WIND ENERGY CONVERSION

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Windmills were once a common sight in many rural areas of this country,[1] and have been used to produce electricity for almost one hundred years.[2] When coal and oil became widely available as sources of large amounts of relatively inexpensive electricity, the windmills gave way to power plants and transmission lines.[3] Today, increasing world fuel prices,[4] fear of foreign control of oil supplies,[5] and recognition of the environmental problems associated with conventional energy sources[6] have contributed to a revival of interest in wind energy conversion systems (WECS). Wind energy proponents claim that the wind, unlike oil and other sources of power, is a renewable resource which can provide

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1. F. Morse & M. Simmons, *Solar Energy*, 1 ANN. REV. ENERGY 131, 142 (1976). In the 19th and early 20th centuries, small wind devices, both homemade and commercially produced, were used extensively throughout the United States, especially by farmers. Six million small machines were built since the 1850s, yet by 1975, only 150,000 were still in operation. J. CANNON & S. HERMAN, ENERGY FUTURES 168 (1977) [hereinafter cited as CANNON]. *See also* J. McGowan & W. Heronemus, *Ocean Thermal and Wind Power: Alternative Energy Sources Based on Natural Solar Collection*, 4 ENVT'L AFF. 629, 631 (1975) [hereinafter cited as McGowan].

2. Electricity was produced from wind power as early as 1890 when a device of Danish origin began operation. McCaull, *Windmills*, 15 ENVIR. 6 (1973). Admiral Richard Byrd harnessed the wind to produce electricity at "Little America" at the South Pole in the 1930s. W. CLARK, ENERGY FOR SURVIVAL 540 at note (1974). The device used by Byrd, the Jacobs wind generator, was manufactured in the United States from 1928 to 1957. D. HALACY, EARTH, WATER, WIND, AND SUN 98 (1977); W. CLARK, *supra*, at 539. Before this time, wind devices were used to provide mechanical energy, often to pump water. *Id.* In 1850, windmills provided 1.4 billion horsepower-hours of work in the U.S., or the equivalent of burning 11.8 million tons of coal. McGowan, *supra* note 1, at 631.

3. As the energy requirements of homes, farms, and ranches increased after World War II, wind devices no longer could meet demand reliably and economically. Instead, coal, oil, or natural gas was substituted. McGowan, *supra* note 1, at 631. *See also* McCaull, *supra* note 2, at 6. In the 1930s, as part of the New Deal, the Rural Electrification Administration began to provide federally subsidized electricity to farmers in remote regions. W. CLARK, *supra* note 2, at 524. This accelerated the decline in wind energy use; windmills were maintained only in areas not reached by the Administration. D. HALACY, *supra* note 2, at 98-99. Most private wind system manufacturers had gone out of business by the 1960s. CANNON, *supra* note 1, at 168.

4. CANNON, *supra* note 1, at 167.

5. *See*, Merriam, *Wind, Waves, and Tides*, 3 ANN. REV. ENERGY 29, 30 (1978).

6. UNION OF CONCERNED SCIENTISTS, ENERGY STRATEGIES: TOWARD A SOLAR FUTURE 145 (1980).

clean, safe, and economical power.[7] The federal government has responded by funding wind power research[8] and the construction of experimental wind systems by private corporations through government contracts.[9] In addition, utilities,[10] entrepreneurs,[11] and individual homeowners[12] have recently constructed WECS to produce economical electrical power.

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7. *See, e.g.*, McGowan, *supra* note 1, at 629-60; FEDERAL POWER COMMISSION, NATIONAL POWER SURVEY, ENERGY SOURCES RESEARCH 118-22 (1974).

8. The National Aeronautics and Space Administration (NASA) began wind-generator research in 1972. D. HALACY, *supra* note 2, at 113. It built the first large wind machine in the United States, a 100-kilowatt (kW) machine located outside Cleveland, Ohio. Metz, *Wind Energy, Large and Small Systems Competing*, 197 SCI. 971, 971 (Sept. 2, 1977). NASA later constructed a 200-kW machine at the same location. Torrey, *Blowing Up More Kilowatts from Wind*, TECH. REV. 12, 12 (Feb. 1980). The National Science Foundation (NSF) and NASA sponsored workshops on WECS in 1973, 1975, 1977, and 1979. Torrey, *supra*, at 12. *See generally* NSF/NASA, WIND ENERGY CONVERSION SYSTEMS WORKSHOP PROCEEDINGS (1973) [hereinafter cited as WECS WORKSHOP PROCEEDINGS]. For a WECS study funded by NSF, *see generally* NSF, LEGAL-INSTITUTIONAL IMPLICATIONS OF WIND ENERGY CONVERSION SYSTEMS (WECS) (Sept. 1977) [hereinafter cited as IMPLICATIONS OF WECS]. The study discusses legal problems associated with various WECS applications and states that there are "relatively few serious legal impediments" to WECS use. *Id.* at 1-2.

Discussions of electric power refer to the rates of energy usage which is usually measured in kilowatts (kW) or megawatts (MW; 1 MW = 1,000 kW), or energy which is usually measured in kilowatt-hours (kW-hr). Using energy at a rate of one kilowatt is the same as burning 10 100-watt light bulbs continuously. A kilowatt-hour represents using energy at a rate of one kilowatt for one hour.

9. In 1975, for example, the Energy Research and Development Administration (ERDA) awarded specialized contracts to several corporations. The Boeing Company was to study the characteristics of wind device bladed roters, General Electric was to determine the wind-flow patterns of the United States, and the Grumman Aerospace Corporation was to investigate using an open cone to draw air past windmill blades at an accelerated rate. CANNON, *supra* note 1, at 171-76. Also, 200-kW wind turbines were built at Clayton, N.M., Culegra, P.R., and on Block Island, R.I., under Department of Energy (DOE) contracts. Smith, *Wind Power Excites Utility Interest*, 207 SCI. 739, 739 (1980). The Clayton device was built by the Lockheed Corporation. S. SCHURR, RESOURCES FOR THE FUTURE: ENERGY IN AMERICA'S FUTURE 312 (1979). Other DOE-sponsored projects include a 2-megawatt (MW) device at Boone, N.C., and a cluster of three windmills produced by Boeing and rated at 2.5-MW each to be constructed along the Oregon-Washington border. Smith, *supra*, at 739-40.

10. Utilities in Oregon and Pennsylvania have purchased WECS, while the Southern California Edison Co. has constructed a 200-ft, 3-MW wind machine in the California desert outside Palm Springs. Smith, *supra* note 9, at 739. *See also* note 114 *infra*.

11. A group of West Coast investors formed the wind energy firm of Windfarms, Ltd., and contracted with the Hawaiian Electric Co. to supply 80 megawatts of power to the island of Oahu with WECS. Smith, *supra* note 9, at 741.

Some states have promulgated rules requiring utilities to buy electric power from independent producers, and, in New Hampshire, U.S. Windpower Associates has installed a medium-sized windmill system to produce power for such an arrangement. The company has erected 20 machines on Crotched Mountain in New Hampshire, and will sell the generated electricity to the local utility at $0.077 per kW-hr. Telephone interview with Ken Cohn, Second Wind, Inc., Cambridge, Mass., (Feb. 17, 1981).

12. *See, e.g.*, Clews, *Electric Power from the Wind*, PRODUCING YOUR OWN POWER 14 (C. Stoner ed. 1974). There are approximately 40 windmills operated by homeowners in Massachusetts. Telephone interview with Doug Short, Long Range Utility Planning, Mass. Public Utilities Dep't (Feb. 19, 1981) [hereinafter cited as Short].

