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Environmental Assessment of Small Wind Systems: Progress Report

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SERI

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A Division of Midwest Research Institute

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ENVIRONMENTAL ASSESSMENT OF SMALL WIND SYSTEMS: PROGRESS REPORT

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PREPARED UNDER TASK NO. 3531.39

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FOREWORD

This progress report is the first formal product of the Environmental Assessment of Small Wind Energy Conversion Systems (SWECS) study. It presents an overview of the study's structure, planned activities, and a synopsis of task progress to date.

This report was prepared as part of Task No. 5322 in the Institutional and Environmental Assessment Branch of the Solar Energy Research Institute (SERI). The authors gratefully acknowledge the assistance provided by Fred Perkins of SERI's Systems Analysis Branch, and by the Rocky Flats Wind Systems Group, Boulder, Colorado.

Approved for:

SOLAR ENERGY RESEARCH INSTITUTE

Robert Odland

Robert Odland, Chief
Institutional and Environmental
Assessment Branch

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SECTION 1.0

INTRODUCTION

Until recently, most U.S. Department of Energy (DOE) supported research on the environmental effects of wind energy conversion systems (WECS) has focused on medium- to large-size machines (rated power of 100 kW or above) that are amenable for use in the utility grid system. This DOE program has been expanded to include the environmental effects of small WECS (SWECS), generally rated at less than 100 kW.

The main objective of this SERI study is to identify and quantify, as much as possible, potential environmental effects associated with SWECS. A second objective is to identify where additional environmental research for SWECS is needed (and where it is not needed). Achieving these objectives will help ensure that SWECS development proceeds in an environmentally acceptable manner.

Progress made toward obtaining these task objectives is summarized in this report. Section 2.0 presents a description of the overall study structure. Substantive progress toward assessing the environmental effects of manufacturing SWECS is summarized in Section 3.0. Initial estimates of air emissions associated with SWECS production are also included. The "environmental effects" classification has been defined rather inclusively for purposes of this study; it encompasses health and ecological effects, electromagnetic interference, noise, and aesthetic (visual) acceptability. SERI designed a pilot survey of aesthetics which has been distributed at the Rocky Flats Wind Test Site. Section 4.0 presents a synopsis of past WECS aesthetic research, SERI's aesthetic acceptability survey, and a brief description of expected results. A literature review of past WECS environmental research is provided in Section 5.0. Critical information gaps in applying past environmental research to SWECS are discussed, and planned SERI activities to fill information gaps are outlined.

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SECTION 2.0

ENVIRONMENTAL ASSESSMENT OF SWECS: STUDY STRUCTURE

A broad interpretation of effects of SWECS on the environment has been utilized for this study. Environmental effects are defined to include three basic categories: (1) electromagnetic (EM) interference and noise impacts, (2) aesthetic (visual) acceptability, and (3) health and ecological effects.

Generic machine designs (see Sec. 3.0) and end-use applications were selected for study. SWECS with power ratings of 2 kW and 8 kW were specified for rural residential use, and a SWECS rated at 40 kW was specified for a commerical application. Estimates of EM interference and noise levels associated with the 2-, 8-, and 40-kW SWECS designs will be based on literature reviews and contacts with the Rocky Flats Wind Systems Group, Sandia Laboratories, and others.

At the request of DOE, SERI supported the preparation of a color videocassette describing potential television interference by the 200-kW WECS on Block Island, Rhode Island. Preparation of this film was completed in early June 1979; it was shown at the September 1979 Block Island town meeting. In addition, the videocassette has proved to be a useful tool for the Blue Ridge Cooperative management in understanding the characteristics of television interference which may be encountered with WECS in Boone, North Carolina.

A potentially important factor in deploying SWECS, particularly in populated areas, is visual acceptability. SERI is conducting a nonrandom pilot field study to determine whether visual appearance of SWECS is a factor in a potential purchaser's decision process and, if so, whether certain rotor and tower design configurations are more desirable than others. As a prelude to development of the pilot survey, an in-depth review of past WECS aesthetics research was performed and researchers active in the field were contacted. The aesthetics survey and background literature reviews are presented in Sec. 4.0.

The third major environmental category comprises health and ecological effects. A life-cycle approach to health and ecological effects identification is being utilized. The life-cycle is divided into four phases: (1) materials acquisition and processing, (2) system production and assembly, (3) system operation and maintenance, and (4) system decommission and component disposal or recycling.

All phases of the life-cycle will involve occupational and public health plus ecological effects. For purposes of this study, occupational health effects are defined as primarily direct, and public health effects are primarily indirect. Ecological effects from SWECS manufacture and decommission are defined as indirect, while those associated with operation are direct. Direct health effects of the selected SWECS designs deployed under the two deployment options are being identified and quantified where possible. The materials required for fabrication of the SWECS designs were determined through tabulation of data developed under contracts funded by the Rocky Flats Wind Systems Group (see Sec. 3.0). Following quantification of materials requirements, the labor hours necessary per ton of material mined and processed will be tabulated. Incidences of illness, accident, injury, and death per labor hour required in each material industry will be obtained from published industry statistics (e.g., Dept. of Labor 1978). Direct occupational health risks then will be calculated by applying industry statistics to the materials requirement tabulations. Determination of labor requirements necessary for operation and maintenance of SWECS will be based on results of recent SERI research on the quantitative labor aspects of solar energy technologies (Burns et al. 1979).

Additional direct health effects, and the indirect occupational and public life-cycle health effects possible under the selected SWECS deployment options, will be identified by examining the emissions and effluents released during manufacture and operation. Emission factors (e.g., pounds of particulates released per ton of steel processed) will be obtained from recent EPA publications and other selected sources (EPA 1977; EPA 1978; Sittig 1975). The health implications of major emission categories will be determined based on synthesis of published research (NAS 1977). Also, rotor safety during SWECS operation will be considered.

Noise emitted from the operation of the wind turbine and associated equipment will affect on-site SWECS personnel and, possibly, nearby residents. Data on noise levels will be obtained through literature review and from field-monitoring studies (if data are available) of selected WECS and SWECS that are funded and supervised by SERI's Systems Analysis Branch. The health and ecological implications of SWECS operational noise will be assessed briefly, based on literature reviews and contacts with noise research teams.

