washington Letter* and *Solar Energy Industry Report.*

International Solar Energy Intelligence Report
Business Publishers, Inc.
951 Pershing Drive
Silver Spring, MD 20210-4464
(301) 587-6300

The Journal of the Acoustical Society of America

Frequency: Monthly. First published in 1929. Aims to increase and disseminate knowledge of acoustics and promote its practical applications. Covers such fields as general linear acoustics; acroacoustics; atmospheric sound; ultrasonics, quantum acoustics, and physical effects of sound; structural acoustics and vibration; noise effects and control; and acoustical measurement and instrumentation. Other regular features include letters to the editor, U.S. acoustical news, foreign acoustical news, standards news, book reviews, and reviews of acoustical patents.

Indexed by: *Current Physics Index.*

The Journal of the Acoustical Society of America
American Institute of Physics
Subscription Fulfillment Division
335 East 45th Street
New York, NY 10017

Journal of Wind Engineering and Industrial Aerodynamics

Frequency: 9 per year. First published in 1975. Provides a means for the international publication and interchange of information on those aspects of wind engineering that are included in the activities of the International Association for Wind Engineering. These are

- Social and economic impacts of wind effects
- Wind characteristics and structure
- Local wind environments
- Wind loads and structural responses
- Wind effects on building heat loss and ventilation
- Wind effects on transport systems
- Wind power generation
- Wind effect codification.

Papers on these subjects describing full-scale measurements, wind-tunnel simulation studies or theoretical methods are included, as are papers dealing with the development of techniques and apparatus for wind engineering experiments. **Formerly:** *Journal of Industrial Aerodynamics.*

Journal of Wind Engineering and Industrial Aerodynamics
Elsevier Science Publishers B.V.
P.O. Box 211
1000 AE Amsterdam, Netherlands

Indexed by: *Applied Mechanics Review, Current Contents, Engineering Index, Science Abstracts, Science Citation Index, Agricultural Engineering Abstracts, Fluidex, Geographical Abstracts, INSPEC,* and *Index to Scientific Reviews.*

Journal of Solar Energy Engineering—Transactions of the ASME

Frequency: Quarterly. First published in 1980. Publishes peer-reviewed papers dealing with basic research, design, and engineering applications of solar energy technologies, including wind. Includes book reviews and events calendar. A special edition devoted to wind energy papers from the Fifth Biennial Wind Energy Conference was published in May 1982.

American Society of Mechanical Engineers
United Engineering Center
345 East 47th Street
New York, NY 10017

Modern Power Systems

Frequency: 11 per year. First published in 1963. Communicates power developments and technology worldwide. Review articles describe new power plants, systems, and products. Technical articles focus on topics of interest to the power industry, including wind power. Occasional product guides are provided for a particular topic. Regular departments include a world digest, renewable news, a comment column, energy events, technical briefs, generation set reviews, and descriptions of new equipment.

Indexed by: *Business Periodicals Index, Excerpta Medica, Science Abstracts, Business Index, Key to Economic Science,* and *Trace and Industry Index.* **Incorporates:** *Energy International* (1981).

Modern Power Systems
United Trade Press Ltd.
U.T.P. House, 33/35 Bowling Green Lane
London EC1R ODA, England

Renewable Energy Review Journal

Frequency: Semiannual. First published in 1979. Covers energy conservation, energy planning, solar energy, biofuels, wind energy, and small-scale hydro power. The Renewable Energy Resources Information Center (RERIC) is a nonprofit organization founded in May 1978 at the Asian Institute of Technology. The main geographical areas it serves are the tropical countries in Asia and the Pacific, and other tropical developing regions in Africa and Central and South America.

Indexed by: *Abstracts of Selected Solar Energy Technology, Environmental Periodicals Bibliography, Renewable Energy Alerting Data Service,* and *Wind Energy Abstracts.*

Renewable Energy Review Journal
Asian Institute of Technology
Renewable Energy Resources Information Center
G.P.O. Box 2754
Bangkok 10501, Thailand

Solar Energy

Frequency: Monthly. First published in 1957. Covers all forms of solar energy applications over the range of technical, economic, environmental, social, and legal issues. *Solar Energy* is the official journal of the International Solar Energy Society (ISES). **Microform available from:** University Microfilms International.

Indexed by: *Applied Mechanics Review, Applied Science and Technology Index, Biological Abstracts, Chemical Abstracts, Current Contents, Engineering Index, Science Abstracts, Automatic Subject Citation Alert,* and *Fuel and Energy Abstracts.*

Solar Energy
Pergamon Press, Inc., Journals Division
Maxwell House, Fairview Park
Elmsford, NY 10523
(914) 592-7700

Solar Today

Frequency: Bimonthly. First published in 1987. Provides topical news of the latest in solar technology development. As the official publication of the American Solar Energy Society (ASES), *Solar Today* serves as an effective means for communication to ASES members. Each issue includes feature articles, industry news, an events calendar, editorial from the chairman, ISES news, and ASES news.

Solar Today
American Solar Energy Society, Inc.
2400 Central Avenue
Unit B-1
Boulder, CO 80301
(303) 443-3130

Solar and Wind Technology

Frequency: Quarterly. First published in 1985. Covers all forms of solar and wind energy, encompassing technical, environmental, social, and economic issues with particular emphasis on the practical applications of solar energy. Provides an international forum for the science and technology of solar and wind energy application. Submissions from developing countries and the Arab world are especially welcome. **Microform available from:** Microforms International Marketing and University Microfilms International.

Indexed by: *Current Contents* and *Science Abstracts.*

Solar and Wind Technology
Pergamon Press, Inc., Journals Division
Maxwell House, Fairview Park
Elmsford, NY 10523
(914) 592-7700

Windirections

Includes an events calendar, abstracts of recent books, commission of the European Communities news, industry developments, UK news, European news, machine features, international notes (including U.S.), and developing world news. *Windirections* is the official newsletter of the British and European Wind Energy Associations.

Windirections
British Wind Energy Association
4 Hamilton Place
London, W1V 0BQ
England

Wind Energy Abstracts

See *Bibliographies*

Wind Energy Weekly

Frequency: Weekly. Provides information on wind energy developments worldwide. Subjects covered include business opportunities, legislation and regulation, international issues, windfarm projects, wind and renewable energy events, research and technical findings, and market projections. In addition, *Wind Energy Weekly* reports on such areas as trade news, economics, new products, and new announcements. *Wind Energy Weekly* is a newsletter of the American Wind Energy Association (AWEA).

Wind Energy Weekly
American Wind Energy Association
1730 North Lynn Street, Suite 610
Arlington, VA 22209

Wind Engineering

Frequency: Quarterly. First published in 1977. Covers all aspects of wind energy systems, including measurement methods and related economic and environmental topics. In addition to technical papers, the journal contains abstracts of relevant papers from other journals, news items, book reviews, and upcoming conferences.

Indexed by: *Science Abstracts, Fluidex, Geographical Abstracts*, and *International Aerospace Abstracts.*

Wind Engineering
Multi-Science Publishing Company, Ltd.
107 High Street
Brentwood, Essex CM14 4RX England

Windpower Monthly News Magazine

Frequency: Monthly. First published in 1985. Includes feature articles; an opinion column; news from India, Holland, the United States, and Denmark; a company profile; statistics; letters; and an events calendar. **Formerly:** *Windpower Monthly.*

Windpower Monthly News Magazine
U.S. Office of Forlaget Vistoft A-S
P.O. Box 6007
Redding, CA 96099

Windletter

Frequency: 8 per year. Covers many major issues concerning events covering wind and other alternative energy sources, including legislation and regulatory reporting, national and international news, and items relating to windfarms and residential systems. An AWEA newsletter.

