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ENVIRONMENTAL ASPECTS OF SOLAR ENERGY TECHNOLOGIES

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ABSTRACT

Solar energy technologies have environmental effects, and these may be positive or negative compared with current ways of producing energy. In this respect, solar energy technologies are no different from other energy systems. Where solar energy technologies differ is that no unresolvable technological problems (e.g., CO_2 emissions) or sociopolitical barriers (e.g., waste disposal, catastrophic accidents) have been identified. This report reviews some of the environmental aspects of solar energy technologies and ongoing research designed to identify and resolve potential environmental concerns. It is important to continue research and assessment of environmental aspects of solar energy to ensure that unanticipated problems do not arise. It is also important that the knowledge gained through such environmental research be incorporated into technology development programs and policy initiatives.

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SECTION 1.0

INTRODUCTION

A concern with any new technology is that it is often difficult to anticipate adverse environmental effects that may occur during its development and use. Frequently, we discover environmental problems only after significant damage has occurred to natural ecosystems or human health—and often at significant social and economic cost (Budnitz and Holdren 1976; Harte and Jassby 1978). Correcting the problems is then usually much more difficult economically, politically, and socially than if they had been identified and corrected earlier. Acid rainfall and food-chain accumulation of potentially toxic chemicals are specific examples of unanticipated environmental effects from technological development (Likens et al. 1979; Woodwell 1967).

With respect to solar energy (as broadly defined under the Solar Energy Research, Development and Demonstration Act of 1974 to include biomass, wind, solar thermal, photovoltaic, and ocean energy systems), it is tempting to conclude that there are no serious environmental concerns. Solar energy is not associated with belching smoke stacks; pollution of oceans, lakes and streams; discharges of toxic substances; or the destruction of the land and its biota. The absence of such obvious effects has led to the general belief that solar energy technologies are "environmentally benign." Considering the many diverse technologies included under solar energy, it would be unprecedented if some do not have adverse environmental effects. Furthermore, although solar energy technologies are not new, they have never been deployed, individually or collectively, at levels which are anticipated for the future. In cases where solar energy was widely used in the past (e.g., wind, wood burning), the environment also did not have the legal protection and public support for that protection that it has now. With the exception of a few studies (e.g., Davidson et al. 1977; Lawrence 1979; Holdren et al. 1980), environmental aspects of solar energy technologies have received relatively little attention, and few reliable quantitative data exist. It is important to consider environmental aspects early in the development of solar energy for the following reasons:

- If we are entering a period of widespread solar energy use, we have a unique opportunity to include environmental protection in the early planning and deployment of solar energy systems.
- We must avoid focusing solely on technological and economic aspects of solar energy systems at the expense of environmental and social considerations. Holdren et al. (1980) and others have suggested that ultimate limits on the use of energy are more likely to be imposed by rising environmental and sociopolitical costs than by resource exhaustion or internal production costs. One need only consider recent events in the nuclear power industry to become aware of the pitfalls that can occur in these areas.
- Legal and regulatory considerations will require that some attention be given to environmental aspects of solar energy (Phillips 1979; Schwab 1980).
- Solar energy has some positive environmental aspects when compared with conventional sources; it is important to consider these.

The following report reviews some of the environmental aspects of solar energy technologies and ongoing research designed to identify and resolve potential environmental problems. It will not consider advanced systems (e.g., solar power satellites), storage systems, or environmental effects from back-up sources of energy. It is organized around the topics of air, water, land, and biota—the basic compartments in which all ecosystem processes and environmental impacts occur.

SECTION 2.0

AIR

Effects on air quality from solar energy technologies may be either positive or negative, depending upon the particular technology and how it is used. Wind, photovoltaics, and various solar thermal collectors have one distinct benefit in that no atmospheric pollutants are emitted during their operation. Furthermore, there are no indirect atmospheric emissions such as those that result from mining or refining fuels. The only air quality impacts are indirect ones, which occur during the production of the raw materials used to manufacture the systems. In most cases, these appear to be relatively minor (Neff 1979; Holdren et al. 1980). Thus, energy produced by these solar energy systems can displace not only valuable fossil fuels, but also air pollutants emitted during the mining, refining, and combustion of fuels. This feature may have practical application in implementing the EPA's emission offset policy, which requires reductions from existing air pollution sources in certain nonattainment areas before additional sources can be added (Environmental Science and Technology 1978). The attractiveness of solar energy here is that it may be useful in providing emission offsets and in reducing total air pollution emissions from new or existing facilities (O'Brien and Euser 1980). The use of alcohol fuels in automobiles may provide similar benefits.