Evaluation of ecological effects will cover land use, air and water quality, and impacts on biota. Factors included under land use are quantification of land use for placement of SWECS towers and other attendant facilities; a brief examination of SWECS land use (both amounts and permanence of land alterations) compared with other energy options; and land reclamation and land use for waste disposal following SWECS decommission. Consideration of the air and water quality categories will include both direct and indirect effects. Estimation of indirect effects will be based on the air and water emissions associated with production of SWECS units. Water degradation from soil erosion and run-off will be considered for the construction, operation, and decommission phases. Also to be assessed are the effects of SWECS land use on local plant and animal communi-ties. The extent of these and other effects will depend on SWECS design, location, and size. Potential impacts include habitat alteration or destruction, release of toxic substances throughout the life-cycle of the system, and effects of rotor blades.

A necessary first step in the in-depth examination of SWECS environmental effects is developing a critical awareness of past research results. A literature review was performed for each of the environmental effects categories. Results of this effort are summarized in Sec. 5.0.

SECTION 3.0

GENERIC SWECS DESIGNS

Tabulation of the materials required for fabrication of a SWECS is a critical first step in a life-cycle environmental assessment. Material quantities form the data base upon which estimates of direct and indirect health and ecological impacts of system manufacture are made.

The power ratings of SWECS cover a rather broad range; i.e., all machines considered to be small systems are rated at 100 kW or less. Assessment of all machines within this range would probably provide less detailed information and results than in-depth analysis of several representative SWECS and is beyond the scope of this study. Based on this hypothesis, the task team conducted several late spring 1979 meetings with personnel from SERI's Systems Analysis Branch, contacted individuals in other organizations, and performed a literature review to select SWECS designs and end-use applications. Three machine sizes and two end-use applications were selected: 2- and 8-kW SWECS providing electricity to a rural residential application and 40-kW units providing electricity for a small commercial user.

Specific data on materials required for fabrication of machines of the above sizes were provided by the Rocky Flats Wind Systems Group of Rockwell International. A meeting coordinated by Irwin Vas of SERI and Dick Williams of Rockwell was held in August 1979 at SERI. Specific data requirements and intended use of data were discussed. Bill Briggs of Rockwell compiled fabrication materials data for nine SWECS design options. Table 3-1 displays the data.

Based on these materials amounts, SERI calculated the pollutant releases associated with mining and processing the materials necessary for fabrication of each SWECS design. The estimation of SWECS production emissions involved three basic steps. First, materials estimates were gathered for each SWECS design (performed by Rockwell personnel). Second, emission factors (e.g., pounds of particulates released per ton of steel processed) were tabulated for industries processing the materials required for SWECS fabrication. Two factors were used for each industry: a factor representing emissions from a processing facility that employs no pollution abatement, and a factor representing emissions from a facility equipped with the best available control technology. Third, the emission factors were applied to the materials estimates compiled in the first step. Results are shown in Tables 3-2 through 3-4.

Discrete emission estimates will not be used for the health and ecological assessments in the final report. SWECS options shown in Table 3-1 undoubtedly will undergo design changes before they are deployed in large numbers. These design changes probably will affect the amounts of specific materials required for machine manufacture. Therefore, the environmental analysis of SWECS will utilize a range of pollutant emissions for each power rating category. The ranges will be based on data given in Tables 3-2 through 3-4 and should encompass emissions from producing a number of SWECS design options within power rating categories.

Analysis of emissions from SWECS production will be performed during October and November 1979 and will be reported in the final report. Incidence of injury, illness, and death for the materials industries will be tabulated from industry statistics (e.g., Dept. of Labor 1978) and used to estimate direct occupational health impacts. The labor hours

TABLE 3-1. SWECS MATERIALS REQUIREMENTS[a]

Design	Avg kWh at V = 12 mph	14 mph	16 mph	Output Type	lb/SWECS Unit: High Grade Steel	Low Alloy Steel	Aluminum	Fiberglass Wrapped Plastic	Wood	Concrete	Copper
1 kW / 1 kW, VAWT											
3 blades	1,700	2,450	3,150	24 VDC							
Rotor/Generator					33	301	162				40
Tower						900					
Foundation						160				36,530	
2 kW / 2 kW, HAWT											
3 blades, upwind	4,900	6,900	8,550	24 VDC							
Rotor/Generator					40	365	175		27		40
Tower						700					
Foundation						150				9,520	
2 kW, HAWT											
2 blades, downwind	7,000	10,300	12,600	24 VDC							
Rotor/Generator					40	270		27	44		40
Tower						825					
Foundation						150				9,520	

TABLE 3-1. SWECS MATERIALS REQUIREMENTS[a] (continued)

Design	Avg kWh at V = 12 mph	14 mph	16 mph	Output Type	lb/SWECS Unit: High Grade Steel	Low Alloy Steel	Aluminum	Fiberglass Wrapped Plastic	Wood	Concrete	Copper
8 kW											
8 kW, HAWT											
2 blades, downwind	25,000	37,000	48,000	220 VAC							
Rotor/Generator				1 or 3 ϕ	143	1,287	20	350			70
Tower						2,470					
Foundation						3,172				14,330	
8 kW, HAWT											
3 blades, downwind	24,000	34,000	36,500	220 VAC 1 ϕ							
Rotor/Generator					116	1,040	390	15			80
Tower						1,860					
Foundation						245				23,900	30, Samarium/Cobalt Magnets
8 kW, HAWT											
3 blades, downwind	35,000	50,000	62,500	220 VAC 1 or 3 ϕ							
Rotor/Generator					253	2,280	500				70
Tower						2,621					
Foundation						245				23,900	
8 kW, VAWT											
3 blades	31,000	47,000	63,000	460 VAC							
Rotor/Generator				3 ϕ							70
Tower					670	12,790	1,116				
Foundation						4,200				406,500	

TABLE 3-1. SWECS MATERIALS REQUIREMENTS[a] (concluded)

Design	Avg kWh at V = 12 mph	14 mph	16 mph	Output Type	lb/SWECS Unit High Grade Steel	Low Alloy Steel	Aluminum	Fiberglass Wrapped Plaxtic	Wood	Concrete	Copper
40 kW											
40 kW, HAWT 2 blades, downwind	121,330	157,000	187,000	480 VAC 3 ø							
Rotor/Generator					640	5,760		1030			100
Tower						4,000					
Foundation						2,580				166,870	
40 kW, VAWT 3 blades	105,900	150,000	175,000 3 ø	480 VAC							
Rotor/Generator					945	8,505	1,050				100
Tower						7,900					
Foundation						356				62,000	

[a]Source: Bill Briggs, Rocky Flats Wind Systems Group. Boulder, Colorado, September 1979.