Windletter
American Wind Energy Association
1730 North Lynn Street, Suite 610
Arlington, VA 22209

Windstats Newsletter

Frequency: Monthly. Presents statistics relating to wind machines, wind energy, and the wind energy industry. A quarterly *Wind Power Economy Index* gathers data on the cost of electricity produced by wind turbines and compares the results with the cost of conventionally produced energy. A monthly statistics overview provides operation and production information on more than 1000 wind turbines. Other articles report on technical developments, brief news items, book reviews, and opinion.

Windstats Newsletter
U.S. Office of Forlaget Vistoft A-S
P.O. Box 6007
Redding, CA 96099

Chapter 9
Computer Models and Design Tools

This section lists wind energy models, software directories, and software depositories that include energy as an area of interest. Most of the available wind energy models are designed for researchers, engineers, turbine designers, and utility companies. However, manufacturers, financiers, and planners or policy-makers may also find them useful. These models cover such areas of the technology as siting, economics, aerodynamic performance, power output, efficiency, fatigue analysis, and energy storage. They cover both horizontal- and vertical-axis and two- and three-dimensional machines. A model is included only if it is available for general use and has accompanying documentation.

The directory citations include a bibliographic reference and an abstract describing the software and its organization. Depository entries include the depository name; sponsoring organization name, address, and telephone number; and a description of the software collection, intended audience, and any documentation. Many other sources of information about software are available, such as reports, conferences, and associations.

Models

ADAM2

Numerically models two-dimensional airfoils in unsteady motion with boundary layer separation. The airfoil and wake surfaces are represented by a finite set of combined source and vortex panels. The source strengths are prescribed to have the same magnitude as the normal relative velocity on the surface because of the freestream and motion of the airfoil. The vortex strengths on the airfoil surface are determined by applying a kinematic surface tangency condition to a Green's function representation of the potential field and simultaneously enforcing the Kutta condition. Wake shedding is governed by a dynamic free surface condition and the characteristics of the flow near any boundary layer separation points. Wake deformation is predicted by applying a geometric free surface condition. Calculation results are presented for steady motion, impulsively started rectilinear motion, harmonic pitch oscillations, and constant pitching motions. Experimental data and analytical solutions are also presented for comparison.

Availability: NTIS

Language: FORTRAN

Machine: VAX

Documentation: Oler, J. W.; Strickland, J. H.; and Im, B. J. (June 1987). *A Numerical Model for Unsteady Two-Dimensional Flow Calculations with Flow Separation.* SAND86-7183. Albuquerque, NM: Sandia National Laboratories; 122 pp. Work performed by Department of Mechanical Engineering, Texas Tech University, Lubbock, TX.

Developed by: J. H. Strickland, Sandia National Laboratories; B. J. Im, Flow Wind, Pleasanton, CA

Contact: J. W. Oler
Department of Mechanical Engineering
Texas Tech University
Lubbock, TX 79409
(816) 742-3563

CARDAA

Calculates independent upwind and downwind interference factors. CARDAA is a double-multiple stream tube model of a vertical-axis wind turbine. Input includes rotor geometry and blade section data. Output is blade loads as well as turbine power and torque.

Availability: Model available to the public

Language: FORTRAN

Machine: Mainframe

Documentation: Paraschivoiu, I. (December 1982). "Aerodynamic Loads and Performance of a Darrieus Rotor." *Journal of Energy.* Vol 6. (No. 6); pp. 406-412.

Developed by: Ion Paraschivoiu, Institut de Recherche d'Hydro-Quebec

Contact: Dale Berg
Sandia National Laboratories
Division 6225
Albuquerque, NM 87185
(505) 844-1030

Ion Paraschivoiu
Institut de Recherche d'Hydro-Quebec
1800 Monte St. Julie
Varennes, Quebec
Canada
(514) 652-8011

DART

Assists engineers who need to determine and compare power efficiency factors of several vertical-axis wind turbine designs. Although developed for use with three-dimensional turbines, the model also can be adapted for two-dimensional turbines. Inputs required are tip to wind speed ratio, solidity (number of blades times chord divided by radius), and airfoil data. This model is the predecessor of VDART2 and VDART3.

Availability: Model available to the public; user's manual available from NTIS

Language: FORTRAN

Machine: Mainframe; adaptable to minicomputer

Documentation: Strickland, J. H. (1975). *Darrieus Turbine: A Performance Predictive Model Using Multiple Stream Tubes.* SAND75-0431. Albuquerque, NM: Sandia National Laboratories. Work performed by Texas Tech University, Lubbock, TX.

Developed by: J. H. Strickland and Texas Tech University

Contact: Dale Berg
Sandia National Laboratories
Division 6225
Albuquerque, NM 87185
(505) 844-1030

DARTER

Assists engineers who need to determine and compare power efficiency factors of several vertical-axis wind turbine designs. This model, based on DART and adapted by Sandia Laboratories, differs from DART in that it allows for local Reynolds number information. Although designed for use with three-dimensional turbines, the model also can be adapted for use with two-dimensional turbines. Inputs required are tip to wind speed ratio, solidity (number of blades times chord divided by radius), and airfoil data.

Availability: Model available to the public; user's manual available from NTIS

Language: FORTRAN

Machine: Mainframe; adaptable to minicomputer

Documentation: Klimas, P. C. and French, R. E. (1980). *User's Manual for the Vertical-Axis Wind Turbine Performance Code DARTER.* SAND80-1155. Albuquerque, NM: Sandia National Laboratories. 48 pp.

Developed by: J. H. Strickland and Texas Tech University

Contact: Dale Berg
Sandia National Laboratories
Division 6225
Albuquerque, NM 87185
(505) 844-1030

DCLDA

See *TEETER*

ECON 16

Analyzes the economic performance of a Darrieus vertical-axis wind turbine operated at a constant rpm in conjunction with an existing utility grid. The model is intended for use in an interactive time-sharing mode, with required basic input data that include rotor geometry, site wind speed distribution, and system component specifications. Basic output information includes annual energy, estimated system costs, peak power output, and component efficiencies.

Availability: Model available to the public

Language: FORTRAN IV

Machine: Mainframe

Documentation: Sullivan, W. N. (1979). *Economic Analysis of Darrieus Vertical-Axis Wind Turbine Systems for the Generation of Utility Grade Electrical Power: Vol. 2, The Economic Optimization Model.* SAND/78-0962. Albuquerque, NM: Sandia National Laboratories; 100 pp.

Developed by: Sandia National Laboratories

Contact: W. N. Sullivan
Sandia National Laboratories
Division 1524
Albuquerque, NM 87185
(505) 844-7357

FEVD

Predicts modes and frequencies of a rotating vertical-axis wind turbine using the finite element method. Using a standard NASTRAN bulk data deck, FEVD modifies the deck to include the appropriate rotating coordinate system effects. No further input is required. Output is a new NASTRAN bulk data deck, which can be used for obtaining the desired modes and frequencies of the rotating turbine.

Availability: Model available to the public

Language: FORTRAN

Machine: Mainframe; minicomputer

Documentation: Carne, T. G.; Lobitz, D. W.; Nord, A.R.; and Watson, R. A. (1982). *Finite Element Analysis and Modal Testing of a Rotating Wind Turbine.* SAND82-0345. Albuquerque, NM: Sandia National Laboratories; 24 pp.