Concern about adverse effects of solar energy systems on air quality currently focuses on two areas. One of these is wood combustion emissions. Air pollution episodes, caused by residential wood burning, are already a problem in certain local areas. In one study (Cooper 1980), measurements with a ^{14}C tracer technique indicated that between 36% and 49% of the respirable (<2.5 μm) particulates in the air of a Portland, Oregon, residential area were from residential wood combustion sources. Table 2-1 shows annual emissions from direct combustion of various residential fuels and the relative importance of wood combustion to particulate, hydrocarbon, and carbon monoxide emissions. When all emissions sources are considered, particulates, hydrocarbon, and carbon monoxide from residential wood combustion sources were estimated to contribute 1%, 1.5%, and 3.8%, respectively, of the total national emissions burden for those species in 1976 (DeAngelis et al. 1980a).

Table 2-1. TOTAL ANNUAL EMISSIONS FROM RESIDENTIAL COMBUSTION SOURCES[a]

	Emissions, 10^3 mt/yr				
Fuel	Particulates	SO_x	NO_x	CO	Hydrocarbons
Gas	47	1.4	190	49	19
Oil	74	1,100	89	37	23
Coal	17	81	6.9	72	7.6
Wood	160	2.8	12	3,100	380
Total[b]	300	1,200	300	3,300	430

[a]Source: DeAngelis et al (1980a).
[b]Entries may not equal the totals because of rounding.

Although air pollution effects from residential wood combustion depend to some extent upon site-specific characteristics such as topography and weather conditions, the emissions burden is bound to increase if the number of wood-burning stoves in use continues to grow as rapidly as it has in the past few years. Increased emissions from wood combustion, in turn, may have important implications for both human health and government policy. The health implications derive from the fact that wood combustion emissions can be relatively high in respirable particulates and carbon monoxide. Numerous polycyclic organic matter compounds, including at least fourteen carcinogens, also have been identified in smoke from residential wood combustion sources (Cooper 1980; DeAngelis et al. 1980b). Government policy implications may develop if wood stoves become a significant source of space heating in residential or urban areas, since current government efforts to improve air quality are directed toward reducing industrial and automotive emissions. As Cooper (1980) pointed out, ". . . most metropolitan areas of the United States have banned backyard trash incineration and simply moving the incinerator indoors doesn't make the emissions any more environmentally acceptable."

The second area of concern about air quality relates to indoor air. Solar-heated buildings, and an increasing number of conventional ones, are well insulated and characterized by low exchange rates between indoor and outdoor air. A low air exchange rate serves to keep heat within the building, but it may also retain pollutants generated within the building (Hollowell et al. 1979). These pollutants may include radon and its decay products from building materials, well water, rock bed storage systems, or the soil beneath a home; formaldehyde and other volatile organic compounds from insulation, particle board, and synthetic fabrics and materials; and numerous other compounds with potential health effects (Hollowell et al. 1979; World Health Organization 1979). Research in this area has been directed toward identifying pollutants and their sources, their health implications, and ways of resolving potential problems (e.g., by using heat exchangers and different building materials).

SECTION 3.0

WATER

Energy systems can affect both the quality of water and its availability, and the impacts from solar energy systems may be either positive or negative. Wind, photovoltaics, some solar thermal collectors, and some biomass systems require no water at all for cooling or other consumptive purposes than periodic cleaning. This must be considered one of their most positive environmental aspects, particularly in arid areas of the West where water can be a limiting factor in energy development (Harte and El Gasseir 1978). In contrast, fossil fuel and nuclear-derived electricity use water at the estimated rates of about 0.5 $km^3/10^{18}J$ and 0.7-0.8 $km^3/10^{18}J$, respectively (Holdren et al. 1980). Integrating solar energy systems such as wind farms with existing hydroelectric facilities can also contribute to water conservation and energy storage. Because these solar energy systems do not consume water, they do not affect water quality. The only exceptions are secondary impacts confined to the processes involved in manufacturing the materials used in the systems. Holdren et al. (1980) estimated these indirect impacts to be about an order of magnitude lower than direct impacts.