Legend: HAWT = horizontal axis wind turbine
VAWT = vertical axis wind turbine
VDC = voltage direct current
VAC = voltage alternating current
ø = phase
kWh = kilowatt hours
V = wind velocity

TABLE 3-2. PRODUCTION EMISSIONS FOR 2-kW SWECS[a]

Design	lb of Pollutant per 2-kW Unit									
	Particulates		SO_x		NO_x	CO	HF		Particulate Fluorides	
	NC[b]	BACT	NC	BACT	NC[c]	NC[c]	NC	BACT	NC	BACT
HAWT, 3-blade, upwind	480.2	3.6	109.2	14.6	2.4	1,161.3	2.3	neg[d]	2.2	neg
HAWT, 2-blade, downwind	456.4	3.0	109.3	14.6	0.6	1,179.7	neg	neg	0.4	neg

[a]SERI estimates based on data in Table 3-1 and U.S. EPA 1977; U.S. EPA 1978; and Sittig 1975.

[b]NC = no pollution control; BACT = best available control technology.

[c]Emission factor for controlled conditions was not available.

[d]Neg = negligible, emissions less than 0.1 lb.

TABLE 3-3. PRODUCTION EMISSIONS FOR 8-kW SWECS[a]

Design	lb of Pollutant per 8-kW Unit									
	Particulates		SO_x		NO_x	CO	HF		Particulate Fluorides	
	NC[b]	BACT	NC	BACT	NC[c]	NC[c]	NC	BACT	NC	BACT
HAWT, 2 blade, downwind	1,277.6	10.2	189.4	24.4	9.8	126.84	0.4	neg[d]	4.7	neg
HAWT, 3 blade, downwind	450.2	5.4	202.4	21.1	3.5	3,003.8	neg	neg	1.2	neg
HAWT, 3 blade, downwind	1,465.5	10.7	198.1	29.0	6.4	4,974.6	6.5	0.1	6.8	0.1
VAWT, 3 blade, Darrieus	15,197.1	51.9	564.9	212.4	101.1	16,272.0	14.6	0.1	17.1	0.3

[a]SERI estimates based on data in Table 3-2 and U.S. EPA 1977; U.S. EPA 1978; and Sittig 1975.

[b]NC = no pollution control; BACT = best available control technology.

[c]Emission factor for controlled conditions was not available.

[d]Neg = negligible, emissions less than 0.1 lb.

TABLE 3-4. PRODUCTION EMISSIONS FOR 40-kW SWECS[a]

Design	lb of Pollutant per 40-kW Unit										
	Particulates		SO_x		NO_x	CO	HF		Particulate Fluorides		
	NC[b]	BACT	NC	BACT	NC[c]	NC[c]	NC	BACT	NC	BACT	
HAWT, 2 blade, downwind	6,811.0	27.0	410.1	104.9	15.2	11,960.0	0.2	neg[d]	4.8	0.1	
VAWT, 3 blade, giroblade	4,130.0	28.4	309.6	54.7	42.4	16,307.7	13.9	0.1	16.5	0.3	

[a]SERI estimates based on data in Table 3-1 and U.S. EPA 1977; U.S. EPA 1978; and Sittig 1975.

[b]NC = no pollution control; BACT = best available control technology.

[c]Emission factor for controlled conditions was not available.

[d]Neg = negligible, emissions less than 0.1 lb.

necessary for SWECS assembly and maintenance will be extracted from a SERI research project (Burns et al. 1979). Additional evaluations of occupational health impacts will be based on these numbers. The task team also will evaluate the ecological implications of SWECS production emissions. All analyses of health and ecological impacts will include consideration of whether emissions are amenable to control and permanence of emission impacts (e.g., long-term water degradation due to toxic effluents versus the temporary degradation associated with site preparation). Finally, estimates of health and ecological impacts of SWECS production emissions will be combined with operation, maintenance, and disposal impacts to appraise life-cycle impacts.

SECTION 4.0

PILOT FIELD STUDY OF AESTHETICS

Small wind energy conversion systems (SWECS) are any machines with a theoretical maximum output of 100 kW or less. Currently, more than 30 manufacturers produce commercially available versions of SWECS (AWEA 1978). Unfortunately, the availability of cheaper utility-grid power and the lack of adequate wind regime data appear to be major barriers to the widespread use of electricity-producing SWECS. Public acceptance is another potential problem of SWECS deployment.

4.1 LITERATURE REVIEW

Public acceptance refers to "the level of positive attitudes some aggregate of people hold toward an idea or judgment" (Coty 1976). Some recent legal cases (Solar Law Reporter 1:2; 1979) relating to public acceptance involve individuals who proposed construction of SWECS in residential communities. For example, in Mechanicsburg, Pennsylvania, local ordinances prevented a resident from erecting a SWECS on his property after neighbors circulated a petition stating the proposed structure was aesthetically objectionable. Another person was denied permission to construct a SWECS in Hanover, New Hampshire, by the Hanover Zoning Board of Adjustment. Neighbors again protested that the windmill would be aesthetically displeasing. These two cases form a basis for the assumption that aesthetics could influence public acceptance of SWECS.

Furthermore, a study concerning legal and institutional implications of WECS concludes that windpower might suffer from certain public perceptions, one of which is aesthetic objections (George Washington University 1977). According to a U.S. Department of Interior study, the aesthetic element of design may be important in the widespread use of wind machines, especially in scenic areas (Howell 1979). In an environmental issue assessment of wind energy, it is stated that wind energy conversion systems could represent a significant new element in the visual landscape under projected deployment goals (EEA 1979). In general, various studies concur that the issue of "visual pollution" of the landscape is possible in windmill siting, and the larger the array of wind machines, the greater the potential of visual impact (Labuszewski 1977; SAI 1976; Coit 1979; Lindley 1977). Supporting this potential issue, the U.S. Department of Energy (DOE) expressed concern over the aesthetics of wind machines. In the Environmental Development Plan for Wind Energy Conversion, DOE states, "Research is needed to further define public aesthetic reactions to wind energy systems and to identify unacceptable configurations and locations" (DOE 1978c).

Because of a lack of data on this potentially important issue, the Institutional and Environmental Assessment branch of SERI has undertaken a pilot study of the aesthetic appearance of SWECS. This study uses the Rocky Flats Wind Systems Test Center as a site for the sampling of public opinion to determine visual acceptance of SWECS and what design configurations, if any, are visually preferred among the commercially available models under study at Rocky Flats.

