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ENVIRONMENTAL EFFECTS OF SMALL WIND ENERGY CONVERSION SYSTEMS (SWECS)

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NOTICE

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ABSTRACT

Small wind energy conversion systems (SWECS) provide an environmentally benign source of electricity compared with conventional energy sources such as coal. SWECS operation produces no air pollutants, water contaminants, waste heat, or solid wastes. However, SWECS are not without environmental effects. This paper reviews the potential pollution releases and risks that might result from the manufacture, operation and maintenance, and decommission of SWECS with power ratings of 2, 8, and 40 kW. SWECS manufacture will release pollutants during mining and processing of resource inputs, and during fabrication of system components. Pollutants characteristic of these life cycle phases include the criteria air pollutants, and gaseous and particulate fluorides. National (and, in many cases, regional) incremental pollutant releases are negligible compared with total industry releases, even for fairly high levels of SWECS market penetration. In addition, pollutant releases that occur are controllable by pollution abatement technologies currently available. Although operation of SWECS will not release pollutants, unique effects may occur. Included in this category are the noise associated with rotor operation, possible collision of flying species with rotors and towers, television video interference, and aesthetic considerations resulting from the visual appearance of SWECS. Initial field measurements indicate SWECS noise levels are fairly low, and are indistinguishable from background levels 50-200 feet from the tower base. The probability of flying species collision is extremely small for SWECS due to their relatively low total height. Television interference has not been reported to date from SWECS. A pilot field survey was conducted by SERI at the Rocky Flats Small Wind Systems Test Center to determine aesthetic preferences for selected commercially available SWECS, and major conclusions drawn from this study are presented. The final stage of the SWECS life cycle, decommission, includes disassembly of the SWECS, removal from the deployment site, and subsequent recycling or disposal of solid wastes. No environmental problems are expected for SWECS decommission since no exotic or toxic materials are used.

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I. Introduction

Until recently, environmental research for wind energy conversion systems (WECS) has focused primarily on designs with power ratings of 100 kW and above. This research is designed to complement the U.S. Department of Energy's (DOE) large WECS technical systems' development program. Environmental research activities now have been expanded to include small wind systems (SWECS), whose designs are undergoing extensive technical testing at the DOE's Rocky Flats Small Wind Systems Test Center near Golden, Colorado.

As part of the environmental research program, the Solar Energy Research Institute (SERI) assessed the potential environmental effects of SWECS. The environmental assessment focused on SWECS in three power rating categories: 2, 8, and 40 kW. Manufacture of SWECS for electricity generation was about 750 units in 1975 and 1,150 units in 1976 (1). Production in 1979 is estimated at about 1,500 units, of which about 95% are rated at 8 kW or less.* Only an extremely small fraction is larger than 40 kW. Thus, examination of SWECS rated at 2, 8, and 40 kW provided information on environmental effects for virtually all SWECS that might be deployed in the near term.

Environmental effects can occur throughout a technology's life cycle. For the purposes of this analysis, the life cycle of SWECS was divided into three phases: system manufacture and installation; operation and maintenance; and decommission. Potential environmental effects associated with each phase are reviewed in Sections II, III, and IV, respectively. Section V provides a summary.

II. Environmental Effects of SWECS Manufacture and Installation

Energy systems' potential for affecting the human and physical environment results not only from operation and maintenance of the systems, but also from manufacture and installation procedures. For many of the solar energy options, including SWECS, environmental effects (from air and water pollutants and solid wastes) occur primarily during manufacture and installation phases.

Identification of environmental effects requires knowledge of avenues of impact; i.e., pollutant emissions. Estimations of the kinds and quantities of pollutants depend on the types of materials required for SWECS manufacture, and on the nature of the fabrication process. Thus, determining the quantities of materials necessary for SWECS manufacture is a critical first step in assessing the environmental effects of the first phase of the system's life cycle.

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* Unpublished SERI market survey, 1979.

As previously noted, SWECS in three power rating categories (2, 8, and 40 kW) were selected for examination. Data on materials required for manufacture of the SWECS were provided by the Rocky Flats Wind Systems Group. These data were for nine designs being developed under contract to Rocky Flats. From these data, a range of materials quantities was compiled for each power rating category. A range of quantities was used because 1) materials requirements for various SWECS designs (e.g., horizontal and vertical axis rotors) are encompassed within the range, and 2) changes in SWECS designs to improve performance and/or reduce costs will probably produce designs falling within that range.