This article assesses the feasibility of producing significant amounts of electricity with wind energy conversion systems. Part I presents background material on the energy resource potential of wind and on the operation of WECS. Part II discusses the major economic, technical, and environmental considerations, and regulatory constraints relevant to wind energy use. Because many of these parameters vary with the size of the wind system involved,[13] part II analyzes the economic considerations for wind systems in three categories: small systems used to power individual homes, medium-sized systems used to provide power to neighborhoods and collectives, and large-scale wind projects capable of supplying entire cities. Finally, part III concludes by identifying the most practical and economical methods of wind energy conversion.

I. BACKGROUND

Wind is created by a transformation of solar energy to heat in the atmosphere.[14] The warmer air masses tend to rise, drawing cooler air underneath, thus forming air currents and wind.[15] The energy trapped in wind is constantly dissipated by turbulence and friction in the atmosphere and at the earth's surface, but it is also continually replenished by incoming solar radiation.[16] Only a fraction of the solar energy reaching the earth is absorbed by the atmosphere,[17] and only a small portion of the absorbed energy, between one and four percent, is transformed into wind energy.[18]

The exact amount of power available from wind is unknown, but all estimates of that amount are large, varying from 2×10^{10} to 1×10^{13} kilowatts.[19] Aside from practical, technological, and economic limits on large-scale utilization of wind energy, it is unknown how much wind energy can be extracted from the atmosphere without causing environmental damage. Large-scale extraction could modify the earth's climate resulting in effects as severe as the melting of the polar ice caps.[20]

13. *See, e.g.*, Metz, *supra* note 8, at 971 (large WECS interfere with television reception while small WECS seldom do); S. SCHURR, *supra* note 9, at 312 (small WECS have been tested successfully in practical operation, while larger devices have experienced technical difficulties); IMPLICATIONS OF WECS, *supra* note 8, at 9 (small, individual home systems will often be subject to zoning restrictions, while utilities, which will tend to use larger systems, may be exempt from such regulations).

14. J. KRENZ, ENERGY CONVERSION AND UTILIZATION 277 (1977). Factors such as clouds, suspended moisture, and ground objects make this heating uneven.

15. CANNON, *supra* note 1, at 165.

16. Gustavson, *Limits to Wind Power Utilization*, 204 SCI. 13, 13 (1979).

17. About 20% of the total incident solar power, or about 4×10^{12} kW, is absorbed by the earth's atmosphere. J. KRENZ, *supra* note 14, at 277. *See also* note 8 *supra*.

18. UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 145. *See, e.g.*, Gustavson, *supra* note 16, at 13, where an estimated conversion rate of two percent is used to compute an average transformation of solar energy to wind energy of seven Watts per square meter.

19. McGowan, *supra* note 1, at 632. By way of comparison, the electrical consumption rate in the United States averaged 2.5×10^8 kW in 1978. See UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 146.

20. Gustavson, *supra* note 16, at 14.

Because of possible environmental damage, one commentator has suggested that extraction of wind energy should be limited to ten percent of the energy dissipated within one kilometer of the earth's surface.[21]

Wind energy is not distributed evenly over the earth's surface; some areas have virtually no wind, while others have strong, nearly continuous winds. Statistics on wind speeds at particular sites are therefore more useful than figures on the worldwide wind energy potential.[22] Regions in the United States shown to be suitable for WECS include parts of Alaska, the Great Plains, the Pacific Northwest coast, the New England coast, the Great Lakes region, and the Texas Gulf coast.[23] For example, due to the wind characteristics of the Great Plains, some estimates claim that that region alone could provide the United States with several times the present electrical energy use rate.[24] In addition, several areas having high windspeed characteristics are near urban areas such as New York, Boston, and Los Angeles.[25] Development of such sites could provide energy to proven markets without additional transmission costs.

Wind energy conversion devices vary in physical size and design but generally fall into two categories. Horizontal devices are those with blades which move about on an axis which is parallel to the ground; vertical devices, on the other hand, have moving parts which rotate about an axis perpendicular to the ground.[26] Regardless of the type of

21. *Id.* Note that Gustavson admits that "an allowable level" for wind energy extraction "cannot be calculated on the basis of current knowledge." *Id. See also* McGowan, *supra* note 1, at 648-49; J. Holdren, G. Morris & I. Mintzer, *Environmental Aspects of Renewable Energy Sources,* 5 ANN. REV. ENERGY 241, 279 (1980) [hereinafter cited as Holdren].

22. Site-specific data, while useful, is often difficult to obtain, although wind maps of the country are available. *See, e.g.,* UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 147. Site-specific data at sites and heights suitable for WECS are known for only a few hundred locations worldwide, however. Merriam, *supra* note 5, at 45. At certain sites close to ground level in the United States, the average wind velocity is high enough so that the wind power averages 500 Watts per square meter. Wind machines located at such sites can convert up to 35% of this power to electricity. Merriam, *supra* note 5, at 43-44.

23. UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 146-48.

24. *Id.* at 146, 148.

25. *Id.* at 148.

26. *See generally,* D. HALACY, *supra* note 2, at 93-122; Kadlec, *The Darrieus Vertical-Axis Wind Turbine Program at Sandia Laboratories,* 7 SHARING THE SUN 349 (1976) (proceedings of the Joint Conference of the American Section of the International Solar Energy Society and the Solar Energy Society of Canada, Inc., Aug. 15-20, 1976). Horizontal machines are usually what one thinks of as a windmill; the Dutch and New England windmills used to grind grain and pump water were horizontal axis machines. Kadlec, *supra,* at 350. The vertical device receiving the most attention today, the Darrieus wind turbine, was designed in 1925, but was not developed until the early 1970s when workers at the National Aeronautical Establishment of the National Research Council of Canada reinvented the concept. D. HALACY, *supra* note 2, at 119. The vertical devices actually resemble the world's first windmills. Those devices, designed to turn millstones, had sails or blades which were turned horizontally by the wind around a vertical axis. Torrey, *supra* note 8, at 13.

For a WECS design that does not fit easily into either a horizontal or a vertical classification, see Teller, *Natural Energy Sources,* 30 MERCER L. REV. 445, 462-63 (1979); D. HALACY, *supra* note 2, at 119-22.

machine, the theory of wind power extraction is the same: a moveable part intercepts a cross-section of air and is rotated about an axle which is linked to an energy transformation device, often an electrical generator.[27] The moveable parts of WECS can be made of metal,[28] wood,[29] fiberglass,[30] or even fabric.[31] Horizontal devices may be single-, double-, triple-, or multi-bladed;[32] the blades of the most recently constructed devices resemble airplane propellers.[33] Vertical devices may have circular,[34] S-shaped,[35] or eggbeater-shaped[36] rotors. At present, the prevalent design is that of double- and triple-bladed horizontal machines.[37]

Aspects of WECS design can best be understood with reference to the physical properties of wind power. The power extractible from wind is proportional to the cross-section of wind intercepted by the moving parts.[38] Thus, to obtain more power, the device's blades must be made larger. For example, at a site with an average windspeed of ten meters per second, a WECS with a designed capacity of one MW would have blades extending thirty-two meters from the axis.[39] Also, wind at a given site is generally intermittent.[40] Thus, a storage system or connection to

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27. CANNON, *supra* note 1, at 166; UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 148. Wind devices can also be used to pump water, compress air, and produce heat. *Id. See also* Sørensen, *Wind Energy*, BULL. ATOM. SCIENTISTS, Sept. 1976, at 38, 39-43. In addition, windmills can be used to produce hydrogen by electrolysis of water. Hydrogen is a convenient form of storable, transportable energy and can be used to regenerate electricity or to heat buildings directly. Sørensen, *supra*, at 42; W. CLARK, *supra* note 2, at 531.