A detailed literature search on four computerized data bases was performed to identify past WECS-aesthetics research. A number of references were located, but only one report dealt in depth with WECS visual impacts. The report was authored by Robert Ferber from Survey Research Laboratory who conducted a random sample survey across the United States (SRL 1977). One of Ferber's primary objectives was to gather information on public acceptance of various wind machine designs deployed in different environmental settings. Individuals surveyed were asked to give their reactions to color slides of various types of windmills built in different geographical sites. Six different windmill designs were chosen and illustrated in flatlands, rolling hills, or shoreline settings. Three of these six designs were horizontal-axis machines. One was mounted on a steel-truss tower, one was mounted on a columnar tower, and the third was supported on a "Dutch motif" tower. The other three designs were a Giromill, a Darrieus machine, and an antiquated "Dutch" style windmill. Of all the possible combinations of design and location, 12 slides were selected to show to respondents (SRL 1977, Appendix A). Respondents were asked to rate the appearance of the machines according to the following scale: very pleasing, somewhat pleasing, not too pleasing, not at all pleasing, or don't know (SRL 1977, Appendix C, Part 1, p. 8). Table 4-1 shows the percentage of total respondents who gave positive responses (very pleasing or somewhat pleasing) to the various pictures. The range of positive opinion toward the machines indicates that the respondents showed a definite preference for some machine designs over others. On the other hand, there appears to be little difference in preference among locations for any particular machine.

TABLE 4-1. FAVORABLE RESPONSES TO WIND MACHINE DESIGNS[a]

	Tower Design[b]			Rotor Design		
Setting	Lattice Tower	Columnar Tower	Dutch Tower	Dutch	Darrieus	Giromill
Flatlands	74[c]	73			66	41
Rolling Hills		74	86	84	65	
Shoreline	70		83	89		40

[a]Source: SRL 1977.

[b]All tower designs were shown with horizontal axis rotors.

[c]Percentage of total respondents who gave a favorable rating to various wind machines.

The machines favored in Ferber's study—Dutch style and horizontal axis on a Dutch tower—both incorporate the antiquated Dutch design. Some of these Dutch windmills were designed to provide shelter while grinding grain, hence the large enclosed towers. However, current technology does not incorporate the Dutch design. The other machines pictured in the slides are far more representative of current technology. The horizontal-axis machine and the Darrieus machine, both current technologies, were viewed favorably by a majority of respondents. However, the Giromill was viewed as favorable by less than half of the respondents and as visually less acceptable, compared with the other machines.

There appeared to be little variation in locational preference for any single windmill design. The favorable response variation for different locations was greatest for the Dutch design (84% for rolling hills vs. 89% for shoreline) and negligible for the Darrieus and Giromill designs. This slight variability in locational preference implies that the setting of the windmill has little influence on the overall appearance of the picture.

However, in a separate question regarding site location, one of four respondents objected to locating windmills along a shoreline (SRL 1977, p. 67). It should be emphasized, however, that the respondents were viewing color slides, not actual machines.

Ferber realized the constraints of using photographs and slides to assess public acceptance and, therefore, surveyed visitors at the Sandy Hook Unit of the Gateway National Recreation Area in New Jersey (SRL 1977, pp. 94-105). During a one-season span, visitors to the area were asked to give their impressions of several windmill pictures. The following season, an actual wind machine (three-bladed, horizontal-axis, steel-lattice tower) was erected on the site. After viewing the machine, visitors were asked again to respond to pictures showing potential windmill deployment sites. Before and after construction of the windmill, the respondents showed virtually no difference (18% before vs. 17% after) regarding the asethetics of windmills located along the shoreline (SRL 1977, p. 99). Respondents also were questioned about their aesthetic reaction to the windmill (SRL 1977, p. 105). A majority (65%) found the design pleasing or somewhat pleasing. When asked if the windmill would be more pleasing at another location in the area, respondents overwhelmingly said no (82%). Again, respondent opinion implied no preference to location of a windmill. It appeared as if the majority of the population sampled by Ferber would not object to erecting a windmill on any type of terrain. Unfortunately, respondents were not asked if a nearby neighbor's yard or even their own back yard would be a satisfactory location.

A question concerning the location of a wind machine near one's own home was asked of respondents at the Plum Brook Test Site, operated by NASA at the Lewis Research Center, Sandusky, Ohio. The windmill design viewed was a 100-kW, horizontal-axis, 2-bladed wind machine on a 100-ft structural steel tower. Ferber conducted a convenience sample of 154 respondents who answered questions about having a windmill near their homes or locating windmills on the shoreline or in a national park. Of these respondents, three of four said they would be willing to have a wind machine near their homes. The sample responded even more favorably (91%) toward locating a WECS along a shoreline. However, about one of four respondents left the shoreline question blank. Such a large number of nonrespondents (25%) indicates some uncertainty when answering the question. Therefore, the favorable opinions toward shoreline WECS should be accepted with some reservation because the nonresponses could be interpreted as negative opinions.

The Plum Brook questionnaire also investigated the aesthetic appeal of windmill design configurations. Respondents were asked to choose between a horizontal-axis machine on a steel-truss tower, a Darrieus machine, or a horizontal-axis machine on a columnar tower (SRL 1977, Appendix C, Part 4, p. 1). The favored structure was the horizontal-axis windmill on a columnar tower (49%), followed by the Darrieus machine (28%), then the horizontal-axis design on the steel-truss tower (23%). There appeared to be an obvious preference toward the horizontal-axis windmill on the columnar tower within this study. The possibility of tower design influencing respondent preference is evident from these results.

Unfortunately, the respondents at Plum Brook were not a random sample. In fact, over half of the respondents visited the site because of interests in wind machines (SRL 1977, p. 106). Because of these interests, data from the Plum Brook Study cannot be interpreted as the opinion of the general public. The results from Plum Brook are useful when compared with results from Ferber's random sample questionnaire. The possible influence of tower structure was illustrated in the Plum Brook study, and to some degree in the random sample. It would appear from these studies that tower design does influence the acceptability of one windmill over another.

The horizontal-axis machine was preferred visually over the Darrieus machine by a majority of respondents in the Plum Brook study and slightly in the random sample studies. However, it must be noted again here that respondents answered when viewing color slides of windmills rather than actual machines in field settings.

4.2 DEVELOPMENT OF THE SERI SURVEY

The influence of the topographic setting of a windmill was tested in each of Ferber's surveys. Interestingly, respondents in the random sample, the Plum Brook sample, and the Sandy Hook sample showed no major preference for one site over another. In fact, the strongest objection toward windmill location was when roughly one person in four responded negatively to a windmill on the shoreline. It appears from these studies that location does not influence the aesthetic appearance of wind machines, whereas machine design does influence the public's opinion toward WECS.