Developed by: Don Lobitz, Sandia National Laboratories

Contact: Dale Berg
Sandia National Laboratories
Division 6225
Albuquerque, NM 87185
(505) 844-1030

FFEVD

Predicts forced vibration response of a rotating vertical-axis wind turbine turning in a steady wind using the finite element method. Using a standard NASTRAN bulk data deck, FFEVD modifies the deck to include appropriate rotating coordinate system effects and aerodynamic loads. Input includes wind speed and wind shear exponent. Output is a new NASTRAN bulk data deck, which can be used for obtaining the desired forced vibration response of the rotating turbine.

Availability: Model available on a limited basis

Language: FORTRAN

Machine: Mainframe; minicomputer

Documentation: Lobitz, D. W. and Sullivan, W. N. (1983). "A Comparison of Finite Element Predictions and Experimental Data for the Forced Response of the DOE 100 kW Vertical Axis Wind Turbine." *Sixth Biennial Wind Energy Conference and Workshop: Abstracts; Minneapolis/St. Paul, MN; 1-3 June, 1983.* New York: American Solar Energy Society; p. 92.

Developed by: D. W. Lobitz, Sandia National Laboratories

Contact: Dale Berg
Sandia National Laboratories
Division 6225
Albuquerque, NM 87185
(505) 844-1030

FINAM

See *WECS (Wind Energy Value to Electric Utilities)*

FLAP (Force and Loads Analysis Program)

Analyzes wind turbines with either rigid- or teetering-hub configurations. FLAP is a single-degree-of-freedom model. The code does not currently account for the delta-3 effect for teetering-hub designs; the code assumes zero delta-3 in this case. The rotor blade's flapping or teetering motion is represented by coordinate shape functions in the form of simple polynomials. For the rigid-hub configuration, these polynomials satisfy the boundary conditions for a cantilevered blade. For the teetering-hub configuration, these polynomials are written to satisfy both the cantilevered boundary condition (for the symmetric bending modes) and the pinned boundary condition (for the asymmetric and teetering modes).

The computer solution was divided into two main modules. The first module, FLAP1, is a data preprocessor. The raw blade- and turbine-property data file is processed by the first module to produce a data file that is read by the second module. The quantities produced are variables that do not generally change from one run to the next, such as mass and stiffness matrices. The second module, FLAP2, performs the actual model run, which includes solving the equation of motion, computing the loads, and printing the results.

Availability: Floppy disks and documentation available from the Solar Energy Research Institute (SERI)

Language: FORTRAN 77

Machine: IBM PC; compatible installation suggestions are provided for other machines

Documentation: Wright, A. D.; Buhl, B. L.; and Thresher, R. W. (January 1988). *FLAP Code Development and Validation.* SERI/TR-217-3125. Golden, CO: Solar Energy Research Institute; 334 pp. Available NTIS: Order No. DE88001131.

Developed by: A. D. Wright, M. L. Buhl, and R. W. Thresher, SERI.
Original version of FLAP developed at Oregon State University.

Contact: Alan D. Wright, Robert W. Thresher
Solar Energy Research Institute
Wind Research Branch
1617 Cole Boulevard
Golden, CO 80401
(303) 231-1897

HAWTWIND

Simulates turbulent wind for horizontal-axis wind turbine (HAWT) analysis and, with minor modifications, for vertical-axis wind turbine (VAWT) analysis. The input includes descriptions of the HAWT rotor and atmospheric turbulence. Output consists of time series of wind speed as seen by each selected point on the rotating wind turbine blades. Correlation between points on the rotor is implicitly included. Any number of points on any number of blades can be selected; the limitations depend on the available computer storage. With minor modifications, this code can be adapted to simulate wind speed at stationary points arbitrarily located in a crosswind plane (i.e., for VAWT analysis).

Availability: Model available to the public; documentation available from NTIS

Language: FORTRAN

Machine: VAX

Documentation: P. S. Veers (March 1988). *Three-Dimensional Wind Simulation.* SAND88-0152. Albuquerque, NM: Sandia National Laboratories. 40 pp.

Developed by: Paul S. Veers, Sandia National Laboratories

Contact: Paul S. Veers
Sandia National Laboratories
Applied Mechanics Organization 1524
Albuquerque, NM 87185
(505) 846-5995

LIFE

Predicts fatigue life of a VAWT blade component based on three assumptions: frequency distribution of the vibratory stresses about the operational mean stress as described by a Rayleigh probability density function; wind speed distribution follows a Weibull function; and damage accumulates linearly (Minin's Rule).

Availability: Available to the public at no charge

Language: BASIC

Machine: Personal computer

Documentation: Sutherland, H. J.; Ashwill, T. D.; and Slack, N. (August 1987). *The LIFE Computer Code Fatigue Life Prediction for Vertical Axis Wind Turbine Components.* SAND87-0792. Albuquerque, NM: Sandia National Laboratories; 69 pp. Available NTIS: Order No. DE87013400.

Developed by: H. J. Sutherland, Sandia National Laboratories

Contact: Herbert J. Sutherland
Sandia National Laboratories
Division 6225
Albuquerque, NM 87185
(505) 844-2037

LIFE2

Predicts fatigue life of VAWT blade components using LIFE code analysis generalized to WECs components.

Availability: Free

Language: FORTRAN

Machine: Personal computer

Documentation: Sutherland, H. J.; Ashwill, T. D.; and Naassan, K. A. (1987). "Fatigue Analysis Codes for WECS Components." *Windpower '87 Proceedings; October 5-8, 1987; San Francisco, California.* SERI/CP-217-3315. Arlington, VA: American Wind Energy Association; pp. 160-167. Work performed by Pacific Northwest Laboratory, Richland, WA. Available from the American Wind Energy Association, 1730 North Lynn Street, #610, Arlington, VA 22209.

Developed by: H. J. Sutherland, Sandia National Laboratories

Contact: Herbert J. Sutherland
Sandia National Laboratories
Division 6225
Albuquerque, NM 87185
(505) 844-2037

LSWT (Lifting Surface Wind Turbine)

Applies numerical lifting surface theory to the calculation of the aerodynamic characteristics and performance of a horizontal-axis wind turbine. The employed method has evolved from rotary wing and helicopter applications and features a detailed prescribed wake. The wake model is extended from a hovering rotor experimental generalization by including the effect of the windmill brake state on the radial and axial displacement rates of the trailing vortex system. Performance calculations are made by coupling the lifting surface circulation solution to a blade element analysis that incorporates two-dimensional airfoil characteristics as functions of angle of attack and Reynolds number. Several analytical stall models are also provided to extend the airfoil characteristics beyond the limits of available data. Although the primary emphasis is on the steady performance problem, the method includes facilities to investigate the effects of wind shear profile, tower shadow, and off-axis shaft alignment. These influences are included in a quasi-steady sense and add additional displacement detail to the wake model.

Availability: Model available to the public

Language: FORTRAN 77

Machine: IBM PC and compatible microcomputers; fully expanded hardware with a floating-point accelerator recommended

Documentation: Kocurek, D. (June 1987). *Lifting Surface Performance Analysis for Horizontal Axis Wind Turbines.* SERI/STR-217-3163. Golden, CO: Solar Energy Research Institute; 319 pp. Available NTIS: Order No. DE87001176.

Developed by: J. David Kocurek, Computational Methodology Associates, Hurst, TX.