Materials data ranges for the three SWECS power categories are shown in Table 1. Data in the first column are in pounds required for manufacture of a single wind machine. Materials required for manufacture of 2500 SWECS per year in each power rating category are shown in the second column. These figures are compared with projected 1985 domestic production capacity and projected demand for each material in other uses. As indicated in Table 1, significant SWECS production levels would represent an insignificant percentage of both domestic production and demand in 1985. For all the materials shown in Table 1, demand for manufacture of 2500 units in each of the 2-, 8-, and 40-kW power rating categories (7500 total) would not exceed 0.5% of projected U.S. 1985 production capacity. It is, therefore, extremely unlikely that material constraint problems will develop in the near term for the SWECS industry.

Acquiring raw materials, processing them into industrial materials, and fabricating SWECS from them will generate pollutants. Based on the materials shown in Table 1, air emissions associated with mining and processing the materials inputs were estimated. Emission factors (e.g., pounds of particulates emitted per ton of steel produced) were applied to the materials quantities. Because industrial emission control is expected to become more stringent with time, it was assumed that the materials industries were using best available control technologies (BACT).

Emission estimation results are shown in Table 2. Estimates for both the low and high points of the materials requirements range are shown. Emission levels attributable to processing materials for SWECS manufacture relative to total industry releases are proportional to the materials usage estimates shown in Table 1. Thus, manufacture of 7500 SWECS units annually would create a national pollution increase of at most 0.5% for the industries which supply materials for SWECS manufacture. For most pollutants, the release would be only about 0.1% above levels in 1985 attributable to processing the materials listed in Table 1 for other demands. Production of the wind systems from industrial materials (e.g., sheet metal) will probably occur in a high volume metal fabrication facility (5).

The primary source of particulates is the production of concrete, which involves manufacture of cement, acquisition of sand and gravel, and batching of the concrete. Sixty-seven to 73% of sulfur oxide (SO_x) releases are due to copper processing. The cement industry may make significant contributions to SO_x levels depending on amounts required relative to other materials. Nitrogen oxide releases occur almost exclusively from the processes of the cement industry. The steel industry is the primary contributor of carbon monoxide, although production of fiberglass will also result in very small

Table 1. Materials Requirements for SWECS Manufacture[a)]

Power Rating	Lbs. Unit[b)]	Tons per 2500 Units/yr[b)]	Percent of Estimated U.S. (1985):	
			Production	Demand
2 kW				
Steel	1255-1285	1569-1606	.001	.001
Aluminum	0 - 175	0 - 219	0 - .03	0 - .002
Fiberglass	0 - 27	0 - 34	0 - .009	NA[c)]
Cement	1752	2190	.002	.002
Copper	40	50	.002	.002
Wood	27 - 44	34 - 55	NA	NA
8 kW				
Steel	3261-7072	4076-8840	.003 - .007	.003 - .006
Aluminum	20 - 500	25 - 625	.004 - .09	.0002 - .005
Fiberglass	15 - 350	19 - 438	.005 - .11	NA
Cement	2637-4398	3296-5498	.003 - .005	.003 - .004
Copper	70 - 80	88 - 100	.004	.003 - .004
Samarian/Cobalt[d)]	0 - 30	0 - 38	.51	.14
40 kW				
Steel	12980-17706	16225-22133	.01 - .02	.01 - .02
Aluminum	0 - 1050	0 - 1313	0 - .19	0 - .012
Fiberglass	0 - 1030	0 - 1288	0 - .32	NA
Cement	1142-30704	1428-38380	.001 - .038	.001 - .029
Copper	100	125	.005	.005

a. Source: Developed by SERI based on SWECS materials data provided by the Rocky Flats Wind System Group, Golden, CO., and industry production data in Bureau of Mines, 1975, [2] and ERDA 1977 [3].

b. Data ranges are based on several specific SWECS designs in each power category and includes materials for towers, working parts and bases; not all material types (e.g., fiberglass, wood) are used for every design.

c. NA - Not Available

d. Required for fabrication of magnets.