SERI designed a pilot survey of aesthetics* to determine whether rotor and tower designs significantly affect SWECS visual appeal to a nonrandom group of survey respondents. The Rocky Flats Small Wind Systems Test Center is being used for survey data collection. Rocky Flats conducts regular weekly public tours (and some special tours) of the Test Center. During late summer 1979, about nine SWECS existed at the Test Center. The SWECS are sited on a uniform open plain at the base of the Rocky Mountains. Each SWECS occupies an equal sized, fenced plot. Plots also contain a small steel shed that houses study instruments.

The SWECS deployed at the Test Center represent several rotor and tower design configurations. Designs include upwind and downwind horizontal-axis SWECS with two and three blades; vertical axis SWECS; columnar wood, concrete, and steel towers, including structural steel truss towers of various designs.

Use of the Rocky Flats SWECS Test Center has both disadvantages and advantages. Respondents to the SERI survey will not be randomly selected from the general population; individuals visit Rocky Flats on their own initiative. Thus, the sample will be biased according to individuals' interest in SWECS.

Although the convenience sample technique is acceptable to a pilot study, survey results cannot and should not be extrapolated to apply to the general public's aesthetic preference for SWECS designs. However, the opinions expressed by the respondents are valid for the sample group and should prove useful in assessing the need for additional, larger studies of the effect of design configuration on SWECS aesthetic appeal.

Distribution of the SERI pilot survey on aesthetics offers several distinct advantages over past public acceptance studies. First, survey respondents will be viewing actual SWECS, not slides or photographs. As mentioned, Ferber states that use of photographs or slides in soliciting information on visual appeal has disadvantages. Because respondents to the SERI survey will be viewing actual wind machines, the possibility of misinterpreting pictures (for example, SWECS size) is eliminated. Secondly, all the SWECS are displayed at the same general site—a uniform, open plain. Thus, the variable of geographic deployment location is controlled. Finally, visitors to the Rocky Flats Test Center

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*Under the supervision of Carl Strojan and Kathryn Lawrence, the survey was developed by Daniel O'Donnell.

will judge the visual appearance of commercially available SWECS designs, not "Dutch designs" with high nostalgic appeal. A variety of SWECS designs are deployed at the Test Center. Survey results will be reported on a design, not brand-name, basis. Therefore, results should prove useful in designing additional aesthetics studies based on random sampling techniques.

A three-page questionnaire was designed to achieve the objectives of this study (see Exhibit 4-1). Page one, containing questions 1-5, attempts to determine why the respondent visited Rocky Flats, and if the respondent considers the aesthetic appearance of a SWECS to be an issue when considering a wind machine for his/her property. These questions were to be answered and collected before the tour. The second page, questions 6 and 7, gathers data concerning respondents' preferences in SWECS design. Also, question 7 mentions aesthetics in a listing of factors that could be interpreted as advantages or disadvantages of owning a SWECS. Lastly, page three addresses the possibility of a respondent being an adopter of a wind machine, and includes demographics. Demographics are necessary to determine how the sample compares with the general public.

Each question serves a specific purpose and was designed to generate data in areas where available data are limited. Question 1 queries the respondent as to how s/he heard about the windmills at Rocky Flats. This open-ended question directs the individual to Rocky Flats and wind machines in general. The question was also designed to encourage the respondent to be receptive to the remaining portions of the questionnaire.

The second question was designed to determine what type of interest, if any, the respondent has in SWECS. Results from this forced-choice question should be useful in determining the bias of the sample toward windmills.

Question 3 was designed to provide data about the potential issue of aesthetics in public acceptance. Specifically, the respondent lists what factors he or she considers important to a home-installed SWECS. Since the question was asked before the tour, responses for this open-ended question should reflect the individual's prior knowledge of wind machines. If aesthetics appears as a factor, the respondent considers the visual appearance of a SWECS an issue of public acceptance. The absence of aesthetics among responses would seem to indicate that respondents do not consider appearance an issue when deciding on home installation of a SWECS, or have not considered aesthetics in their decision-making process. Questions 4 and 5 ask the respondent to rate the factors listed in question 3. After questions 1 through 5 are answered, the first page of the questionnaire is collected by a SERI representative. Collection of page one eliminates the possibility of item changes by respondents after they learn some potential new issues during the site tour.

The first question on page 2 of the questionnaire (question 6) represents the source of data on visual preferences of SWECS design. Respondents are asked to give an appearance rating according to a five-point Likert scale: very attractive, attractive, neutral, unattractive, or very unattractive. While viewing each machine, the respondent is asked to rate the appearance of the working part (nacelle and blade), the tower, and the overall SWECS design. As each machine is unique, it is imperative to gather data on design structure relationships and on individual parts of the machines. The segmented rating shows tower preferences and axis orientational preferences. Question responses should determine if any design preferences exist across the sample. Question 6 is completed during the tour.

After each machine is viewed, respondents complete question 7, concerning possible factors respondents might consider in adopting a SWECS at home. The question is asked after the tour of the site, when the respondent has been exposed to various SWECS configurations.

The final page of the questionnaire contains two purchase questions (8-9), six questions on demographics (10-15), and one reiteration on factors affecting purchase of a SWECS. The demographics—residence by state, residence by community, sex, age, education, and income—were included to qualify the sample of visitors to Rocky Flats. Questions 8 and 9 will provide data on whether or not the respondent can be considered an adopter of a SWECS. The answers to these questions could be significant in that the adopter would be a likely candidate for dissemination of SWECS relative to the general public. Therefore, the opinion of the adopter on aesthetics and other issues could be very influential in the public acceptance of SWECS. The final question, 16, was included to determine whether exposure to SWECS during the tour influenced respondent opinion relative to the answers given in question 4.

Data collection at Rocky Flats began 31 August 1979 during a public tour of the test site. Data will be gathered until approximately 250 individuals have responded to the questionnaire. Analysis and evaluation will be included with the task final report, which will be completed in mid-February 1980. Survey methodology and results will also be published in greater detail in a technical paper.

EXHIBIT 4-1

ROCKY FLATS SMALL WIND SYSTEMS TEST CENTER QUESTIONNAIRE

THE SOLAR ENERGY RESEARCH INSTITUTE IS CONDUCTING A PILOT STUDY OF PUBLIC OPINION ABOUT SMALL WIND ENERGY CONVERSION SYSTEMS. YOUR OPINION IS VALUABLE TO THIS RESEARCH, AND THE RESEARCH TEAM WOULD APPRECIATE YOUR PARTICIPATION BY COMPLETING THIS QUESTIONNAIRE; HOWEVER, RESPONSE IS ENTIRELY OPTIONAL.