28. W. CLARK, *supra* note 2, at 523.

29. A WECS sold by Cambridge Alternative Power Co. has wooden blades. Telephone interview with Kemp Battle, Cambridge, Mass. (Feb. 18, 1981) [hereinafter cited as Battle].

30. UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 157. The windmills installed in New Hampshire by U.S. Windpower Associates have fiberglass blades. Telephone interview with Russel Wolfe, Vice President, U.S. Windpower Associates, Burlington, Mass. (Feb. 18, 1981) [hereinafter cited as Wolfe].

31. *See, e.g.*, CANNON, *supra* note 1, at 175. A wind device developed at Princeton, the "Sailwing," has blades of a flexible fabric mounted on a framework. *Id.* European windmills using canvas sails to trap wind were common by the 13th century. W. CLARK, *supra* note 2, at 520.

32. Merriam, *supra* note 5, at 32-34; UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 148. Windmills used for pumping water usually have a large number of blades, a feature which allows them to function efficiently in low-speed winds. Wind devices generating electrical energy usually have fewer blades and are designed to operate at higher windspeeds. W. CLARK, *supra* note 2, at 525.

33. For photos and sketches of horizontal WECS, see D. HALACY, *supra* note 2, at 109, 114; UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 149, 153.

34. *See* J. KRENZ, *supra* note 14, at 284-85.

35. *Id.*

36. The Darrieus rotor is often described as eggbeater-shaped. For photos of Darrieus devices, see UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 152; D. HALACY, *supra* note 2, at 120.

37. UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 150.

38. For derivation of the property, see J. KRENZ, *supra* note 14, at 277-80.

39. Merriam, *supra* note 5, at 30-31.

40. CANNON, *supra* note 1, at 166.

a backup source of energy is an essential part of most wind energy systems.[41] Although several other systems have been suggested,[42] the major storage system used today is the lead-acid battery.[43]

WECS are usually designed to operate only within a certain range of speeds.[44] The "cut-in speed" is that speed below which the machine will not operate at all, and the "rated windspeed" is that speed at which the capacity of the electrical generator of the WECS is reached.[45] Above the rated windspeed, some wind power is intentionally wasted to avoid causing irreparable damage to the generator.[46] By varying the pitch of the blades of a WECS, a constant speed of rotation of the device, and hence a constant power output, can be achieved.[47] Furthermore, the force exerted by the wind on the WECS is proportional to the square of its velocity.[48] At a certain speed the forces become so great that the WECS must be turned out of the wind or otherwise shut down to prevent dangerous structural damage. The speed at which this occurs is called the "furling speed."[49] Even at speeds less than the furling speed, how-

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41. *Id.* This factor is especially a problem with WECS built to provide power to individual homes or collections of homes. One way to avoid this problem is to disperse WECS over a large geographical area and to feed the energy generated by them into the existing power grid. This design relies on the assumption that wind would be blowing in at least a section of the area covered at any given time. *See* SCIENCE AND PUBLIC POLICY PROGRAM, UNIV. OF OKLAHOMA, ENERGY ALTERNATIVES: A COMPARATIVE ANALYSIS 11-18 (May 1975) (prepared for the Council of Environmental Quality, ERDA, Environmental Protection Agency, Federal Energy Administration, Federal Power Commission, Department of Interior and NSF) [hereinafter cited as ENERGY ALTERNATIVES].

42. Those systems include hydrogen production, *see* W. CLARK, *supra* note 2, at 531; ENERGY ALTERNATIVES, *supra* note 41, at 11-15; Sørensen, *supra* note 27, at 41, 42; McGowan, *supra* note 1, at 646, compressed air, *see* Szego, *Energy Storage by Compressed Air* (contained in WECS WORKSHOP PROCEEDINGS, *supra* note 8, at 152-54), flywheels, W. CLARK, *supra* note 2, at 530-31; UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 152, and pumped water, CANNON, *supra* note 1, at 151-52.

43. *See* CANNON, *supra* note 1, at 169. For factors favoring battery storage, see Schwartz, *Batteries for Storage of Wind-Generated Energy* (contained in WECS WORKSHOP PROCEEDINGS, *supra* note 8, at 146-50).

44. *See* ENERGY ALTERNATIVES, *supra* note 41, at 11-15 to 11-17; Merriam, *supra* note 5, at 31.

45. *Id.* A typical cut-in speed is 8 mph. D. HALACY, *supra* note 2, at 114. Rated windspeeds are usually chosen to be between one and a half and two times the site's average windspeed. Merriam, *supra* note 5, at 31-32. *See, e.g., Wind Energy Systems Act of 1980: Hearings Before the Subcomm. on Energy Development and Applications of the House Comm. on Science and Technology*, 96th Cong., 1st Sess. 218 (1979) [hereinafter cited as *Wind Energy Systems Act Hearings*] (statement of Louis Divone, Chief of Wind Systems, DOE). "[A year-round average of] 12-miles-an-hour wind merits attention, particularly with small machines. Fourteen miles an hour is very good, and anything over that, one would immediately consider putting [a WECS] there as an exceptional location."

46. Merriam, *supra* note 5, at 31-32.

47. J. KRENZ, *supra* note 14, at 282. Varying the pitch of a blade involves rotating it about its own axis to change the angle at which it slices into the moving air.

48. For derivation of this property, see J. KRENZ, *supra* note 14, at 277-82.

49. Merriam, *supra* note 5, at 31.

ever, the wind device must be capable of withstanding significant forces,[50] thus adding to the cost of large wind devices.[51]

Additionally, the total power contained in wind is proportional to the cube of its speed.[52] For example, a ten mile-per-hour wind contains eight times as much power as a five mile-per-hour wind. It is thus very important to site windmills where the strongest winds exist. Because wind speed is generally greater higher above the ground,[53] WECS employ tall support structures to obtain the larger amounts of energy available.[54] Finally, because wind is variable in direction, horizontal machines are turned mechanically to follow the changing wind.[55] Vertical machines do not have this problem; because they are symmetrical and rotate about a vertical axis, they can catch the wind from any direction.[56]

Like all other machines, a WECS cannot extract all the energy stored in its power source.[57] Theoretically, the maximum power extractible by a horizontal axis machine is sixty percent, while the corresponding figure for a vertical machine varies with its design.[58] Typically, a WECS operating within its windspeed range converts from thirty to forty percent of the available wind energy to electricity.[59]

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50. J. KRENZ, *supra* note 14, at 282. *See, e.g., Wind Energy Systems Act Hearings, supra* note 45, at 200 (statement of Donald A. Beattie, Director, Energy Systems Division, Off. of Aeronautics and Space Technology):

> The wind turbines at Culebra, P.R. [200-kW]; Boone, N.C. [2-MW]; and Block Island, R.I. [200-kW] all survived Hurricane David and its aftermath. It is estimated that the maximum wind experienced at these sites was approximately 60 miles per hour; and, although no damage was expected, . . . none occurred. The machines are designed to sustain 150 mile per hour winds when the blades are horizontal and feathered into the wind.