Contact: James L. Tangler
Solar Energy Research Institute
Wind Research Branch
1617 Cole Boulevard
Golden, CO 80401
(303) 231-7134

MOSTAB-HFW

A wind turbine and rotor craft analysis program that calculates periodic solutions of blade motions. It assumes no shaft motion and requires a physical description of the turbine and tower, and wind speed and direction. A complex, technical model, it is a restricted version of MOSTAS and is used in earlier stages of design than MOSTAS.

Availability: Model costs $4,000

Language: FORTRAN

Machine: Mainframe

Documentation: Series of publications (both user's guide and descriptions); see Contact

Developed by: J. A. Hoffman, Paragon Pacific Inc.

Contact: John A. Hoffman
Paragon Pacific Inc.
1601 E. El Segundo Boulevard
El Segundo, CA 90245
(213) 322-9111

MOSTAS

A highly technical, complex wind turbine and rotor craft analysis program. MOSTAS calculates blade loads, performance, stability, controllability, and vibration levels. Input includes a physical description of the turbine and tower and wind speed and direction. Nearly any kind of turbine can be modeled. It is used for a single turbine per run.

Availability: Model costs $20,000

Language: FORTRAN

Machine: Mainframe

Documentation: Series of publications (both user's guide and descriptions): see Contact

Developed by: J. A. Hoffman, Paragon Pacific Inc.

Contact: John A. Hoffman
Paragon Pacific Inc.
1601 E. El Segundo Boulevard
El Segundo, CA 90245
(213) 322-9111

Multiple Measurement Wind Power Output Array Model

Uses wind speed measured at every desired wind turbine site to simulate the wind power output of that site and sums it to produce the wind power from the array.

Availability: Model available to the public; user's manual available from NTIS

Language: FORTRAN

Machine: Mainframe

Documentation: Schlueter, R. A.; Park, G. L.; Dorsey, J.; Lotfallian, M.; and Shayanfar, A. (May 1981). *Operations Model for Utilities Using Wind-Generator Arrays.* DOE/ET/23168-80/2. Washington, DC: U.S. Department of Energy; 40 pp. Work performed by Michigan State University, Division of Engineering Research, East Lansing, MI.

Developed by: R. A. Schlueter and G. L. Park, Michigan State University

Contact: R. A. Schlueter
Michigan State University
Department of Electrical Engineering and Systems Science
East Lansing, MI 48824
(517) 355-5244

NOABL (New Objective Analysis Boundary Layer)

Predicts wind fields based on terrain features and observed wind data. This mass-consistent model has been merged with an optimizing scheme to provide optimum values of empirical stability and the initial wind direction. Verification efforts have shown that the optimized NOABL model prediction errors are about 5%. A desktop version of NOABL is under development.

Availability: Available to the public

Language: FORTRAN

Documentation: Barnard, J. C.; Wegley, H. L.; and Hiester, T. R. (1987). "Improving the Performance of Mass-Consistent Numerical Models Using Optimization Techniques." *Journal of Climate and Applied Meteorology.* Vol. 26 (No. 6); pp. 675-686. Barnard, J. C. and Germain, A. (1988). *Verification of the Optimizing NOABL Model Using a Spatially Dense Wind Data Set.* PNL-6543, Richland, WA: Pacific Northwest Laboratory.

Developed by: G. Phillips, SAI; refined by J. C. Barnard, PNL

Contact: James C. Bernard
Pacific Northwest Laboratory
P.O. Box 999
Richland, WA 99352

PROP

Computes horizontal-axis wind turbine performance using Glauert momentum strip theory. The basic computer program is an updated version of the PROP code developed at Oregon State University in 1976. Momentum strip theory determines the WECS performance by equating the blade forces determined by two-dimensional airfoil theory, with the change in momentum of the air going through the annular strip. Once the change in momentum is known, the axial and circumferential interference factors are computed. This allows computation of the flow angle of attack at the blade element. Several program options may be used to increase accuracy, including the use of tip-loss corrections and the inclusion of wind shear.

Availability: Model available to the public

Language: FORTRAN IV

Machine: Adaptable systems supporting FORTRAN

Documentation: Hibbs, R. and Radkey, R. L. (1983). "Chapter 3: Calculating Rotor Performance with the Revised PROP Computer Code." *Horizontal-Axis Wind Systems Rotor Performance Model Comparison: A Compendium.* RFP-3508. Golden, CO: Rocky Flats Wind Energy Program.

Developed by: AeroVironment, Inc.

Contact: James L. Tangler
Solar Energy Research Institute
Wind Research Branch
1617 Cole Boulevard
Golden, CO 80401
(303) 231-7134

PROPSH-PC

Produces tabulated dimensional and nondimensional output of rotor performance parameters as a function of either tip speed ratio (wind turbine default option) or advanced ratio (propellers) for a given set of blade pitch angles. PROPSH-PC is a blade element momentum code. Input includes rotor geometry, airfoil section data, and operating condition data. Specific output includes detailed blade element data or summary data. The model can accommodate shaft tilt input and calculate resultant cross-flow effects. Additionally, tip speed ratio and blade pitch angle sweeps can be included in the same run. PROPSH is based on the nondimensional AeroVironment PROP model that uses as input the twist, chord, and the lift-drag characteristics of the airfoils at several stations along the blade.

Availability: Model available to the public

Language: FORTRAN 77

Machine: Mainframe; microcomputer with CP/M or Microsoft DOS operating system

Documentation: Tangler, J. L. (1983). *Horizontal Axis Wind Turbine Performance Prediction Code PROPSH User's Guide.* Golden, CO: Rocky Flats Wind Energy Research Center; 27 pp.

Developed by: J. L. Tangler, Rocky Flats Wind Energy Research Center

Contact: James L. Tangler
Solar Energy Research Institute
Wind Research Branch
1617 Cole Boulevard
Golden, CO 80401
(303) 231-7134

ROSEW

See *WECS (Wind Energy Value to Electric Utilities)*

SDOF

See *YawDyn*

SEACC (Systems Engineering and Analysis Computer Code)

Optimizes the performance of a complete horizontal-axis small wind energy conversion system at a specific site. Key inputs include rotor airfoil shape and diameter, rotor control method (constant rpm, constant tip speed ratio, or special governing schedule), cut-in and cut-out speed, drive train characteristics and efficiency, tower height, and wind distribution. The program uses a PROP code to calculate aerodynamic efficiency, which is then modified by power train efficiency to calculate system performance. The output consists of a wind system performance table for specific site and user load characteristics.

Availability: Model available to the public

Language: FORTRAN

Machine: Personal computer

Documentation: Tu, P. K. C. and Kertesz, V. (1983). *SEACC: The Systems Engineering and Analysis Computer Code for Small Wind Systems.* RFP-3510. Golden, CO: Rocky Flats Wind Energy Research Center; 153 pp.

Developed by: P. K. C. Tu, Rocky Flats Wind Energy Research Center

Contact: Peter Tu
Solar Energy Research Institute
1617 Cole Boulevard.
Golden, CO 80401
(303) 231-7199

SIDIF (Sine Distribution Interference Factor)

Assumes a sine distribution for the upwind and downwind interference factors. SIDIF is a double-multiple stream tube. It incorporates the effects of the wind boundary layer dynamic stall and local blade Reynolds number variations. Input includes rotor geometry and blade section data. Output includes blade loads and turbine power and torque.

Availability: Model available to the public

Language: FORTRAN

Machine: Mainframe

Documentation: Berg, D. (1983). "An Improved Double-Multiple Streamtube Model for the Darrieus-Type Vertical Axis Wind Turbine." *Sixth Biennial Wind Energy Conference and Workshop: Abstracts; Minneapolis/St. Paul, MN; June 1-3, 1983.* New York: American Solar Energy Society; pp. 25-26.