PLEASE ANSWER THE FIRST FIVE QUESTIONS BEFORE YOU BEGIN THE TOUR OF THE ROCKY FLATS SMALL WIND SYSTEMS TEST CENTER.

1) How did you happen to hear about the wind machines at the Rocky Flats Small Wind Systems Test Center?

____

____

2) Why did you come to see these wind machines? (CHECK ALL THAT APPLY)

______ Concern about the energy situation
______ Seeking information about a purchase decision
______ Curiosity and desire to be informed
______ Professional affiliation with subject area
Other (please specify) ______________________________

____

3) The wind machines you see at the Rocky Flats Small Wind Systems Test Center are designed for individual residential use. If you were thinking of installing a small wind system at your own home, what factors would you take into account in making your decision?

____

____

4) Of the factors you mentioned in question 3, please circle the most important one.

5) Please box-in the least important one.

EXHIBIT 4-1 (continued)

AS THE TOUR PROCEEDS, PLEASE RESPOND TO QUESTION 6 FOR EACH WIND MACHINE WHILE YOU ARE VIEWING IT.

6) Imagine that you are in the process of choosing a small windmill for your residence. Thinking now only about the visual appearance of the wind machines at Rocky Flats Small Wind Systems Test Center, please indicate for each one whether it is:

very attractive (1)
attractive (2)
neutral (3)
unattractive (4)
very unattractive (5)

	Tower Appearance	Appearance of Working Part	Overall Appearance
(Site 1.1)	___	___	___
(Site 1.2)	___	___	___
(Site 1.3)	___	___	___
(Site 1.4)	___	___	___
(Site 1.6)	___	___	___
(Site 1.7)	___	___	___
(Site 1.8)	___	___	___
(Site 1.10)	___	___	___
(Site 2.10)	___	___	___
(Site 2.6)	___	___	___
(Site 2.5)	___	___	___
(Site 2.4)	___	___	___
(Site 2.2)	___	___	___
(Site 2.1)	___	___	___

AFTER THE TOUR, PLEASE COMPLETE THE REST OF THE QUESTIONNAIRE.

7) The following factors have been mentioned as advantages or disadvantages of owning a small wind machine to produce electricity. For each factor, please indicate whether you think that it is an advantage (A), neutral (N), or a disadvantage (D) of having a small windmill for your home.

___ Environmental effects
___ Adequacy of energy supply
___ What neighbors think
___ Reliability
___ Other (please specify) ____________________

___ Aesthetics, visual
___ Lifestyle effects
___ Aesthetics, sound
___ Wind conditions

___ Costs
___ Safety

EXHIBIT 4-1. (concluded)

NOW, A FEW QUESTIONS ABOUT YOURSELF...

8) Do you presently own a small wind machine?

___ Yes ___ No

9) Do you have any plans to invest in a small wind energy system in the next five years? (CHECK ONE)

___ Yes ___ Maybe ___ No ___ Don't Know

10) In what state do you live? ______________________

11) In what type of community do you live? (CHECK ONE)

___ Urban ___ Suburban ___ Small Town ___ Rural

12) Are you male or female?

___ Male ___ Female

13) What is your approximate age group? (CHECK ONE)

___ 24 or less
___ 25-34
___ 35-44
___ 45-54
___ 55-64
___ 65 or over

14) What is your highest level of formal education? (CHECK ONE)

___ Less than a high school graduate
___ High school graduate
___ Some college
___ College graduate or more
___ Professional degree (Ph.D., LL.B., M.D., etc.)

15) What was your approximate annual family income before taxes in 1978? (CHECK ONE)

___ Under $8,000
___ $8,000 - 15,000
___ $15,000 - 20,000
___ $20,000 - 25,000
___ $25,000 - 30,000
___ $30,000 - 40,000
___ Over $40,000

16) Now that you have seen the wind machines, what would be the single most important factor that would affect your decision to invest in a small wind system?

____

____

THANK YOU FOR YOUR PARTICIPATION IN THIS STUDY!

SECTION 5.0

HEALTH AND ECOLOGICAL EFFECTS OF SMALL WIND SYSTEMS: LITERATURE CRITIQUE

Health and ecological issues pertaining to wind systems deserve attention for at least two reasons. First, a recent controversial study (Inhaber 1979) suggested that risk to human health from alternative energy sources (including wind) can be comparable to, or even higher than, that from conventional sources, such as natural gas, oil, coal, and nuclear. Although the Inhaber report has been strongly criticized for faulty assumptions, incorrect use of data, and arithmetical errors (e.g., Herbert et al. 1979; Holdren et al. 1979) the idea of considering life-cycle environmental costs is important. For this reason, it is useful to develop a sufficient data base so that accurate comparisons can be made of the environmental effects of wind systems versus other forms of energy conversion. Secondly, legal statutes, such as the National Environmental Policy Act of 1969 (NEPA) and laws pertaining to worker safety (e.g., NIOSH, OSHA) may be applicable to wind systems. The role of NEPA with respect to wind systems has been reviewed by Phillips (1979), who points out that although wind systems may result in short- or long-term environmental benefits, this does not imply that they are exempt from the provisions of NEPA.

The following section presents a review of previous environmental studies on wind systems and their relevance to our own assessment of small wind systems (100 kW). The review is organized according to phases of the machine's life cycle (materials acquisition and processing, system production and assembly, operation and maintenance, and decommissioning). Material for this review was based on the following sources: Black and Veatch (1978), Coty (1976), Davidson et al. (1977), Garate (1977), Howell (1978), Inhaber (1979), James (1978), Kornreich and Kottler (1979), Lubore et al. (1975), Meier and Merson (1978), Phillips (1979), Rogers et al. (1976), Rogers et al. (1977), Sengupta and Senior (1978), Senior et al. (1977), U.S. Department of the Interior (1979), U.S. Department of Energy (1978a), U.S. Department of Energy (1978b), U.S. Department of Energy (1978c), and U.S. ERDA (1977).

5.1 MATERIALS ACQUISITION AND PROCESSING

Only a few of the published assessments of wind systems have considered the health and ecological effects associated with the mining and processing of raw materials used in the construction of the towers, blades, and nacelles of wind machines (e.g., Davidson 1977, Meier and Merson 1978, Inhaber 1979). This is somewhat surprising since particulates, SO_x, NO_x, CO, and other pollutants emitted during the production of the material components of wind machines probably represent the major adverse environmental effect of the machines during their life cycle. This situation arises because of the nature of the wind energy system life cycle. Although wind machines emit virtually no pollutants during their operation, they require large amounts of materials per unit of energy production, primarily because of the diffuse nature of the wind resource. Furthermore, small wind systems are more materials-intensive than large wind systems per unit of energy (Table 5-1).