Table 2. Emission Releases From Manufacture of 2-, 8-, and 40-kW SWECS

EMISSION	Total Tons Per Year From Manufacture of 2500: 2-kW SWECS	8-kW SWECS	40-kW SWECS
Particulates	6.93 - 7.85	12.43 - 24.56	20.51 - 105.77
SO_x	18.09 - 18.10	30.42 - 39.24	34.89 - 129.76
NO_x[b)]	2.86 - 2.91	4.34 - 7.83	3.18 - 51.22
CO	1.41 - 1.42	3.67 - 7.96	14.60 - 19.92
Gaseous Fluorides (HF)	0 - 0.03	neg.[c)] - 0.08	0 - 0.16
Particulate Fluorides	0 - 0.04	neg. - 0.13	0 - 0.27

[a)] Source: Developed from materials data in Table 1 and emission factors published in (4); estimate ranges correspond to ranges in Table 1; industrial use of best available pollution control technology (BACT) is assumed except for NO_x.

[b)] NO_x emissions are uncontrolled; data on BACT removal rates were not available.

[c)] Neg. = negligible, <0.01 tons.

releases. Annual releases of fluoride compounds are insignificant (<.269 tons gaseous hydrogen fluoride and .436 tons particulate fluorides) on a national basis, and come entirely from the aluminum industry.

Increases in pollution from a near quadrupling of the SWECS industry (i.e., to an annual production level of 7500 units) are very insignificant nationally, but may not be so regionally or locally. Expansion of production levels to supply materials to the SWECS industry may not be distributed among all industrial facilities. Thus, increases in pollutant releases may be regionally concentrated and therefore produce specific regional environmental effects. However, the magnitude of incremental effects are still a function of the regions' industrial activity in the affected materials categories.

SWECS will arrive at the deployment site in prefabricated form. Installation will involve preparation of the site (pouring of foundation, and perhaps leveling and grading); erection of the tower and placement of the rotor and nacelle; electrical interconnection with the end user (e.g., with a residence); and, possibly, tying in with the local utility grid.

Because the SWECS arrive in prefabricated form, the time required for installation is fairly short. Potential impacts from on-site assembly include accidents to workers and potential disruption of local ecosystems from site preparation. However, ecological effects resulting from installation of a SWECS near a home or farm should be extremely minor to negligible. The number of workers and amount of site preparation required for SWECS installation will depend upon the physical deployment location; i.e., whether the SWECS is erected near the home on a tower requiring a concrete foundation, on a rooftop, or elsewhere.

The labor requirements for installation of a SWECS will depend on 1) the amount of site preparation required (grading, concrete foundation pouring, etc.); 2) the design of the tower; 3) size and weight of the machine; and 4) whether the turbine is placed on the tower prior to or after tower erection. Few published data are available on the labor amount and skill requirements for SWECS installation. One source (5) indicates installation of a 1-kW SWECS will require 7-8 days for one engineer and one semiskilled worker (a total of 14-16 person-days). It is unclear whether site preparation is included in this estimate. Industry estimates vary due to the four factors mentioned above. For example, an Enertech 1500 is normally installed by three persons in four days (12 person-days) (10). Installation of a SWECS with an octahedron-style steel truss tower is estimated to require three men 1-2 days after the foundation has been prepared. This time would drop to one day with the use of five installers. Erection of an 8-10 kW SWECS where the turbine and columnar tower are assembled on the ground and hoisted as one unit could require as little as four hours (after foundation preparation) using three installers.

Placement of a SWECS on a rooftop will not require additional land use. Installation of the SWECS near the end-use site will require commitment of land for the base, and possibly for a safety exclusion zone. SWECS rotor designs must be matched with the proper tower designs to avoid torsional stress when the system is operating. Tower designs vary in their site preparation and foundation requirements. For example, land use for a 2-kW

SWECS may vary from 35.4 ft^2 to 196 ft^2, depending upon the area of the concrete pads required for the tower. Representative measurements of SWECS land use at the Rocky Flats Small Wind Systems Test Center are shown in Table 3. Information on machine size and tower design is also provided. These representative land use figures do not include safety zones (which may or may not be necessary), or guy wire attachment points. In addition, the size of concrete pads at the Test Center may be larger than those used in commercial installations.