Developed by: D. Berg, Sandia National Laboratories

Contact: Dale Berg
Sandia National Laboratories
Division 6225
Albuquerque, NM 87185
(505) 844-1030

SIMWEST (Simulation Model for Wind Energy Storage)

Determines the type and size of storage best suited for a given wind energy application. SIMWEST has the capability of modeling wind energy storage systems using any combination of pumped hydro, battery, thermal, fly-wheel, and pneumatic storage facilities. It can also be adapted to evaluate storage systems for other renewable energy conversion systems. SIMWEST consists of two basic programs and a library of system components. The Model Generation Program is a precompiler that generates a computer model of a complex wind energy generator/storage/application system from specifications constructed by the user from SIMWEST library components. The library consists of routines for modeling physical, environmental, load, logic, and utility components of the wind energy system. The second program executes the computer model to perform analyses of cost and potential use.

Availability: Program is available to the public from COSMIC for $1,605; user documentation for $57

Language: FORTRAN IV and Assembler for batch execution

Machine: UNIVAC 1100

Documentation: Warren, A. W. (1979). *Technical Report.* NASA CR-159601. Cleveland, OH: NASA Lewis Research Center. Work performed by Boeing Computer Services, Bellevue, WA.

Warren, A. W. (1979). *Univac Operations Manual Revisions.* NASA CR-159602. Cleveland, OH: NASA Lewis Research Center. Work performed by Boeing Computer Services, Bellevue, WA.

Developed by: Boeing Computer Services

Contact: Computer Software Management and Information Center (COSMIC)
University of Georgia
Computer and Information Services
112 Barrow Hall
Athens, GA 30602
(404) 542-3265

Single Measurement Wind Array Power Output Model

Delays wind speeds records to represent propagation of the weather front, thereby producing a wind speed record at each site. These records are used to simulate power output (in kilowatts or megawatts) of each wind turbine and then summed to produce estimated wind power output from the array. The model is designed for MOD-2 wind turbines but can be modified to similar machines.

Availability: Model available to the public; report available from NTIS

Language: FORTRAN

Machine: Mainframe

Documentation: Schlueter, R. A.; Park, G. L.; Modir, H.; Dorsey, J.; and Lotfallian, M. (October 1979). *Impact of Storm Fronts on Utilities with WECS Arrays; Final Report.* COO-4450-79/2. Washington, DC: U.S. Department of Energy; 249 pp. Work performed by Michigan State University, Division of Engineering Research, East Lansing, MI.

Developed by: R. A. Schlueter and G. L. Park, Michigan State University

Contact: R. A. Schlueter
Michigan State University
Department of Electrical Engineering and Systems Science
East Lansing, MI 48824
(517) 355-5244

STOCH1D

Predicts the stochastic (random) aerodynamic loads on a VAWT produced by atmospheric turbulence, which are believed responsible for premature blade fatigue, using a double-multiple stream-tube analysis. The model includes the effects of mean wind shear, local Reynolds number variations, and an empirical model of blade dynamic stall. Besides the usual operating parameters and geometry input, the user specifies an assumed turbulence intensity and power spectral density, which are used to simulate a simplified one-dimensional field of turbulence. The model predicts integrated blade and rotor aerodynamic loads, as well as local loads at a specified set of node points. The latter are designed for direct input to structural dynamic models.

Availability: Available to the public at no charge

Language: FORTRAN 77 (ANSI Standard)

Machine: VAX 8600 or equivalent

Documentation: Homicz, G. F. (1988). "VAWT Stochastic Loads Produced by Atmospheric Turbulence." *Seventh ASME Wind Energy Symposium: The Eleventh Annual Energy-Sources Technology Conference and Exhibition; New Orleans, Louisiana; January 10-13, 1988.* SED-Vol. 5. Swift, A. H. P. and Thresher, R. W., eds. New York: American Society of Mechanical Engineers; pp. 127-137. Work performed by Wind Energy Research Division, Sandia National Laboratories, Albuquerque, NM.

Developed by: G. F. Homicz, Sandia National Laboratories

Contact: Gregory F. Homicz
Sandia National Laboratories
Computational Aerodynamics Organization 1556
Albuquerque, NM 87185-5800
(505) 844-9065

STRS2PC

Produces estimates of unmeasured turbulence characteristics in the crosswind plane that spans the disk of a wind turbine rotor, based on wind measurements obtained form anemometers on a single upwind tower. The time variations in wind velocity, measured by the anemometers on the tower (across the wind), are transformed into a model of the longitudinal (or along-wind) and vertical dimensions. A further transformation turns the along-wind variations into a representation of crosswind and vertical wind velocity variations at points around a circular path. The program selects time series from an actual data set and rotationally samples the data to simulate the time series of a point moving around on a circle of a specified radium and revolution frequency.

Availability: Available to the public

Language: FORTRAN

Machine: IBM PC or equivalent

Documentation: Connell, J. R.; Morris, V. R.; Powell, D. C.; and Gower, G. L. (1988). *The PNL Single-Tower Measurement Model of Rotationally Sampled Turbulent Wind, with User's Guide for STRS2PC.* PNL-6580. Richland, WA: Pacific Northwest Laboratory.

Developed by: J. R. Connell, V. R. Morris, D. C. Powell, and G. L. Gower.

Contact: James R. Connell
Pacific Northwest Laboratory
P.O. Box 999
Richland, WA 99352
(509) 376-6950

TEETER

Predicts the teetering motion of a two-bladed wind turbine rotor with a teetering hub. TEETER is a single-degree-of-freedom computer model. The model is intended for use by designers in selecting "worst case" design conditions and in determining sensitivity of teetering motion to the wide variety of machine and wind characteristics that must be considered. It is a relatively simple method requiring minimal computing hardware and negligible computing time or cost. Thus, it is well suited to rapid design tradeoff studies and point design calculations. Two programs are required for a complete analysis. The primary program, TEETER, calculates the teeter angle history of a rotor for one complete rotor revolution and also provides information on the maximum teeter rate and maximum hum moment during the revolution. TEETER requires the input of an airfoil lift-curve slope. The value of an effective (or moment weighted) slope is calculated in a second program called DCLDA.

Availability: Available to the public

Language: FORTRAN 77, can be adapted to BASIC

Machine: Microcomputer

Documentation: Hansen, A. C. (January 1987). *The TEETER Program—Analysis and User's Guide.* SERI/STR-217-3050. Golden, CO: Solar Energy Research Institute; 55 pp. Work performed by University of Utah, Salt Lake City, UT. Available NTIS: Order No. DE87001139. (Appendices include the TEETER and DCLDA code.)

Developed by: A. C. Hansen, University of Utah

Contact: Alan Wright
Solar Energy Research Institute
Wind Research Branch
1617 Cole Boulevard
Golden, CO 80401
(303) 231-7651

UFlap

See *YawDyn*

ULMOD

See *WECS (Wind Energy Value to Electric Utilities)*

VDART2 (Vortex Analysis of the Darrieus Turbine in Two Dimensions)

Predicts performance of two dimensional Darrieus turbines, in the form of power efficiency, blade loading distribution, and wake velocity profiles. This aerodynamic code is one of the latest versions of several codes based on the vortex method of analysis (see DART). Inclusion of dynamic effects (dynamic stall, pitching circulation, and added mass) are major improvements over other codes. The model, designed for engineers, requires a considerable amount of computer time and is used for a detailed look at the performance of selected candidate turbines. Major input includes number of blades, chord-to-radius ratio, tip-to-wind-speed ratio, blade-mounting-point-to chord ratio, airfoil-thickness-to chord ratio, airfoil chord Reynolds number and other static airfoil data.