TABLE 5-1. MATERIALS PER QUAD OF END-USE ENERGY GENERATED BY WIND SYSTEMS[a]

(10^3 tons per quad)

Material	15-kW Machine Low[b]	1,500-kW Machine Low[b]	1,500-kW Machine Moderate[b]	1,500-kW Machine High[b]
Steel	2,241.0	586.0	311.0	188.0
Copper	48.3	4.5	3.1	2.6
Concrete	6,138.0	1,846.0	1,050.0	725.0
Fiberglass	—	65.2	31.4	16.6

[a]Adapted from Meier and Merson (1978).

[b]Low, moderate, and high wind regimes.

Blades may be fabricated from aluminum, fiberglass, steel, wood, or combinations of materials. The nacelle may include steel, fiberglass, and copper. Towers may be constructed of steel, concrete reinforced with steel, or wood. Finally, towers are set on a reinforced concrete base. Pollutants produced during the manufacture of these materials should be considered part of the life-cycle environmental costs associated with producing energy from wind systems.

SERI is using existing source data to make quantitative estimates of air and water pollutants emitted during the fabrication of the materials required for the generic wind machines used in our assessment (see Section 3.0). Additional source data are being used to estimate quantitatively the risk to industrial workers who manufacture these materials. Finally, emission estimates for wind machines will be compared with current industry-wide emissions to determine the increments of pollutants and health risk attributable to small wind systems at various deployment levels. In both cases these increments are expected to be very small. For example, preliminary estimates indicate that manufacture of steel for enough wind machines (500-, 1,000-, and 1,500-kW capacity) to yield an installed electric capacity of 1,000 MW would produce 0.3 to 12.9 x 10^6 pounds of particulates (with pollution control). Assuming this level of deployment were to occur by 1985, cumulative particulates from steel production for wind machines are estimated to be, at most, 0.1% of estimated emissions attributable to the production level necessary to satisfy 1985 steel demand excluding wind machines.

In addition to these secondary environmental impacts associated with production of wind machine components, there may be tertiary impacts if deployment is widespread. Most concrete and steel producers are located in the Midwest and East. In contrast, sites where wind regimes make deployment of wind energy systems attractive are often in the West. Massive deployment of wind systems might cause relocation of some materials-producing industries to regions closer to use sites (Davidson et al. 1977).

5.2 SYSTEM PRODUCTION AND ASSEMBLY

Environmental effects from wind-machine production tend to occur off-site and include health, safety, and ecological effects associated with manufacturing and transporting the machine to its destination. Potential effects from on-site assembly of component parts include worker accidents and potential disruption of local ecosystems from site preparation, road construction, etc. Ecological effects would most likely be minor for individual small wind systems constructed near a home or farm. The nature and magnitude of any effects would be site-specific, depending also on the size and design of the wind machine (e.g., see U.S. Department of Energy 1978a and U.S. Dept. of the Interior 1979). Nevertheless, several general environmental effects of the production and assembly phase can be identified from previous studies.

WECS assessments that have considered the environmental effects that occur during on-site construction have done so only for large machines (e.g., Lubore et al. 1975, U.S. DOE 1978a, U.S. Dept. of the Interior 1979, Black and Veatch 1978). Comparable effects may occur for small machines (<100 kW), but on a much smaller scale. For example, installation of a SWECS at a home or farm generally involves some site preparation, which may include grading and earth removal. In most cases, however, this would cause only minor disturbance and modification of use of existing lands because of the small size of the machine. Effects on air quality of vehicular emissions and fugitive dust, and the effects on water quality of additional runoff or soil erosion, are also likely to be very small on an individual machine basis or even cumulatively for all small wind machines. Lubore et al. (1975) estimated cumulative air emissions from transport of components for ten 1.5-MW wind machines and concrete needed for ten 35 ft X 35 ft X 10 ft bases. Transport was estimated to require 685 truck trips (50-mile round trip each) with fuel efficiency of 5 mpg. Emissions were estimated as follows:

carbon dioxide	1.9 tons
hydrocarbons	0.6 tons
nitrogen oxides	8.3 tons

Cumulative emissions from the transport and assembly of small machines would be much less than even these relatively small amounts. The forthcoming final report should provide quantitative estimates for these effects based on the experiences of commercial manufacturers in erecting their machines.

Land requirements have been estimated for large wind machines, but not small ones (e.g., Garate 1977; Coty 1976). Minimum spacing between large machines generally includes 10 to 15 rotor diameters, thus significantly affecting other potential land uses if clusters of machines are built. Average wind speed also significantly affects the number of machines that can be placed in an area. Extractable energy is proportional to the cube of the wind speed; therefore, the energy available in a unit area significantly increases with only a small increase in average wind speed. Garate (1977) estimated that in an area with a low wind speed regime (9-12 mph), one square mile could accommodate 1.3 large wind machines (1500 kW) with blade diameters of 331 ft. If the average wind speed were increased to 12-15 mph, 1.9 units with 278-ft rotors could be placed in one square mile. At speeds above 15 mph, units would require 218-ft rotors and 3 units could be sited in one square mile.

5.3 OPERATION AND MAINTENANCE

The operational phase makes up nearly all of the 20- to 30-year life of a small wind machine. This phase has received most of the attention in previous assessment studies. Again, however, all of these assessments and data collections have concerned the operational phase of large wind machines (>100 kW). Several potentially adverse environmental effects from large machines have been identified, but these may not be problems for residential-type machines because of their much smaller size.

Virtually no air pollutants are emitted during the operational phase of wind energy systems. Indeed, this must be considered one of the greatest environmental benefits of generating electricity from wind. The final report on this study should contain estimates of the atmospheric emissions that would occur if the electricity produced during the operating life of generic wind machines were generated by fossil fuels instead. Likewise, since no fuel is required for wind-generated electricity, the secondary emissions from the mining and refining of conventional fuels would be eliminated. Effects on downwind air quality from micrometeorological changes caused by placement of the structure and movement of the wind turbine blades were measured at the 100-kW NASA/Lewis wind machine (Rogers et al. 1977). The inherent range of variability of the natural environment was found to be far greater than the very minimal influences to the microclimate of the zone immediately downwind of the machine. Because of their considerably smaller size, residential wind machines are expected to have no measurable effect on microclimate.