III. Environmental Effects of SWECS Operation and Maintenance

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

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 power from wind. Likewise, since no fuel is required for wind-generated power, secondary emissions from the mining and refining of conventional fuels are 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 (6). The inherent variability in the natural environment was found to be far greater than the very minimal influences on the microclimate in the zone immediately downwind of the machine. Because they are considerably smaller, residential wind machines are expected to have no measurable effect on the microclimate.

No environmental effects on water quality are evident during the operational phase of SWECS. This must be considered as another environmental benefit of generating power from wind. No steam is required to drive turbines, nor is water required for cooling or other consumptive purposes. In addition, no water is required for the mining and refining of fuel. This is an especially attractive benefit in arid regions.

Effects of wind systems' operation on plant and animal life have been assessed only for large systems (6-9). These effects were found to be minimal and highly site-specific. The possibility of flying species colliding with wind machine blades and towers depends on several factors: 1) solidity of the 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 structural height. The odds of colliding with a wind machine should be extremely small, especially when considered in the context of the natural hazards which these species face during their life. The only exception might be if a very large wind machine were placed along a migratory route. The possibility of collision with small machines obviously should be significantly lower than for large machines. Field observations and experiments were conducted at the 100-kW NASA/Lewis machine to assess potential collision of birds and

Table 3. SWECS Land Use[a)]

POWER RATING	DESIGN OF: ROTOR	TOWER	TOWER HEIGHT	TOWER AND PLATE AREA	CONCRETE PAD(S) AREA	TOTAL LAND USE
1 kW	3 blade HAWT[b)]	columnar, steel truss	55 ft	2.6 ft^2	16 ft^2	16 ft^2
1.5 kW	3 blade HAWT	columnar, wood	40 ft	1.2 ft^2	7.1 ft^2	7.1 ft^2 + guy wires
2 kW	2 blade HAWT	columnar, steel truss	40 ft	2.25 ft^2	81 ft^2	81 ft^2 + guy wires
2 kW	3 blade HAWT	steel truss	40 ft	27.6 ft^2	9.3 ft^2	35.4 ft^2 [c)]
2 kW	3 blade VAWT	steel truss octahedral	55 ft	28 ft^2	196 ft^2	196 ft^2
2 kW	multi-blade "bicycle" style HAWT	columnar steel truss	55 ft	5.25 ft^2	36 ft^2	36 ft^2
10 kW	3 blade HAWT	columnar, concrete	55 ft	47.25 ft^2	21.3 ft^2	65 ft^2 [c)]
15 kW	3 blade HAWT	columnar, concrete	55 ft	3.1 ft^2	28.3 ft^2	28.3 ft^2
40 kW	3 blade HAWT	columnar, steel	40 ft	29.3 ft^2	400 ft^2	400 ft^2
			RANGE:	1.2 - 47.25 ft^2	7.1 - 400 ft^2	7.1 - 400 ft^2
			MEAN:	16.3 ft^2	88.3 ft^2	96.1 ft^2

a) Source: Physical measurements by SERI at the Rocky Flats Small Wind Systems Test Center.

b) HAWT = Horizontal axis wind turbine; VAWT = Vertical axis wind turbine.

c) Total land use equals tower and plate plus 5/6 of concrete pad area since 1/6 of concrete pad area is under the tower itself.

insects. No significant effects were found, but the machine was operative for only 10% of the nighttime hours of two migratory seasons. Because of the small total height of SWECS, they should present no significant hazards to migrating birds. 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.

Noise emissions from large wind machines have elicited some concern. These sounds are produced by the normal operation of components in the machine's nacelle and by rotation of the blades. The only published field measurements that have been made were taken at the 100-kW NASA/Lewis machine and the 5-meter Darrieus vertical axis machine at the 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 large wind machine would be indistinguishable from background noise at about 800 feet from the machine (7). Measurements of infrasound (i.e., 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 annoy people or to cause physiological damage (6). However, recent experiences indicate that annoying infrasound from large WECS is highly influenced by machine design, topography of the site, and weather conditions.