Availability: Model available to the public

Language: FORTRAN IV

Machine: Mainframe with 256K

Documentation: Strickland, J. H.; Smith, T.; Sun, K. (1981). *User's Manual for Vertical-Axis Wind-Turbine Code VDART2.* SAND81-7039. Albuquerque, NM: Sandia National Laboratories; 70 pp. Work performed by Texas Tech University, Lubbock, TX.

Strickland, J. H.; Smith, T.; Sun, K. (1981). *A Vortex Model of the Darrieus Turbine: An Analysis and Experimental Study.* SAND81-7017. Albuquerque, NM: Sandia National Laboratories; 200 pp. Work performed by Texas Tech University, Lubbock, TX.

Developed by: J. H. Strickland and Texas Tech University

Contact: National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4929

VDART3 (Vortex Analysis of the Darrieus Turbine in Three Dimensions)

Predicts performance of a three-dimensional Darrieus turbine, in the form of power efficiency, blade loading distribution, and wake velocity profiles. This aerodynamic code is one of the latest versions of several codes based on the vortex method of analysis (see DART). Inclusion of dynamic effects (dynamic stall, pitching circulation, and added mass) are major improvements over other codes. The model, designed for engineers, requires a considerable amount of computer time and is used for a detailed look at the performance of selected candidate turbines. Major input includes number of blades, chord-to-radius ratio, tip-to-wind-speed ratio, blade-mounting-point-to-chord ratio, airfoil-thickness-to-chord ratio, airfoil chord Reynolds number, shape of rotor, and other static airfoil data.

Availability: Model available to the public

Language: FORTRAN IV

Machine: Mainframe with 256K

Documentation: Strickland, J. H.; Smith, T.; Sun, K. (1981). *User's Manual for Vertical-Axis Wind-Turbine Code VDART3.* SAND81-7020. Albuquerque, NM: Sandia National Laboratories. Work performed by Texas Tech University, Lubbock, TX.

Strickland, J. H.; Smith, T.; Sun, K. (1981). *A Vortex Model of the Darrieus Turbine: An Analysis and Experimental Study.* SAND81-7017. Albuquerque, NM: Sandia National Laboratories; 200 pp. Work performed by Texas Tech University, Lubbock, TX.

Developed by: J. H. Strickland and Texas Tech University

Contact: National Technical Information Service
5285 Port Royal Road
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(703) 487-4929

VSTOC

Simulates stochastic wind for VAWTs. VSTOC yields turbulent wind-velocity fluctuations for rotationally sampled points, allowing three-component wind velocity fluctuations to be simulated at specified nodal points on the wind turbine rotor. A first-order convection scheme is used, which accounts for the decrease in streamwise velocity as the flow passes through the wind turbine rotor. The VSTOC simulation is independent of the particular analytical technique used to predict the aerodynamic and performance characteristics of the turbine. The VSTOC subroutine may be used simply as a subroutine in a particular VAWT prediction code or it may be used as a subroutine in an independent processor. The independent processor is used to interact with a version of the VAWT prediction code, which is segmented into deterministic and stochastic modules. Using VSTOC in this way can decrease computer time for the overall calculation process.

Availability: NTIS

Language: FORTRAN

Machine: VAX

Documentation: Strickland, J. H. (April 1987). *VAWT Stochastic Wind Simulator.* SAND87-0501. Albuquerque, NM: Sandia National Laboratories; 55 pp. Available NTIS: Order No. DE87010532.

Developed by: J. H. Strickland, Sandia National Laboratories

Contact: J. H. Strickland
Sandia National Laboratories
Division 1552
Albuquerque, NM 87185
(505) 846-3920

WECS (Wind Energy Value to Electric Utilities)

Determines the value of WECS to electric utilities. This is a package of five computer models developed by the Solar Energy Research Institute. These models—WTP, WEIBUL, ROSW, ULMOD, and FINAM—can be used with most utility planning models. The value determination procedure begins with the processing of weather data by either the WTP or WEIBUL program to produce hourly wind speed data or wind probability distributions, respectively, for each hour of a typical day each month. The function of WTP is to convert a single year of standard weather data into a format acceptable to the ROSEW program. WEIBUL is preferable to WTP if two or more years of weather data are available because its probabilistic representation of hourly wind speeds is more likely to represent the long-term wind speeds than WTP's hourly average wind speeds. Both programs use the same four types of input weather data—SOLMET, TMY, and TDF from the National Climatic Data Center in Asheville, North Carolina, and Aerospace from Aerospace Corporation.

ROSEW calculates the wind energy system hourly power output using weather data supplied and wind machine characteristics. For WTP-supplied weather data, a single hourly wind power is calculated. For WEIBUL-supplied weather data, a group of wind powers with associated probabilities for each hour is calculated.

ULMOD uses the electricity production estimate calculated by ROSEW to reduce a user-supplied utility hourly load forecast. This reduced load profile is then put into a variety of forms suitable for use with electric utility planning models (e.g., LOLP, PRODUCTION COSTING, GENERATION EXPANSION PLANNING). Utility load forecasting uncertainty can be reflected.

FINAM is designed to determine the value (in dollars per kilowatt) and marginal value of alternative electric utility investment options, such as WECS, by useing base-case utility operating data with as many as ten change cases. Each change case contains operating data for a hypothesized amount of alternative investment. Sensitivity studies can be performed by changing a specific cost component, such as the cost of any fuel type.

Availability: Available to the public; fees vary

Language: FORTRAN IV

Machine: Mainframe, specifically CDC 7600, CYBER 175

Documentation: Percival, D. and Harper, J. (1981 and 1982). *Electric Utility Value Determination for Wind. Energy-Volume I: A Methodology; Volume II: A User's Guide.* SERI/TR-351-604 and SERI/TR-732-604R. Golden, CO: Solar Energy Research Institute; 2 Vols. WECS NESC No. is 932.7600B. WECS tape description, implementation information and errata to Volume II is in National Energy Software Center Note 82-47 (May 31, 1982).

Developed by: D. Percival and J. Harper, Solar Energy Research Institute

Contact: Argonne National Laboratory
National Energy Software Center
9700 South Cass Avenue
Argonne, IL 60439
(312) 972-7250

WECSAM (Wind Energy Conversion System Analysis)

Models wind turbine performance and performs economic analysis. The model with accompanying data bases has been used to determine the economic potential of eight residential, agricultural, commercial, and industrial applications in the Great Lakes Region. Designed for analysis at the county level, it accesses data bases containing wind resource data, application loads, WECS performance characteristics, utility rates, state taxes,

Availability: Available to the public; fees vary

Language: FORTRAN V

Machine: Mainframe, specifically CDC 7600

nd state subsidies for a six-state region (DOE Region V—Minnesota, Michigan, Wisconsin, Illinois, Ohio, and Indiana). WESCAM models the hourly performance of a given WECS and application for one typical day per month for a year. A performance curve for the machine is specified, then adjusted for air density and hub height. The power output is computed using a probability distribution for each hourly wind speed. WECSAM determines for each hour the energy generated, the demand, and the sales and purchases for a utility-connected system. It then performs a life-cycle economic analysis and provides many figures of merit, such as payback period, return on investment, and benefit-to-cost ratio.