51. *Id.*

52. For derivation of this property, see J. KRENZ, *supra* note 14, at 277-78.

53. W. CLARK, *supra* note 2, at 526; Sørensen, *supra* note 27, at 40.

54. *See* McGowan, *supra* note 1, at 634-35. Small generators, those having outputs of a few thousand Watts, are usually placed on 40- to 60-foot towers. W. CLARK, *supra* note 2, at 525. The world's largest wind generator sits atop a 140-foot high tower. Torrey, *supra* note 8, at 12.

55. *See* Merriam, *supra* note 5, at 31.

56. UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 150. For discussions of the advantages and disadvantages of vertical axis machines, see D. HALACY, *supra* note 2, at 119; Kadlec, *supra* note 26, at 350.

57. Merriam, *supra* note 5, at 31. Mechanical power extraction capabilities are measured by efficiencies. For comparison, the efficiency of a car engine is approximately 22%, while the efficiency of a large Diesel oil engine is approximately 40%. R. RESNICK & D. HALLIDAY, PHYSICS 548 (1977).

58. Merriam, *supra* note 5, at 31. The highest efficiency yet achieved by any wind machine is 50%. *Id.*

59. *Id.* Because energy is wasted when wind speeds are below or above the rated windspeed, energy actually converted to electricity is likely to be less than 30%. UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 150. For purposes of comparison, the figures for conversion of solar power to electricity range from only 10 to 12%. Merriam, *supra* note 5, at 44. *See also* Metz, *supra* note 8, at 971.

II. Constraints on Wind Energy Use

A. Economic Considerations

Homeowners, communities, and utilities will decide whether to construct WECS largely by comparing the cost of wind generated electricity with the cost of power produced from conventional sources. Other factors, however, such as environmental and human health effects and the reliability of fuel supply, all of which involve long-term considerations,[60] should also influence the choice of an energy source. These long-term considerations may dictate the choice of WECS even though wind generated electricity is only marginally cost-competitive with other sources in some situations.[61]

At present, energy generated from conventional sources typically costs utility customers between $0.05 and $0.10 per kW-hr, a figure still significantly lower than the cost of most WECS generated energy.[62] However, the cost-effectiveness of WECS varies with the size of the system.

1. Small Individual Home Systems

The cost-effectiveness of an individual residential wind energy conversion system depends upon the extent and pattern of the homeowner's electrical energy needs and on the steadiness of the winds in his area. A typical American household uses approximately 1,000 kW-hr per

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60. It is important to note that market price often does not reflect all the true costs of an activity. *See, e.g.*, R. Stewart & J. Krier, Environmental Law and Policy 113-17 (1978); Sørensen, *Dependability of Wind Energy Generators with Short-term Energy Storage*, 194 Sci. 935, 935 (1976).

61. *See, e.g.*, *Wind Energy Systems Act Hearings*, *supra* note 45, at 21 (statement of Congressman Norman Y. Mineta):

> [A study prepared by] Lockheed—California concluded that if the price of conventional fossil fuels rose by 7 percent per year between now and 1995, wind energy could replace up to five and one-half million barrels of oil a day.
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> [A similar study prepared by] General Electric concluded that if wind energy systems were installed as quickly as possible between now and the year 2000, they could displace the equivalent of up to three million barrels of oil a day.

See also text at note 81.

62. *But see* note 67 *infra*. In telephone interviews on April 6, 1981, utility companies reported the following approximate rates for residential customers: Cambridge, Mass., 8.5¢/kW-hr, Fred Gordon, Consumer Relations Supervisor, Cambridge Electric Lighting Co.; Cedar Rapids, Iowa, 6¢/kW-hr, Stell Woorster, Bookkeeping Supervisor, Iowa Electric Light and Power Co.; Los Angeles, Cal., 7.5¢/kW-hr, Thomas DeWitte, Rate Applications Specialist, Los Angeles Dep't of Water and Power. The variation in rates is due in part to the types of plants operated by particular utilities. Hydroelectric plants cost far less to operate than oil-fired plants, for instance. J. Marion, Energy in Perspective 36 (1974). Even among utilities operating oil-fired plants, unequal fuel costs will cause differences in rates.

month,[63] which is equivalent to an average consumption rate of 1.4 kW.[64] Manufacturers of residential windmills sell systems with generating capacities from two to six kW;[65] the costs of which, including installation, range from near $3,000 to $10,000.[66] The present discussion will consider the economics of a 2-kW wind system priced at $10,000.[67]

The owner of a residential wind energy system who plans to continue to buy electricity from a utility during times of no wind needs no storage capacity for surplus wind generated energy.[68] The key question is whether the ongoing savings flowing from reduced utility bills justify the one-time cost of the wind energy conversion system.

If the 2-kW windmill operates continuously, in one month it will generate 1,440 kW-hr. In practice, because the wind does not blow continuously, the windmill will produce only a fraction of that amount; this fraction is called the "wind load factor."[69] Typical wind load factors range from 0.15 to 0.25.[70] Assuming a wind load factor of 0.15, the 2-kW system would produce 216 kW-hr per month.

Generally, a WECS does not produce exactly the amount of power required by the individual residence at any given time. Predictions of savings from wind energy utilization in such cases depend not only on the reliability of the wind, but also on the degree to which household

63. Lecture by Dr. H. Ehrenreich, Division of Applied Science, Harvard Univ., Cambridge, Mass. (Dec. 9, 1980).

64. In a 30-day month, 1,000 kW-hr used averages to an energy consumption rate of just under 1.4 kW. Note that this figure is an average consumption rate: at any given moment, the actual rate may be either higher or lower.

65. *But see Wind Energy Systems Act Hearings, supra* note 45, at 201 (statement of Donald A. Beattie, Director, Energy Systems Division, Off. of Aeronautics and Space Technology): "[E]arly experience indicates the annual average power production of a wind turbine [is] only 40 to 50 percent of the rated capacity."

66. *See* CANNON, *supra* note 1, at 169; UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 155.

67. Cambridge Alternative Power Co., of Cambridge, Mass., offers a 2-kW system including installation priced from $7,000 to $10,000 depending upon tower height and transportation costs. The device has three wooden blades and is placed on a tower 60 to 90 feet high. Battle, *supra* note 29.

The cost calculations in this section use the "worst-case" figures from the range of values found in the literature to avoid assessments biased in favor of wind energy conversion systems. If, however, the least expensive devices are employed and the price of conventionally generated electricity doubles or triples, the attractiveness of WECS would greatly increase.

68. The alternative for a homeowner is to install a WECS with a capacity to meet all the power needs of the home, and a storage system to retain energy produced in excess of household demand for times when WECS production falls short of that demand. The cost of storage batteries is very high, however, and their use has been limited. *See* J. KRENZ, *supra* note 14, at 284.

69. *See* ENERGY ALTERNATIVES, *supra* note 41, at 11-17.

70. UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 152. In regions with exceptionally steady winds, WECS may produce power at 35-40% of stated capacity. Residential wind systems in Massachusetts have averaged 35%. Battle, *supra* note 29.

energy usage patterns correspond to wind patterns. When the wind velocity is so high that the WECS provides more power than the household is using, it may be possible to sell the excess power generated to the utility through a buy-back scheme.[71] In this case, the entire 216 kW-hr would contribute toward reduction of the WECS user's utility bill. In areas where utility buy-back of power is not possible, however, the blades of the device can be turned so that the energy output equals the current demand.[72] Then, of course, some of the theoretically available 216 kW-hr will not be generated to reduce the homeowner's utility bill.