Not all solar energy technologies are without effect on water resources. By virtue of their location, ocean thermal energy conversion (OTEC) systems could possibly have major impacts. Systems currently being developed require enormous quantities of water to be pumped from both the warm ocean surface layer (10–30m) and from the colder deep ocean (>1000m), and then to be discharged at an intermediate depth (100-200m). For a $1MW_e$ plant, the flow rate is estimated to be almost 4×10^8 litres per day (U.S. Department of Energy 1979c). Although this water is only transported and not consumed, the net effects of such large translocations on temperature changes and nutrient cycling are largely unknown.

Central receiver systems, such as the Solar Thermal Power Stations (STPS), have water requirements for cooling purposes comparable to those of coal-fired power plants (Harte and El Gasseir 1978; Holdren et al. 1980). Since the siting of such systems will probably be confined to sunny, dry areas of the Southwest, the availability of water will likely be one of the most important environmental constraints associated with large-scale development of STPS unless dry cooling towers prove feasible (Davidson and Grether 1977; Turner 1980).

Processing some biomass resources also requires significant quantities of water (e.g., alcohol production). Processing can also lead to significant water pollution unless adequate controls are used. Vegetation itself consumes large quantities of water before it can be considered a biomass fuel. However, unless this water is added by irrigation, its consumption is immaterial. If irrigation must occur, a new dimension may be added to environmental impacts. Various plans have been proposed for biomass plantations in arid regions of the United States (Lipinsky and Kresovich 1979; Johnson and Hinman 1980) and these probably will require at least some irrigation. If lands currently not irrigated are used for these purposes, new water supplies must be developed at additional economic and environmental cost. If currently irrigated croplands in water-scarce, arid regions are converted to plant species adapted to arid regions (e.g., jojoba), significant water savings could result (Foster and Wright 1980). Obviously, factors other than water consumption are involved here, including the controversial practice of replacing food crops with energy-producing species (Brown 1980).

The use of some species of aquatic plants as a source of biomass energy may have beneficial effects on water quality by acting as a passive filter in removing sediment, and by actively removing dissolved nutrients and other elements from water (Woodwell 1977). In this way, the use of aquatic biomass can act both as a source of energy and a means of water purification. Water quality can also be improved by reducing sources of pollution if feedlot wastes are used in methane digesters.

SECTION 4.0

LAND

Because solar energy on earth is diffuse relative to other energy sources, capturing and concentrating it often require relatively large areas. Thus, the impacts of solar energy technologies on land consumption and use are potentially great. Not all solar energy systems require land areas larger than those already being used, however. For example, some active solar collectors and photovoltaic arrays can be placed on existing roofs of buildings, thereby adding nothing to existing land consumption. Angelici et al. (1980) estimated that about 53% of the annual (1978) electrical demand for the San Fernando Valley near Los Angeles could be met from photovoltaic systems utilizing only half of the existing south-facing and flat roofs. Buildings using passive design features also require little or no additional land, although they require consideration of building placement and overall patterns of land use.

Another positive aspect of land requirements of solar energy technologies is that, with the exception of biomass systems, there are no effects on land associated with collecting or refining fuels. Where conventional fuels are used, these associated effects can be large, and may involve surface disturbance, subsidence, and problems with waste disposal. Decentralized solar energy applications also require no extra land for transmission lines or rights-of-way.

Land issues are more complex for wind energy and central receiver systems. For example, the land area taken up by the tower and base of a wind machine may only be several square metres; however, the addition of a safety zone around the machine would require, but not consume, additional land. The clustering of many machines into wind farms also requires, but again does not consume, large areas of land because the machines must be spaced far enough apart to minimize air turbulence. Nearly all of the land required for such a wind farm could retain its former or current uses. A similar situation exists for central receiver stations. Various estimates suggest that solar thermal power stations will require about 3 ha per MW_e capacity (Turner 1980). Again, however, all of this land need not be used consumptively. Neff (1979) suggested that central photovoltaic systems would affect an area not much larger than that committed to a coal plant with identical electrical output—if areas required for mining and ash disposal are included. Holdren et al. (1980), however, reported land requirements for central photovoltaic systems to be over an order of magnitude higher than for fossil fuel plants, but it is not clear whether their data include land required for acquisition of fuels and disposal of fly ash.