Documentation: Arthur D. Little, Inc. (1982). *Wind Energy Conversion System Analysis Model (WECSAM) Computer Program Documentation.* SERI/SP-191-364. Golden, CO: Solar Energy Research Institute; 77 pp. Work performed by Arthur D. Little, Inc., Cambridge, MA.

Developed by: P. L. Hendrick and S. M. Hock, Solar Energy Research Institute

Contact: Argonne National Laboratory
National Energy Software Center
9700 South Cass Avenue
Argonne, IL 60439
(312) 972-7250

WEIBUL

See *WECS (Wind Energy Value to Electric Utilities)*

WESPM (Wind Energy System Performance Model)

Facilitates the design, analysis, and performance simulation of stand-alone and grid-connected wind energy systems. WESPM contains three separate models: the Wind Resources Assessment Model (WRAM), the Wind Turbine Performance Model (WTPM), and the Wind System Cost Model (WSCM). WRAM uses actual wind resource data or user input data and compares them with Rayleigh and Weibull wind frequency distributions. WTPM uses seven input variables, including the wind resource data from WRAM, turbine specifications, and application load demand. The model determines turbine power output by using Simpson's rule to integrate along a user-input turbine performance curve. WSCM computes total "out-of-pocket" costs, including those of hardware, capital, installation, operations and maintenance, and backup power purchased from a utility. WSCM is interactive with WTPM to facilitate cost-benefit analyses.

Availability: Available to the public

Language: BASIC

Machine: IBM PC and compatibles

Documentation: *Wind Energy System Performance Model User's Manual,*; available from the Meridian Corporation.

Developed by: P. A. Borgo, Meridian Corporation

Contact: Peter Borgo
Meridian Corporation
4300 King Street, Suite 400
Alexandria, VA 22302
(703) 998-3600

WEST 1, WEST 2

Simulates the structural dynamic response of horizontal-axis wind turbines. Input needed for this real-time-domain simulator includes a physical description of the turbine, tower, and (optional) wind speed and direction (wind data need to be in the form of electronic signals). Output includes various parameters that indicate blade loads and deflections. The data are presented in analog signals. This is a hybrid analog simulator that handles complex aeroelastic mathematical models in a shorter time than a comparable digital model.

Availability: Model available for a fee

Machine: Analog computer

Documentation: Hoffman, J. A. and Thoren, R. J. (1979). *Mathematical Models and Hybrid Programs for the Wind Energy System Time-Domain (WEST) Simulation—Baseline WEST Unit 1, Revision 6.* PPI-1030-1. El Segundo, CA: Paragon Pacific, Inc.

Hoffman, J. A. (1979). *Development Report: Wind Energy System Time-Domain (WEST) Analyzers Using Hybrid Simulation Techniques.* NASA CR-159737. Cleveland, OH: NASA Lewis Research Center; 29 pp. Work performed by Paragon Pacific, Inc., El Segundo, CA.

Janetzke, D. C. (1983). *Use of the WEST 1 Wind Turbine Simulation to Predict Blade Fatigue Load Distribution.* NASA TM-83532. Cleveland, OH: NASA Lewis Research Center; 10 pp. Report also available under DOE/NASA/20320-56.

Developed by: J. A. Hoffman, Paragon Pacific, Inc.

Contact: John A. Hoffman
Paragon Pacific, Inc.
1601 East El Segundo Boulevard
El Segundo, CA 90245
(213) 322-9111

Windmill Performance

Calculates the annual output of a windfarm connected to a load center, indicating the economic value of the total energy sold back to the utility and the energy savings. Input required includes wind speed and the load profile of the load center.

Availability: Model available for a fee from Rowman and Allanheld, 81 Adams Drive, Totowa, NJ 07512, (201) 256-8600

Language: Compiled BASIC

Machine: Microcomputer with Apple DOS or PC DOS operating system

Documentation: Katzman, M. T. (1984). *Solar and Wind Energy: An Economic Evaluation of Current and Future Technologies.* Totowa, NJ: Rowman and Allanheld; 200 pp.

Developed by: M. T. Katzman and A. Katzman, Solar Economics, Inc.

Contact: Arlene Katzman
Solar Economics, Inc.
7212 Dye Drive
Dallas, TX 75248
(214) 931-8096

Wind Array Power Output Model Using Predicted Wind Speeds

Produces a predicted wind record at wind turbine sites using the predictive wind model at each site along with measurements at referenced meterological towers. These predicted wind speed records are used to predict power output out of each wind turbine and then summed to produce an array power output record.

Availability: Model available to the public; user's manual available from NTIS

Language: FORTRAN

Machine: Mainframe

Documentation: Schlueter, R. A.; Park, G. L.; and Bouwmeester, R. (1983). *Development of Wind Generation Array Models and Their Use in Assuring Power System Operation Reliability.* East Lansing, MI: Michigan State University; 251 pp. Prepared for Oak Ridge National Laboratory, Oak Ridge, TN.

Developed by: R. A. Schlueter and G. L. Park, Michigan State University

Contact: R. A. Schlueter
Michigan State University
Department of Electrical Engineering and Systems Science
East Lansing, MI 48824
(517) 355-5244

Wind Machine Fatigue Analysis and Life Prediction

Measures fatigue, calculates fatigue reduction, and predicts fatigue life for different wind regimes. It is primarily intended for use with vertical-axis wind machines. Updated versions will expand the capabilities of this model, particularly for horizontal-axis machines.

Availability: User's and programmer's manual available to the public from NTIS

Language: HP BASIC

Machine: HP 9845 or machine of similar capability

Documentation: Waldon, C. A. (April 1980). *Wind Machine Fatigue Analysis and Life Prediction.* RFP-3135. Golden, CO: Rockwell International; 63 pp.

Developed by: Rocky Flats Wind Systems Program

Contact: Robert W. Thresher
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WTP

See *WECS (Wind Energy Value to Electric Utilities)*

'awDyn

vestigates the numerous problems associated with yaw on free-yaw nd yaw-driven wind turbines. YawDyn combines two simple models alled SDOF and UFlap (Utah FLAP). SDOF analyzes single-degree-of-eedom yaw motion, calculating the yaw loads and motions of a com-etely rigid rotor under a wide variety of machine and wind conditions. Flap analyzes blade flapping motion under prescribed yaw conditions; is model is a highly simplified version of SERI's FLAP code.

he primary prupose of UFlap is to test and verify the calculation meth-ds and many subroutines that SDOF and UFlap have in common. Both odes use numerical methods to solve the rotor's equations of motion in e time domain. Input includes horizontal and vertical wind shear (lin-ar and power-law profiles), tower shadow, and time-varying wind speed nd direction. Output includes time histories of yaw loads and motion as ell as blade root flap loads and motion.

ecause it combines the SDOF and UFlap models, YawDyn incorporates oth yaw and blade flap degrees of freedom, computing yaw error angle, aw rate, and yaw moment versus time for a two- or three-blade down-ind rotor.

Availability: Available to the public

Language: FORTRAN 77

Machine: VAX 11/750 with VMS

Documentation: Xudong, C.; Hansen, A.; and Siedschlag, N. (February 1988). *Yaw Dynamics of Horizontal Axis Wind Turbines.* SERI/STR-217-3309. Golden, CO: Solar Energy Research Institute; 105 pp. Work performed by University of Utah, Salt Lake City, UT. Available NTIS: Order No. DE88001137. (Appendices include the SDOF and UFlap code.)