If a utility buy-back plan is used whereby the utility buys excess energy at a price equal to the rate charged conventional customers,[73] a WECS user will buy only 784 kW-hr of electricity per month. At a conservative energy cost of $0.05 per kW-hr, the WECS user will save $10.80 on each monthly bill. This savings has a present value of approximately $700 on a WECS with a useful life of fifteen years purchased with a fifteen percent note.[74] If the price of electricity increases to $0.10 per kW-hr, the present value of the savings on the same machine increases to nearly $1,550. Neither case, however, even begins to economically justify a $10,000 investment. The Federal Residential Energy Tax Credit[75] does reduce the after-tax cost of this wind system by forty percent, or from $10,000 to $6,000, but this is still thousands of dollars above a cost-effective level.

71. The New Hampshire Public Utilities Commission issued an order setting a utility buy-back rate of $0.077 per kW-hr for nonreliable energy production such as WECS. NEW HAMPSHIRE PUBLIC UTILITIES COMM., SMALL ENERGY PRODUCERS AND COGENERATORS, DE 79-208 (June 18, 1980). For a detailed discussion of utility buy-back of privately generated power, and the federal directives to state utilities commissions to promulgate rules on the subject, see Gentry, *Encouraging Public Utility Participation in Decentralized Power Production*, 5 HARV. ENVT'L L. REV. 297 (1981).

72. *See* text at note 47 *supra*.

73. The price that the utility pays for buy-back power may not be the same as the selling price to residential customers. In New Hampshire, the average energy cost to consumers is about $0.05 per kW-hr which is more than two cents less than the statutory buy-back price. Wolfe, *supra* note 30. To facilitate comparisons, buy-back and selling prices are assumed to be the same.

74. The available literature contains no estimates of WECS lifetimes, and representatives of WECS-producing companies are unable or unwilling to supply this information. For the purposes of this analysis, a WECS lifetime of 15 years will suffice. If, of course, WECS prove to last significantly longer, this analysis will have been unduly pessimistic. Also, an interest rate of 15% is a somewhat arbitrary choice in an economy of rapidly changing borrowing costs. If money is significantly cheaper to borrow, investment in wind energy will be more attractive than indicated. Furthermore, a WECS exposed to a wind load factor greater than 0.15 has a present value proportionally greater than is stated. Thus, the figures derived in the text cannot be regarded as hard numbers; rather they are generalized approximations to be used for policy considerations. A particular individual who is interested in installing a WECS will make his decision only after considering the specific characteristics of his situation.

75. The Residential Energy Tax Credit reduces one's federal income taxes by an amount equal to 40% of one's solar, geothermal, and wind energy investments, up to $10,000. I.R.C. § 44C(b)(2) (1980).

For an individual homeowner, cost considerations alone do not justify investment in a WECS at present.[76] But, other factors such as a policy to increase the nation's energy self-sufficiency and WECS's minimal environmental impact may make residential WECS use desirable.[77] The government must provide additional economic incentives to bring about such a result.

2. *Neighborhood and Collective Systems*

On a larger scale, WECS can provide electricity to neighborhoods or small towns at a cost comparable with that of other energy sources. Utilities, cooperatives, and local governmental units could also utilize collective WECS[78] in conjunction with other generating systems.

Again assuming that an average American household consumes 1,000 kW-hr per month, the estimated cost of a wind energy device large enough to power 150 homes is $250,000, excluding installation costs.[79] Based on a fifteen year system life, a fifteen percent interest rate, and a 0.15 wind load factor, the system cost per month is about $3,500, or $0.16 per kW-hr,[80] approaching the $0.10 per kW-hr now charged for

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76. *But see Oversight—Wind Energy Program: Hearings Before the Subcomm. on Energy Development and Applications of the House Comm. on Science and Technology*, 96th Cong., 1st Sess. 9-10 (1979) (statement of Dr. Worth Bateman, Deputy Undersecretary, DOE): "The cost goal for the wind turbine varies by a factor of two depending on whether high or low demand surcharges for backup power and buy-sell rate structures are adopted. While this is partly a Federal matter, it is primarily a state level policy question. . . . If demand charges are low and buyback rates reasonable, a large market can be expected. If the converse occurs, market penetration will be slow."

77. *See, e.g.*, 42 U.S.C.A. § 9201(a)(6) (1980) (statement of findings that "the use of small wind energy systems for certain applications is already economically feasible . . . .").

78. In many areas of the country, cooperative or municipal power companies distribute power from the utility to consumers and could provide a convenient framework in which to establish windmill systems.

79. The machine upon which this analysis is based is a 200-kW Canadian-made Darrieus wind turbine. A 200-kW device available from a New York firm costs $200,000, without installation. UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 155.

As with individual home wind systems, the costs of medium-sized WECS vary. In addition, because such systems are not currently mass-produced, the purchase and installation costs are higher than they might be expected to become. *Id.* at 154-55; *see generally* CANNON, *supra* note 1, at 165-82. One author believes that lack of commercial development is the primary impediment to widespread WECS use. Merriam, *supra* note 5, at 51. Ronald B. Peterson, Chairman of the Board, Grumman Energy Systems, Inc., seems to be in agreement: "Our studies indicate that a production rate of 1,000 systems annually would allow us sufficient economies of scale so that we could provide the user with a wind turbine system that would cost approximately six cents per kilowatthour." *Energy Supply Act (Title X): Hearings on S. 1308 Before the Subcomm. on Energy and Nat. Resources of the Senate Comm. on Natural Resources*, 96th Cong., 1st Sess. 41 (1979).

80. A wind load factor of 0.15 is especially conservative for systems of this size; this figure has been used for consistency of analysis. Neighborhoods and collectives generally have a wider range of sites from which to choose than do individuals. They can more effectively maximize their WECS' wind load factors and thereby lower the cost of the energy generated.

electricity in some sections of the United States.[81] Because storage systems for wind devices of this size are not yet available,[82] a collective system using a wind device must depend upon a public utility for backup power in times of no wind. Requirements that utilities buy excess power generated by wind systems could partially offset this backup power cost.[83]

Mass production of the 200-kW machine analyzed here is expected to reduce its cost to $160,000.[84] Such production would therefore result in an even lower cost per kW-hr. The most optimistic estimates predict that systems large enough to power approximately seventy-five homes could be mass produced at a cost of only $10,000.[85]

3. Large-Scale Wind Projects

Large-scale wind projects refer to two configurations of WECS: the use of single large wind devices capable of producing several thousand kilowatts of electricity, and a large array of dispersed smaller wind devices. The latter configuration is called a wind farm.

The federal government,[86] utilities,[87] entrepreneurs,[88] and major manufacturing firms[89] have shown interest in the development and use of single large WECS. The federal government's program of wind development has focused on large rather than on small systems,[90] and some manufacturers interested in wind energy conversion have similarly limited their interest to large systems.[91] To date, utilities in California, Pennsylvania, and Oregon have purchased large wind systems and plan to feed the wind generated electricity into their existing power grids.[92] Southern California Edison, for example, is erecting a wind system in Palm Springs large enough to power approximately one thousand homes.[93] The contract price of the system is $350 per kW,[94] or $0.04 per kW-hr.[95]

81. *See* note 62 *supra.*

82. *See* J. KRENZ, *supra* note 14, at 284; *see also* Kahn, *The Compatibility of Wind and Solar Technology with Conventional Energy Systems,* 4 ANN. REV. ENERGY 313, 331-32 (1979).

83. *See* Gentry, *supra* note 71, at 297.

84. UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 155.

85. According to estimates by William E. Heronemus, 100-kW wind devices could be mass-produced at a cost of $100 per kW. *Id.* This figure, however, excludes the cost of the support and tower structures which usually contribute less than half of the total cost of a wind system. *Id.*

86. *See* Smith, *supra* note 9, at 739-41.

87. *Id.*

88. *Id.* at 741.

89. *See* CANNON, *supra* note 1, at 167, 170-80.

90. In 1977, from a wind energy budget of $21 million, only $2 million went toward small systems development. Metz, *supra* note 8, at 972. *See also* CANNON, *supra* note 1, at 167, 168; UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 151.

91. *See* CANNON, *supra* note 1, at 172-74.

92. Smith, *supra* note 9, at 739.

93. *Id. See also* note 114 *infra.*

94. UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 155.

95. Dollars per kW-hr can be derived from dollars per kW by comparing the one-time installation cost of a WECS measured in dollars per kW with the present value of the cost of conventionally generated electricity measured over the lifetime of the WECS.

Comparisons of this figure with the kW-hr costs of other forms of energy generation show that such large wind systems are cost-effective.[96]

The Department of Energy (DOE) is financing the construction of three 2.5-MW systems on the Oregon-Washington border which will feed into the power grid of the Bonneville Power Administration.[97] The project is expected to cost some $15 million.[98] Nevertheless, one manufacturer expects that the systems, once mass produced, will cost only $2 million each.[99]

Wind farms alone, according to one estimate, could supply well over fifty percent of the nation's energy needs.[100] Most wind farm proposals involve thousands of windmills spread out over hundreds of square miles,[101] but the wide range in possible prices for actual windmill sites[102] makes it difficult to predict the cost of a typical wind farm.

One private firm has constructed a small wind farm in New Hampshire composed of twenty 30-kW devices.[103] The firm, U.S. Windpower Associates, will sell the power it generates to the local utility for $0.077 per kW-hr, which is actually higher than the $0.05 per kW-hr average

96. *See also Wind Energy Systems Act Hearings, supra* note 45, at 201 (statement of Donald A. Beattie, Director, Energy Systems Division, Office of Aeronautics and Space Technology): "Based on our current cost projections, derived from designs now on the drawing boards, the cost of power from [2- to 3-MW] turbines—used in a fuel substitution mode—could be competitive with conventional systems by 1986." Furthermore, DOE estimates that advanced systems will be able to produce electricity for between one-and-a-half and six cents per kW-hr (in 1978 dollars) by the late 1980s. This range depends largely upon production scale and somewhat upon average windspeeds at installation sites. *Id.* at 196 (graph).

97. Smith, *supra* note 9, at 739-40.

98. *Id.*

99. Torrey, *supra* note 8, at 13. *See also Wind Energy Systems Act Hearings, supra* note 45, at 124-25 (statement of John Lowe, Boeing Engineering and Construction Co.): "Our studies show we need an assured market of about 200 large units to warrant commitment to the kind of production facilities required to get the cost down to competitive levels. . . . The point is that production capability is not the limitation."

100. McGowan, *supra* note 1, at 633.

101. One proposal, by W. Heronemus, calls for the installation of one 600-foot high wind machine per square mile across a 300,000 square mile area of the Great Plains. CLARK, *supra* note 2, at 548. The generating capacity of such an array would equal approximately half the 1971 electric generating capacity installed in the United States. *Id.*

According to NSF estimates, use of wind device arrays could result in a maximum yearly wind energy generation of 1.29×10^{12} kW-hr. J. KRENZ, *supra* note 14, at 284. This figure is about 75% of the nation's 1972 electric energy consumption. *Id.* About 780,000 60-meter wind devices would be required to produce this amount of energy. *Id.*

102. Unlike conventional generating sources such as hydroelectric reservoirs, windmills do not require purchase or condemnation of large parcels of land. Furthermore, the land around individual machines may often be left to its original use. *See* ENERGY ALTERNATIVES, *supra* note 41, at 11-19; Sørensen, *supra* note 27, at 44; UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 156. Because parcels acquired for a windmill array need not be contiguous as opposed to pipeline or highway construction, cooperation of all landowners in the area is not required for the project to proceed.

103. Wolfe, *supra* note 30. The horizontal WECS devices are on 60-foot towers, with three 40-foot fiberglass blades each. Onsite installation required just 70 days. The firm is investigating the possibility of similar installations in several states. *Id.*

selling price of that utility's electricity.[104] This suggests that at least small-scale wind farms can be relatively cost-competitive.

The existence of WECS do not, however, allow the utilities to reduce their total power generating capacities in the absence of feasible means of WECS energy storage. Utilities will continue to be required to meet all needs, including peak demands, during times that the wind does not blow.[105] The costs of maintaining two parallel generating systems may thus detract from the economic appeal of installing WECS on a utility-wide basis.

B. Technical Problems

Wind energy conversion systems are still hampered by technical problems, although significant improvements have recently been made on basic windmill technology. These technical problems affect both the economic viability and the social acceptability of wind power.

Storage. Wind energy conversion systems, like solar energy conversion systems, can only produce power when conditions are favorable. While a few parts of the United States have almost continuously blowing winds,[106] wind load factors of 0.15 to 0.25 are typical at most sites.[107] An individual user who depends solely upon a windmill for electricity will require equipment to store excess energy generated for use in times of little or no wind. Heavy, expensive lead-acid cells currently provide the only means for storage.[108] In addition, such cells are not well suited for powering large household appliances.[109] Meanwhile, the effectiveness of other storage means has yet to be proven.[110]

Backup Generation Capacity. Utility buy-back requires a more elaborate electric meter between the homeowner and the utility than is nor-

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104. *Id.*

105. If many windmills were attached to a utility power grid, it is possible that the price charged by the utility for electricity would increase. Power companies, like all regulated utilities, earn a fixed rate of return on investment. Kahn, *supra* note 82, at 346-47. The major part of this investment consists of the utilities' generation facilities, all of which would have to be maintained to satisfy peak demands on windless days—despite installation of windmills. Thus, while the amount of energy generated and sold by the utility decreased, the price per unit of utility-generated energy would increase to sustain the fixed rate of return. *Id.* But because utility companies are often able to resell power they buy from private sources to other customers, utilities may be able to reduce their own power production and thereby consume less fuel. *But see* Gentry, *supra* note 71, at 297.

106. Parts of the New England, Texas Gulf, and Pacific Northwest coasts, as well as sections of Alaska, the Great Lakes area, and the Great Plains, have been shown to have nearly continuously blowing winds. UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 146, 148.

107. ENERGY ALTERNATIVES, *supra* note 41, at 11-17. Wind load factors are defined in the text at note 69 *supra*.

108. J. KRENZ, *supra* note 14, at 284.

109. Lead-acid cells do not respond well to sudden large power demands. *Id.*

110. *Id.*

mally installed.[111] Some utilities have expressed concern that it would be difficult to prevent windmill-generated power from flowing into electrical lines under repair.[112] Any protective devices required by the utility would naturally add to the cost of an individual WECS.