Audible noise and infrasound problems are not anticipated for SWECS. Initial measurements for the 5-meter Darrieus machine indicated that audible noise was indistinguishable from background noise at 50 meters from the machine (7). Additional testing of noise potential from vertical axis wind turbines at Sandia will be conducted by SERI. Initial noise measurements at the Rocky Flats Test Center indicate very acceptable noise levels for SWECS. For example, a 3-kW system produced a maximum of 57 dB(A) at the tower base (wind speed was 12.5 m/sec); an 8-kW system produced a maximum of 59 dB(A) at 77 feet (14.5 m/sec wind), a 3-dB(A) increase over background levels. The 3-kW system could not be heard 50-75 feet from the tower, and the 8-kW system was inaudible at 150-200 feet. These measurements were made in a treeless environment; the presence of trees and shrubs would tend to mask the minimal SWECS noise levels (10). These field data suggest that noise levels may not be cause for serious concern in the siting of small wind machines. However, verification of this is currently being carried out at the Rocky Flats Small Wind Systems Test Center.

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 depends on the size of the machine's 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 interference of large horizontal-axis wind machines on television and radio broadcasts, air navigation systems, and microwave communication systems (11). Interference with television broadcasts appear to present the only concern. Depending on the site-specific factors mentioned above, interference can result in a pulsating television picture which can be an annoying problem. The higher the transmission frequency (or 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 an interference problem, although use of wood or fiberglass for rotor fabrication should decrease the potential for adverse impacts.

Safety aspects of large wind energy systems have been previously reviewed (12). These hazards can result from four principal sources: 1) structural failure of the tower, 2) blade throw, 3) unauthorized public entry to the machine site, and 4) obstruction of air space to low-flying aircraft. The last source is of little or no consequence for small wind systems. Tower failure could result from vibrational stress, inadequate base preparation, rotational forces, wind sheer, and violent weather. In this case the hazard zone would be a circular area with a radius approximately equal to tower height, 40 to 55 ft. (See Table 3). Blade throw can result from stresses similar to those for tower structures. However, experience seems to indicate that a properly installed tower will fail only under extreme circumstances. A variety of towers at Rocky Flats has withstood 100-120 mph peak winds without incident (10). Estimated maximum distances of blade throw are 500 feet for a MOD-OA type 200-kW horizontal-axis machine, and 1/4 mile for a 1,500-kW horizontal-axis machine (4,8). A blade thrown from the Smith-Putnam machine in 1945 traveled a total distance (including ground slide) of 750 feet (12). SWECS may have similar throw distances. Potential safety hazards could be approached through careful engineering and installation, and standards, zoning codes, and building codes.

Aesthetic effects have to do with the visual impact of the machine and any noise produced during its operation. The effects of noise have been discussed. Various studies concur that a potential problem with "visual pollution" of the landscape exists in the siting of wind machines (8,13-15); however, little information is available for assessing the magnitude of the problem or ways of resolving it. Only one previous study has dealt with visual impacts of wind systems (16). To examine them, SERI designed a pilot field study to determine what design configurations, if any, are visually preferred among commercially available SWECS models. The study also tried to determine the importance of aesthetics (defined in terms of visual preference) relative to other wind system issues.

A three-page questionnaire was developed and distributed to participants on tours at the Rocky Flats Small Wind Systems Test Center. In addition to providing background and demographic information, participants were asked what factors they would consider if they were purchasing a small wind system for home use, which one of these factors was most important to them, and how they would rate the visual appearance of each wind machine as they viewed it on the tour. Appearance ratings of the tower, working part, and complete machine were based on a five-point scale ranging from very attractive to very unattractive. Nine different machines were rated. Working parts included vertical- and horizontal-axis designs (both upwind and downwind), while towers included wood, concrete and steel columns, and various truss designs. From late August until mid-November 1979, 139 questionnaires were collected. Sampling was discontinued because of inclement weather.

It should be emphasized initially that these results are based on a small (N=139), nonrandom sample of respondents. Because of this, results should be interpreted carefully and not be considered indicative of attitudes of the general public. Only major points will be covered in this preliminary report on the field study.*

A variety of responses was given when participants were asked what factors they would consider if they were buying a small wind machine. Answers to this question were collected immediately before the tour, and thus should reflect a respondent's existing knowledge or concern about wind machines. Initial cost was the factor most frequently mentioned, noted by 73% of all people who answered the question (N=120). Appearance was the second most frequently cited factor, mentioned by 33% of respondents. Other frequently mentioned factors and their citation rates were as follows: machine's energy output (29%), long-term economics (25%), reliability (25%), efficiency (18%), maintenance (18%), local wind conditions (15%), feasibility (14%), and machine size (13%). Although 25 different factors were identified, each of those remaining was mentioned by less than 10% of the respondents. Based on these informal data, aesthetics seems to be an important factor, but the data should be interpreted carefully. Even though answers to this question were collected prior to the tour, some respondents were undoubtedly aware that the questionnaire concerned aesthetics. They may thus have been more inclined to include appearance as one of their responses.