Biomass energy systems probably have the greatest potential for adversely affecting land. Ironically, these systems also have the potential for restoring productivity and preventing soil erosion on marginal lands that have been previously abused. Problems can arise from production, harvesting, and conversion processes, and large land area requirements (Pimental et al. 1979). All of these potential problems can be resolved through proper management procedures. An additional concern involves the wisdom of removing biomass residues from the land for use as energy feedstocks—particularly residues from agricultural lands—and the implications for this on soil erosion (Flaim 1979; Larson 1979). When soil losses are high, neither a food nor an energy production system can be sustained over a long period of time. Significantly more land per capita is required to produce grain-derived fuel than is required to produce food (Table 4-1). Although the policy implications of this are somewhat controversial (Brown 1980, Hertzmark et al. 1980, Solar Energy Intelligence Report 1980), one inescapable conclusion is that energy derived from grain-based systems requires considerable amounts of land.

Table 4-1. ANNUAL PER CAPITA GRAIN AND CROPLAND REQUIREMENTS FOR FOOD AND FOR AUTOMOTIVE FUEL[a]

	Grain (kg)	Cropland[b] (ha)
Subsistence diet	181	0.1
Affluent diet	726	0.4
Typical European automobile[c]	2,812	1.3
Typical U.S. automobile[d]	6,623	3.2

[a]Source: Brown (1980).
[b]Based on average world grain yields in 1978, according to the U.S. Department of Agriculture.
[c]Based on 11,000 km/yr at 10.5 km/l (7,000 mi/yr at 25 mpg).
[d]Based on 16,000 km/yr at 6.4 km/l (10,000 mi/yr at 15 mpg).

The location of land in relation to solar energy resources is also very important. In the West, many of the best sites for solar energy facilities are located in very scenic or isolated areas. A recent report (California Energy Commission 1980) indicated that many of the most promising wind sites in California are on federal lands, some of which are currently designated as wilderness or being considered for such status. It is not clear that development of solar energy facilities in such areas will be any more acceptable than development for other purposes.

One final point is that for energy systems to be sustainable, their energy output must be based on the carrying capacity of the land, and not on any real or imagined needs of society.

SECTION 5.0

BIOTA

Factors that adversely affect air, water, and land will tend to harm the organisms using or depending upon those same resources. Conversely, preserving or enhancing the abiotic environment will tend to benefit organisms (including man) that constitute the biotic compartment of ecosystems. Thus, effects of solar energy systems on biota are closely related to those previously discussed for air, water, and land.

Most air quality effects on biota from solar energy technologies are negligible—or even beneficial if conventional fuel sources and their emissions are displaced. Of greatest concern are the biological effects from indoor air pollution and wood combustion emissions. Humans have been exposed to wood combustion emissions for thousands of years, so exposure per se is not the issue, but rather emission concentrations, particularly in urban areas and inside homes. Health concerns about indoor air quality have been previously cited. It should be reemphasized that these are a concern in all well insulated buildings, not just those with solar heating systems. Secondary air quality impacts from materials manufacture may have some effects on biota, but these are difficult to quantify. Neff (1979) estimated that the use of cadmium and arsenic in advanced photovoltaic systems could result in the release to the environment of about 73 metric tonnes (mt) of cadmium and 6 mt of arsenic per GWe-year. Both of these elements are toxic to organisms.

Water quality effects on biota from solar energy technologies are also likely to be negligible or beneficial, compared with conventional energy sources. This, of course, is related to the lack of water consumption by many solar energy systems. The major exceptions are possibly ocean thermal energy conversion (OTEC) systems and solar thermal power stations (STPS), precisely because they do consume large quantities of water. Concerns with OTEC systems relate to organism entrainment and changes in nutrient cycles and temperature regimes (U.S. Department of Energy 1979). With STPS, additional concerns relate to availability and quality of water, and to competition between STPS requirements and existing uses. These water issues are particularly acute for biota in arid regions, the same regions where many of the best solar energy resources are located.

Land requirements of solar energy technologies can affect biota in several ways. Perhaps the greatest effect is displacement of existing plant and animal populations through habitat conversion. Biomass farms and central receiver stations have the greatest potential for causing changes in habitat. These two technologies are likely to cause significant changes in existing land uses, vegetation, and wildlife habitat if they are to make significant contributions as sources of energy.

Effects on biota (including humans) can also occur from certain specific features of particular solar energy technologies. For example, recent operation of a 2-MW_e wind turbine at Boone, North Carolina, resulted in complaints from local citizens about noise and vibrations caused by the wind machine. This was largely an unanticipated problem, caused by interference of the tower with wind movement. Local topography and weather conditions sometimes accentuated the effects. The problem has been temporarily solved by not running the machine during certain hours. This one-of-a-kind downwind machine with a steel lattice tower was designed as a prototype. A more recent model, the 2.5-MW_e MOD-2, has a different tower and blade configuration, which is expected to eliminate the noise problem. Another specific effect of wind machines, which only indirectly affects humans, is interference with electromagnetic transmissions (Sengupta and Senior 1978). This interference may occur when wave signals strike the rotating blades of a wind machine. The impluse is then reflected or scattered to form a secondary interference signal. The severity of the interference depends upon the size of the machines' 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 from large 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 problem, and this may require the use of directional antennas or cable transmission if large wind systems are used in populated areas.