Reliability. Manufacturers have developed small, yet reliable, wind energy conversion systems.[113] Although technical problems with large wind devices have interrupted or halted WECS service in the past,[114] progress has been made in the design and testing of reliable windmills of ever-increasing size.[115]

Audible Noise. The noise due to the WECS generator and the associated bearings and gears can be reduced far below even the most stringent standards.[116] The rotor blades themselves create sound because they move so quickly through the air,[117] but it is generally conceded that audible noise is not a serious problem with WECS.[118]

Infrasound. There is concern that large windmills may produce infrasound, that is, vibrations at frequencies so low as to be inaudible.[119]

111. In Massachusetts, customers who sell privately generated power back to the utility have a second meter installed to monitor current flowing the other way. Short, *supra* note 12. The Public Utilities Department has not yet set up standard rates for such metering, though one official believes that from the homeowner's point of view, the energy sold to the utility would not pay for the cost of the second meter. *Id.*

112. CANNON, *supra* note 1, at 170. *But see* Gentry, *supra* note 71, at 297.

113. S. SCHURR, *supra* note 9, at 312.

114. A variety of problems has arisen with large windmills. A 100-kW machine built by NASA near Cleveland, Ohio, developed such "severe forced oscillations and unexpected impulse loads on the propeller" that it operated for only fifty-seven hours in its first eight months of use. Metz, *supra* note 8, at 971. "The 200-kW machine built by Lockheed Corporation . . . at Clayton, New Mexico, revealed three 1- to 2-inch cracks on the leading edge of the 125-foot diameter blades after 1,000 hours of operation. Over-machining of the blades was the apparent cause, and replacements [were] installed." S. SCHURR, *supra* note 9, at 312 (footnotes omitted).

On April 3, 1981, a malfunctioning starter motor on one of Southern California Edison Co.'s experimental windmills caused the device to collapse. Wall St. J., Apr. 6, 1981, at 3, col. 5. A blade of the 139-foot tall structure broke loose and cut a supporting guy wire; no injuries were reported. *Id. See also* text at note 93 *supra*. Probably the most spectacular accident was the loss of the 1-MW windmill built by Palmer Putnam on Grandpa's Knob, Vt., in the 1930s. On March 26, 1945, the spar for one of the whirling blades suddenly broke, and an entire 65-foot blade landed some 750 feet away. McCaull, *supra* note 2, at 225.

115. U.S. Windpower Associates, for instance, is confident of the reliability of its 30-kW machines, and is using its experience to develop a 50-kW device. Wolfe, *supra* note 30.

116. Sørensen, *supra* note 27, at 44. The high frequency whine from the generator of one type of windmill is said to be inaudible at fifty feet. R. Taubenfeld & H. Taubenfeld, *Wind Energy: Legal Issues and Legal Barriers*, 31 Sw. L.J. 1053, 1070 (1977) [hereinafter cited as Taubenfeld].

117. Some blade tips move as fast as 200 miles per hour. Taubenfeld, *supra* note 116, at 1070. It has been reported that if the tip velocity is below 100 meters per second (about 215 miles per hour), the audible noise from the blades is not a problem. Sørensen, *supra* note 27, at 44.

118. CANNON, *supra* note 1, at 166; Sørensen, *supra* note 27, at 44; Taubenfeld, *supra* note 116, at 1070.

119. Sørensen, *supra* note 27, at 44; Taubenfeld, *supra* note 116, at 1070.

Little is known about the effects of infrasound waves, although it is reported that they may affect persons or property.[120] One writer suggests that turbulence will readily dissipate such waves quickly so that infrasound will affect only a very limited area.[121] Since the infrasound waves occur only in the wake of the windmill,[122] one solution is to site large windmills such that no one will be in the path of the wake.

Television Interference. Stationary structures can cause television interference, an inconvenience which has usually been borne by television viewers.[123] In addition to the interference caused by the stationary WECS structure, the moving blades of the rotor may vibrate in synchronization with television signals to produce serious interference.[124] Large WECS, however, are not expected to be sited near housing areas,[125] and small systems have increasingly employed wooden and fiberglass blades[126] which do not interfere with electromagnetic television signals.[127] Thus, WECS are not likely to substantially impair television reception.

C. Environmental Costs

The environmental impacts of wind energy use are minimal in comparison to those of conventional methods of power generation.[128] Furthermore, WECS cannot produce the possible catastrophic effects of a nuclear power plant failure or a hydroelectric dam break, although wind energy devices may cause some damage in their immediate vicinity.[129]

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120. Taubenfeld, *supra* note 116, at 1070. These effects are car sickness and physiological damage. *Id.*

121. Sørensen, *supra* note 27, at 45.

122. *Id.* at 44. The wake of a windmill is downwind.

123. *See, e.g.*, People v. Sears, Roebuck & Co., 52 Ill. 2d 301, 287 N.E.2d 677 (1972), *cert. denied*, 409 U.S. 1001 (1972).

124. Taubenfeld, *supra* note 116, at 1075.

125. Sørensen, *supra* note 27, at 45.

126. Wolfe, *supra* note 30; Battle, *supra* note 29.

127. Taubenfeld, *supra* note 116, at 1075.

128. UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 156-57. Wind energy conversion requires no direct use of fossil fuel and does not degrade air or water quality through emissions. CANNON, *supra* note 1, at 166.

Both noise and interference with bird migration have been cited as potential environmental problems of WECS. *See* UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 156; CANNON, *supra* note 1, at 166. The whirling of the WECS blades may also be dangerous to birds and insects. Holdren, *supra* note 21, at 253. Noise problems of those WECS constructed and operated have been minimal, however, and there is no documentation that WECS have interfered with bird migration. In any case, WECS "whining need be no more bothersome than that of other machines," Torrey, *supra* note 8, at 13, while the danger posed to migrating birds is inconsequential when compared to other sources of bird mortality. UNION OF CONCERNED SCIENTISTS, *supra* note 6, at 156.

129. *See* Holdren, *supra* note 21, at 271. Windmill catastrophes, including broken blades thrown from the device, *see* note 114 *supra*, and fallen support structures, are confined to a small area, and do not have long-lasting effects. By comparison, release of radiation by a nuclear plant in a serious accident could cause destruction over a large land area, due to dispersal of radiation. This land could remain contaminated for years. *See*

The short-term environmental concern of aesthetic damage, that is, unsightly machines in scenic or residential environments,[130] is one that exists with the siting of any power generation facility. This problem can be resolved either by deciding that the power source gained is worth more than the aesthetic loss, or by siting the facility in an area with a low population density.[131] With regard to wind energy, aesthetic considerations would probably lead to WECS sites at places other than those with the strongest winds: the windiest sites are often on scenic mountain ridges or coastal promontories where aesthetic impact would be considered severe.[132]

The major environmental unknown associated with wind energy utilization is that of potential climate or weather modification. Though it is unlikely, small land-based arrays of wind devices might disrupt wind flow patterns sufficiently to cause changes in local or regional ground weather,[133] whereas large-scale wind energy utilization on the planet could have significant and serious effects on climate.[134] Until more is known about climate and weather formation, however, one cannot determine precisely how much wind energy can be taken from the atmosphere without causing unacceptable environmental harm.[135] Certainly, in relatively small amounts, wind power extraction is environmentally preferable to fossil fuel utilization. Serious weather modification problems like those associated with fossil fuels[136] have not yet been linked to WECS.

Offsite environmental effects of WECS include those associated with the mining and processing of metals and other materials used in WECS construction,[137] but such effects are present in the construction of any power generating facility. In addition, because WECS use no mined fuels, the offsite costs are one-time costs, as compared to the continuous fuel extraction expenses incurred by most conventional power plants.[138] Land-use impacts of even large arrays of WECS are not severe.[139] Wind-

J. Krenz, *supra* note 14, at 173-75. In addition, it has been estimated that a large dam break has a 50% chance of causing 10,000 deaths. *See* Holdren, *supra* note 21, at 271.