When asked to cite the single most important factor they would consider in buying a small wind machine, most respondents listed economic considerations. A total of fourteen different factors was mentioned. Not one person mentioned appearance as the most important factor, even though 33% of the respondents indicated it was one they would consider before purchasing a small wind machine.

The major part of the survey was constructed to determine if aesthetic preferences exist for various designs of small wind machines. The purpose of the aesthetic ratings was not to determine consumer preferences for commercial brands, but rather to determine if any general patterns emerged in design preferences. In fact, three major patterns were evident. One was that working parts (rotor and nacelle) were considered more attractive than their towers. For eight of nine machines, working parts were rated higher, on the average, than their corresponding towers. For the ninth machine, both components were rated equally. On the average, downwind horizontal-axis working parts were rated slightly higher than upwind horizontal-axis or vertical-axis working parts. It should be noted, however, that the downwind models all had closed nacelles and were colorful, whereas none of the other models had closed nacelles, and only one had some color. These additional variables thus confound any effects which might otherwise be attributed to rotor orientation.

The second pattern to emerge concerned tower designs. The various towers that were rated can be grouped into three basic designs: columnar, narrow-based truss (<4 ft on a side), and wide-based truss (≥8 ft on a side). The weighted average rating for the four columnar towers was almost one category higher than

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* A complete analysis of study results will be available in Environmental Assessment of Small Wind Energy Conversion Systems, K.A. Lawrence, C.L. Strojan, with D. O'Donnell, Solar Energy Research Institute, TR 354-608, Forthcoming, May, 1980.

the average for the three wide-based truss towers, while the two narrow-based truss towers were intermediate. Fifty-eight percent of all ratings for columnar towers were in the attractive or very attractive categories, while only 36% of the ratings for narrow-based truss towers and 27% of the ratings for wide-based truss towers were. Conversely, only 12% of the ratings for columnar towers were in the unattractive or very unattractive categories, whereas 23% of the ratings for narrow-based truss towers and 37% of the ratings for wide-based truss towers were.

The third major point about the aesthetic ratings concerns overall machine design. In nearly all cases, the rating for the complete machine fell midway between independent ratings for the tower and working part, suggesting that the two component parts equally influenced perception of the overall design. The four highest rated machines all consisted of horizontal-axis working parts on columnar towers.

These results indicate definite preferences for particular wind system designs, but again, they are based on a small, nonrandom sample of individuals. Although our sample population came from twenty states, the District of Columbia, and three foreign countries, about half of the participants were from Colorado. The sample contained a much larger proportion of males, was younger, more highly educated, and had a lower income than the general U.S. population. This was partly attributable to the large number of students touring the Test Center. About 2.5% of our sample owned electricity-producing wind systems, and almost half had definite or possible plans to purchase one within the next five years.

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

IV. Environmental Effects of SWECS Decommission

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 those from the construction phase--or even less. Similarly, noise levels should be minor and temporary. Effects on water quality should also be minor if proper procedures are utilized. Lubore, et al. (17) estimated total water requirements to disassemble a windfarm of 7-10 1.5-MW 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. (17) estimated that decommission of a windfarm (7-10 1.5-MW 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 the remaining materials should present no problems since no toxic components are involved.

Decommission activities should have a limited effect 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.

V. Summary

Serious environmental effects were not evident in any of the three SWECS life cycle phases which were identified (system manufacture and installation; operation and maintenance; decommission). Expansion of the SWECS market would not significantly increase material resource consumption or pollutants generated during the manufacture of those materials. The operational phase provides distinct environmental benefits in that no air or water pollutants are generated, directly or indirectly, and no water is consumed in the production of energy. Concerns about safety, aesthetics, noise, and television interference may become more important if wide deployment of SWECS occurs in populated areas. Removal and proper disposal of machines at the end of their servicable life should present no handling problems because they are built of common materials, many of which can be recycled.

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