The operational phase of small wind systems also has virtually no environmental effect on water quality. This is another important environmental benefit of wind-generated electricity. No steam is required to drive turbines, nor is water required for cooling or other consumptive purposes. This is an especially attractive benefit for arid regions. Likewise, no water is required for the mining or refining of fuel. The final report should include estimates of the amounts of water saved by generating various amounts of electricity from wind.

Effects of operating wind systems on plant and animal life have been assessed only for large systems (Kornreich and Kottler 1979, Rogers et al. 1977, U.S. Department of Energy 1978a, U.S. Dept. of the Interior 1979). These effects tend to be minimal and highly site-specific. Potential collisions between flying creatures and wind-machine blades and towers depend on several factors: (1) solidity of rotor design, (2) airfoil design, (3) number of organisms flying through the sweep area, (4) behavior of organisms within the sweep area; e.g., flight speed, evasive flight patterns, etc., (5) weather conditions, and (6) total structure height. Potential for collision with a wind machine should be extremely small, especially when considered in the context of the natural hazards these organisms face during their life spans. An exception would be a wind machine placed along a migratory route. Potential for collision with small machines should be significantly lower than for large machines. Field observations and experiments were conducted at the 100-kW NASA/Lewis machine to assess the potential for collision with birds and insects. No significant effects were found, but the machine was operative during only 10 percent of the nighttime hours of two migratory seasons. The environmental effect of an operating wind machine on land-dwelling animals should also be negligible except for the very small amount of habitat displaced by the tower base and foundation.

Potential noise emissions from wind machines have elicited some concern. These sounds are produced by normal operation of components in the machine's nacelle and by the interaction of the blades with moving air. The only published field measurements which have been made were done at the 100-kW NASA/Lewis machine and the 5-meter Darrieus vertical axis machine at Sandia Laboratories. In the former case, a maximum audible sound level of 64 dB(A) was measured. NASA/Lewis also estimated that, with measured background noise at 52 dB(A), the sound produced by the wind machine would be indistinguishable from background noise at about 800 feet from the machine (Kornreich and Kottler 1979). Measurements of infrasound (frequencies below the lower limit of human hearing) indicated that operation of the machine at full load and 20-mph velocity would increase infrasound levels by no more than 9.5 dB over the level measured at no load and

10 mph. Such an increase would be too small to disturb people or cause physiological damage (Rogers et al. 1977). Measurements on the 5-meter Darrieus machine indicated that audible noise from it was indistinguishable from background noise at 50 meters from the machine (Kornreich and Kottler 1979). These field data suggest that noise levels may not be cause for serious concern in the siting of small wind machines. Verification of this assumption is now being tested at the Rocky Flats Small Wind Systems Test Site.

Interference with electromagnetic transmissions may occur when wave signals strike the rotating blades of a wind machine. The impulse is then reflected or scattered to form a secondary interference signal. The severity of the interference will depend on the size of the blades, their composition, their rotational speed, and the placement of the machine with respect to the signal transmitter and receiver. Theoretical, laboratory, and field studies have been conducted to assess the interference of large horizontal-axis wind machines on television and radio broadcasts, air navigation systems, and microwave communication systems (Sengupta and Senior 1978). Interference with television broadcasts appears to present the only serious concern. Depending on the site-specific factors mentioned above, interference can result in a pulsating television picture, which can be a problem. The higher the transmission frequency (i.e., channel number) the greater the interference. Nonreflecting blades, directional antennas, or cable transmission may be required to eliminate the problem. It is currently uncertain whether small wind machines create a serious interference problem. Testing of small machines is currently being conducted by T.B.A. Senior of the University of Michigan.

Safety aspects of wind energy systems have been reviewed (James 1978). Potential hazards result from four principal sources: structural failure of the tower, blade throw, unauthorized public entry to the machine site, and obstruction of air space to low-flying aircraft. Tower failure can result from vibrational stress, inadequate base preparation, rotational forces, wind sheer, and violent weather. The hazard zone would be a circular area with a radius approximately equal to tower height plus one-half rotor diameter. Blade throw can result from stresses similar to those for tower structures. Estimated maximum distances of blade throw are 500 ft for a MOD-OA type 200-kW horizontal-axis machine, and 1/4 mile (1,320 ft) for a 1,500-kW horizontal-axis machine (ERDA 1977; U.S. DOE 1978c). A blade thrown from the 1,250-kW Smith-Putnam machine in 1945 traveled a total distance (including ground slide) of 750 ft (James 1978). The fourth hazard source is of little consequence in this study of small wind systems, because towers generally are not higher than 40 ft. It is probable, moreover, that potential safety hazards will be approached through standards, zoning codes, and building codes.

Aesthetic concerns include the visual impact of the machine and the noise produced during its operation. The effects of noise have been reviewed in this section, while visual aspects were covered in Section 4.0. It is not clear, however, whether the visual impact of wind machines will be a positive or negative factor in their deployment. Howell (1978) pointed out that large machines may have an aesthetic appeal simply because of their size and uniqueness. Smaller machines, in comparison, may have a nostalgic appeal.

5.4 DECOMMISSION

Wind systems may be expected to have a life span of 20-30 years. During this time many components may have to be repaired or replaced. These activities would vary considerably from machine to machine, so it is difficult to estimate the amounts of solid wastes generated from such activities without further data.

Final decommission will normally involve two activities: removal of the machine itself and revegetation of disturbed areas. Removal of the machine may involve the use of heavy construction equipment, but total requirements for this phase of the life cycle should not exceed those of the construction phase. Emissions from vehicular exhausts and fugitive dust should be minor and comparable to or less than those in the construction phase. Likewise, noise problems should be minor and temporary. Effects on water quality should also be minor if proper construction procedures are utilized. Lubore et al. (1975) estimated total water requirements to disassemble a windfarm of 7-10 1,500-kW units at 2 acre-feet for revegetation and 9 acre-feet for workers and dust control. The amount of water consumed during decommission of a residential machine should be negligible.

Solid wastes resulting from site decommission would consist primarily of rubble: broken concrete, tower components, and other scrap metal. Lubore et al. (1975) estimated that decommission of a windfarm (7-10 1,500-kW units) would require 0.4 acres of sanitary landfill if no materials were recycled. Many of the metallic components, however, would probably be recycled, thereby reducing landfill requirements. Disposal of remaining materials should present no environmental problems, since no toxic components are involved.

Decommission activities should have very small effects on biota. These effects should be similar to those occurring during the construction phase, since plant and animal life will probably have adapted to and colonized all possible areas around the tower. Similar colonization will likely occur after removal of the tower and base.

SECTION 6.0

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