Developed by: N. Siedschlag, C. Xudong, and C. Hansen

Contact: Alan Wright
Solar Energy Research Institute
Wind Research Branch
1617 Cole Boulevard
Golden, CO 80401

oftware Directories

OSMIC Software Catalog; 1985 Edition

ee *COSMIC* under *Depositories*

irectory of Energy Information Administration odel Abstracts

evises and updates the 1985 version of the same document (DOE/EIA-293). The main body of this directory alphabetically lists all active En-gy Information Administration (EIA) models. Each entry contains a ief statement about the model's title, acronym, purpose, and status, fol-wed by detailed information of characteristics, uses, and requirements. ources of additional information are identified. All models active rough March 1985 are included. Appendix A identifies major EIA mod-ing systems and the models within these systems. Appendix B identi-es active EIA models by type (basic, auxiliary, and developing). The rectory is intended to be used by energy and energy policy analysts the public and private sectors. Machine-readable tapes and record ecific model version noted in the abstracts are available from NTIS.

Directory of Energy Information Administration Model Abstracts. (July 1986). DOE/EIA-0293(86). Washington, DC: Energy Information Administration, U.S. Department of Energy; 56 pp. Available NTIS: Order No. DE86013249.

irectory of Energy Software for Microcomputers

escribes Microsoft programs for the full range of energy applications. ecause microcomputers are changing the workplace for energy profes-onals, hundreds of programs are now available for specific energy appli-tions. These programs relate to engineering design, economic analyses, ergy-demand forecasting, energy management, energy accounting, ogeneration, electric power, natural gas, petroleum, coal, active and assive solar, renewable energy, and energy recovery.

Directory of Energy Software for Microcomputers. (1985). Rockville, MD: Government Institutes, Inc.; 196 pp. Available from Government Institutes, Inc., 966 Hungerford Drive 24, Rockville, MD 20850

Engineering and Industrial Software Directory: A Guide to Computer Programs in the Applied Sciences

Serves as an objective, comprehensive, and current reference guide to software that is available to the public for engineering, manufacturing, and industrial applications. Primarily emphasizes software programs in the major disciplines of traditional engineering (e.g., electrical, electronic, mechanical, civil, chemical, mining, petroleum, metallurgical, and aerospace), transdisciplinary specialities (e.g., structural engineering, piping, transportation, and energy), and computer applications areas that support the engineering disciplines (e.g., finite-element analysis, computer-aided design, and computer-aided manufacture). Energy sources include electricity, energy management, fossil fuels, renewable energy sources (other), solar and photovoltaic energy, and wind power. Entries are indexed according to hardware, operating system, program name, subject, and vendor.

Engineering and Industrial Software Directory: A Guide to Computer Programs in the Applied Sciences. (1985). New York: Engineering Information, Inc.; 951 pp.

National Directory of Energy Software for Microcomputers

Annotates more than 100 microcomputer software packages sources designed to improve energy efficiency through conservation and the use of renewable energy sources. The directory is divided into the following four major software sections: thermal performance and solar-modeling; heating, ventilating, and air-conditioning, and lighting system analysis; energy accounting; and miscellaneous software including active solar, photovoltaic and wind machine sizing, fleet management, and energy economics. Each listing includes a description of the software, hardware requirements, price, contact, and proprietary or copy-protected information. Software descriptions are written by the vendors.

National Directory of Energy Software for Microcomputers. (October 1985). Eugene, OR: Bureau of Governmental Research and Service, University of Oregon; 126 pp.

The First National Conference on Microcomputer Applications for Conservation and Renewable Energy (NCMACRE); Tucson, AZ; 26-28 February 1985

Highlights the widespread applications made possible by the new microcomputer technologies. The applications discussed range from commercial heating, ventilating, and air-conditioning and solar design packages to data-acquisition systems and analysis to advanced energy modeling. Microcomputer impacts on the development and use of solar and other renewable resources as energy-conservation techniques were explored. Papers were organized by the following categories: planning and economic analysis, class A and B monitoring, evaluation of energy models, data-acquisition systems, facilities energy management, general design aids, active solar and wind, photovoltaic systems analysis, building analysis, equipment and components analysis, and passive design. Twenty-four papers deal with hardware, surveys, or methodologies. The remaining 27 papers concern specific microcomputer programs. Nine of these papers include the program listing; six others have made their programs available on disk (ordering information is included).

Osborn, E.E., ed. (May1985). *The First National Conference on Microcomputer Applications for Conservation and Renewable Energy* (NCMACRE); Tuscon, AZ; 26-28 February 1985. Tucson, AZ: University of Arizona; 393 pp. Available from NCMACRE, Special Professional Education, Harvill Building, Box 9, University of Arizona, Tucson, AZ 85721.

Solar Energy Computer Models Directory

Compiles models with applications in six renewable energy technologies: iomass, solar heating and cooling, ocean energy, photovoltaics, solar hermal, wind, and multitechnology. This directory is designed to assist nodel developers and users in obtaining access to more than 300 listed nodels by providing the appropriate contacts for each model. Each entry ncludes a description of the model and information on its availability, udience, language, machine, documentation, developers, and contact.

Solar Energy Computer Models Directory. (August 1985). SERI/SP-271-2589. Golden, CO: Solar Energy Research Institute; 130 pp. Available from GPO: Stock No. 061-000-00661-3. Available from NTIS: Order No. DE85008791.

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The Software Catalog: Science and Engineering. 2d. ed. (1985). New York: Elsevier Science Publishing Co.; 540 pp.

Depositories

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List of Acronyms and Abbreviations

AEE - Association of Energy Engineers
AERO - Alternative Energy Resources Organization
AIAA - American Institute of Aeronautics and Astronautics
ARS - Agricultural Research Service
ARS-USDA - Agricultural Research Service, U.S. Department of Agriculture
ASE - Alternative Sources of Energy
ASES - American Solar Energy Society
ASME - American Society of Mechanical Engineers
ASTM - American Society for Testing and Materials
AWEA - American Wind Energy Association
BHRA - British Hydromechanics Research Association
BMFT - Federal Ministry of Research and Technology
BPA - Bonneville Power Administration
CAREIRS - Conservation and Renewable Energy Inquiry and Referral Service
COSMIC - Computer Software Management and Information Center
DOD - U.S. Department of Defense
DOE - U.S. Department of Energy
EEI - Edison Electric Institute
ENEL - Italian National Unity
EPRI - Electric Power Research Institute
EPSC - Electric Power Software Center
ERDA - Energy Research and Development Administration
FERC - Federal Energy Regulatory Commission
HAWT - Horizontal-Axis Wind Turbine
HNEI - Hawaii Natural Energy Institute
IEA - International Energy Agency
ISCC - Interstate Solar Coordination Council
ISES - International Solar Energy Society
NARU - National Association of Regulatory Utility Commissioners
NASA - National Aeronautics and Space Administration
NATAS - National Appropriate Technology Assistance Service
NCAT - National Center for Appropriate Technology
NCDC - National Climatic Data Center
NCEL - Naval Civil Engineering Laboratory
NESC - National Energy Software Center
NOAA - National Oceanic and Atmospheric Administration
NRECA - National Rural Electric Cooperative Association
NTIS - National Technical Information Service
PGE - Pacific Gas and Electric Company
PNL - Pacific Northwest Laboratory
PURPA - Public Utility Regulatory Policies Act
SERI - Solar Energy Research Institute
SNL - Sandia National Laboratories
TALA - Tethered Aerodynamically Lifted Anemometer
VAWT - Vertical-Axis Wind Turbine
WECS - Wind Energy Conversion Systems
WESA - Wind Energy Systems Act
WTG - Wind Turbine Generator

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