130. *See* Cannon, *supra* note 1, at 166; Energy Alternatives, *supra* note 41, at 11-19.

131. Holdren, *supra* note 21, at 253. One study claims that it may be possible to place WECS in areas of low population density and to transmit the generated electricity to population centers through the existing power grid. Energy Alternatives, *supra* note 41, at 11-19.

132. Energy Alternatives, *supra* note 41, at 11-19.

133. McGowan, *supra* note 1, at 648.

134. Gustavson, *supra* note 16, at 13-15. One commentator argues that these consequences could be avoided by limiting the amount of wind energy used. *Id. See also* Union of Concerned Scientists, *supra* note 6, at 156; McGowan, *supra* note 1, at 648-49; Sørensen, *supra* note 27, at 45.

135. Gustavson, *supra* note 16, at 13-15.

136. *See* Holdren, *supra* note 21, at 277-78.

137. McGowan, *supra* note 1, at 648.

138. Of course, hydroelectric dams do not incur any fuel extraction costs either.

139. Union of Concerned Scientists, *supra* note 6, at 156.

mill structures actually occupy only a small amount of land and do not preclude the possibility of other land uses such as agriculture.[140] To this extent, WECS are similar to electric transmission towers: land under such towers is often used for agriculture or recreation.[141]

D. Legal and Regulatory Issues

Several recent federal actions are designed to encourage WECS investment and research. The Public Utilities Regulatory Policies Act (PURPA)[142] and associated regulations[143] require electric utilities to purchase electric power from, and sell electric power to, qualifying small power generation facilities, including windmill operators.[144] The Residential Energy Tax Credit[145] allows up to forty percent of the cost of a residential WECS to be credited against federal income taxes.[146] This has the effect of reducing the after-tax cost of a WECS by forty percent, which provides further incentive for residential WECS investment.

The Wind Energy Systems Act of 1980[147] was signed by former President Carter on September 8, 1980. The conference committee report on the bill states that the "policy of the United States and the purpose of the legislation are to establish an aggressive eight-year program of research, development, demonstration and technology application of the conversion of wind energy to electricity or mechanical power."[148] The Act authorizes the Secretary of Energy to "use various forms of Federal assistance including, but not limited to—(1) contracts and cooperative agreements; (2) grants; (3) loans; and (4) direct Federal procurement."[149] It directs the Secretary to establish procedures to allow any individual or public or private entity to apply for and receive direct grants for WECS.[150] The particular system applied for must have a capacity of more

140. Holdren, *supra* note 21, at 258. The land actually occupied by a WECS is comparable to that covered by the base of a transmission tower.

141. *Id.*

142. 16 U.S.C. §§ 2601-2645 (1979).

143. 18 C.F.R. § 292 (1980), *as amended by* 45 Fed. Reg. 12,214 (1980) *and* 45 Fed. Reg. 17,959 (1980).

144. PURPA provides an incentive to homeowners to install WECS, and encourages private construction of wind farms. But utilities can often undercut the Act's provisions. *See* Gentry, *supra* note 71, at 297.

145. I.R.C. § 44C (1980).

146. In its originally enacted form, the code allowed a tax credit of 30% of expenditures up to $2,000, and 20% of the next $8,000 of expenditures. I.R.C. § 44C(b)(2) (1979). The Windfall Profits Tax Act increased the credit to 40% for all qualifying expenditures up to a $10,000 ceiling. Pub. L. No. 96-223, 94 Stat. 256, 258 (codified at I.R.C. § 44C(b)(2) (1980)).

147. 42 U.S.C.A. §§ 9201-9213 (West Supp. 1980).

148. H. CONF. REP. No. 96-1217, 96th Cong., 2d Sess. 11 (1980) [hereinafter cited as CONFERENCE REPORT].

149. 42 U.S.C.A. § 9205(c) (West Supp. 1980).

150. *Id.* § 9205(e).

than 100 kW.[151] The grants are to total not more than fifty percent of the system's cost during the first six years of the eight-year program, and not more than twenty-five percent during the seventh or eighth year of the program.[152] The Secretary is also directed to make loans available to individuals and public and private entities for up to seventy-five percent of the purchase and installation costs of wind energy systems which provide an aggregate of up to 320-MW peak generating capacity and involve a minimum of four projects.[153]

According to the Act, the Secretary is to initiate a three-year national wind resource assessment program.[154] The program will provide for validation of existing assessments of known wind resources, performance of future wind resource assessments, initiation of a general site prospecting program, establishment of standard wind data collection and siting techniques, and establishment of a national wind data center.[155] In addition, the Secretary is directed to study and plan for wind energy system use at the facilities of many federal government agencies.[156]

The Act authorizes congressional appropriations of $100 million for fiscal 1981,[157] and the total spending over the eight years of the program is estimated to be $891 million.[158] This total is divided: $186 million for small systems,[159] $675 million for large systems,[160] and $30 million for wind resource assessment.[161] Congress has not, however, appropriated any funds to DOE under this Act.[162]

Once WECS are in widespread use, potential purchasers will benefit if comparisons of the safety and performance characteristics of various systems can be made.[163] DOE has promulgated requirements for WECS installer and inspector certification and WECS safety and performance standards.[164] On the state level, the actions of public utility commissions have an impact on potential WECS users. PURPA requires states to promulgate rules regarding both interconnections between WECS and

151. *Id.*
152. *Id.*
153. *Id.* § 9205(f)(1).
154. *Id.* § 9206.
155. *Id.* § 9210(1).
156. *Id.*
157. *Id.* § 9213(a)(1).
158. *See* CONFERENCE REPORT, *supra* note 148, at 13.
159. *Id.*
160. *Id.*
161. *Id.*
162. Telephone interview with Page Rosenblatt, Off. of Consumer Affairs, DOE, Boston, Mass. (Feb. 17, 1981).
163. With or without government regulation, private firms may choose to provide safety and performance information. For example, Underwriter's Laboratories tests appliances for electrical safety, and Consumers Union of Mount Vernon, N.Y., compares the performance of appliances.
164. *See* Standards for Wind Energy Devices, 45 Fed. Reg. 63,432 (1980) (to be codified in 10 C.F.R. § 456.705).

the power grid, and utility buy-back of power from WECS.[165] On the local level, the most frequent barriers to WECS installation are zoning restrictions.[166] Height, setback, and aesthetic requirements often inhibit WECS construction.[167] Rapid development of aesthetically pleasing WECS would be favored by even-handed application of zoning laws.[168]

III. CONCLUSIONS

Wind energy conversion systems, although technically feasible at all levels, are clearly cost-effective only for the largest systems capable of supplying many consumers with electric power. The environmental benefits of WECS over conventional fuel utilization may provide the ultimate incentive for construction of nearly cost-effective systems for neighborhoods or collectives, but WECS designed for the individual consumer demand too large an investment in conversion and storage devices to be economically attractive.

Energy self-sufficiency, decreased environmental impact, and restrained use of nonrenewable resources are all factors suggesting that further deployment of WECS would be beneficial to society as a whole. Appropriate application of grants and incentives for WECS research, development, and construction can overcome the technological and economic barriers to widespread WECS utilization.

165. 45 Fed. Reg. 12,214 (1980). *See generally* Gentry, *supra* note 71, at 297.
166. Taubenfeld, *supra* note 116, at 1057.
167. *Id.* at 1058.
168. *Id.* at 1059.