Changes in microclimate which may then affect biota have been cited as potential environmental issues for some solar technologies (Davidson and Grether 1977; Rogers et al. 1977; Patten 1978). Measurements taken downwind of a 100-kW wind turbine showed that any changes, if they occurred, could not be distinguished from natural variations (Rogers et al. 1977). Undoubtedly, some microclimatic changes will occur from solar energy systems. Important factors, however, are the magnitude and importance of any changes relative to those that occur as results of other human activities.

Finally, issues involving workers' health and safety should be addressed as part of the environmental costs of building and maintaining solar energy systems. Some of these issues involve practices common to many mining and manufacturing activities, while others are more specific to solar energy systems. Examples of concerns for specific solar technologies can be found in a series of reports on worker health and safety at the proposed Barstow STPS (Ullman and Sokolow 1979; Ullman et al. 1979a-e) and in the proceedings of a workshop on health effects of photovoltaic technology (Stang et al. 1980).

SECTION 6.0

DISCUSSION

Solar energy technologies have environmental effects, and these may be positive or negative compared with current ways of producing energy. In this respect, solar energy technologies are no different from other energy systems. Where solar energy technologies do differ is that no unresolvable technological problems (e.g., CO_2 emissions) or sociopolitical barriers (e.g., waste disposal, catastrophic accidents) have been identified. An important factor, however, will be how solar energy technologies are developed. Environmental impacts from solar energy technologies identified to date can be minimized or eliminated—if the technologies are developed with environmental protection as one explicit goal. On the other hand, if we concentrate primarily on the narrower technological and economic aspects of solar energy, unanticipated environmental problems surely will arise, as they have with many other technologies.

Compared with existing energy technologies, solar energy currently appears to have few serious adverse environmental effects. It is important, however, to continue research and assessment of environmental aspects of solar energy to ensure that this situation remains true. The U.S. Department of Energy (DOE) has an ongoing research and assessment program in this area. Part of this program involves a periodic assessment of environmental concerns, research needs, and environmental readiness for various solar energy technologies (U.S. Department of Energy 1978a-c, 1979a-m). DOE-funded environmental research is also conducted at all of the national laboratories, and under subcontracts at numerous universities and private firms (e.g., Romney et al. 1979; Turner 1979). It is important that the knowledge gained through such environmental research be incorporated into technology development programs and policy initiatives.

The development of solar energy offers a unique opportunity to address and resolve environmental concerns before large-scale deployment occurs. The purpose of addressing such concerns is not a negative one in the sense of being an impediment to the development of solar energy. On the contrary, early identification and resolution of environmental issues will expedite solar energy deployment in a safe and environmentally sound manner. Clearly, the full potential of solar energy will be realized only if it can be developed in a manner that avoids the kind of environmental damage currently associated with conventional sources of energy.

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REFERENCES

Angelici, G. L.; Bryant, N. A.; Fretz, R. K.; Friedman, S. Z. 1980. Urban solar photovoltaics potential: an inventory and modelling study applied to the San Fernando Valley region of Los Angeles. JPL Technical Publication 80-43. Pasadena, CA: Jet Propulsion Laboratory, California Institute of Technology.

Brown, L. R. 1980. Food or fuel: new competition for the world's cropland. Report 35. Washington, D. C.: Worldwatch Institute.

Budnitz, R. J.; Holdren, J. P. 1976. "Social and environmental costs of energy systems." Annual Review of Energy 1: 553-580.

California Energy Commission. 1980. Solar/wind programs. Final environmental impact report. Sacramento, CA: California Energy Commission.

Cooper, J. A. 1980. Environmental impact of residential wood combustion emissions and its implications. Presented at the Wood Energy Institute Wood Heating Seminar VI. Atlanta, GA.

Davidson, M.; Grether, D. 1977. The central receiver power plant: an environmental, ecological, and socioeconomic analysis. Report LBL-6329. Springfield, VA: National Technical Information Service.

Davidson, M.; Grether, D.; Wilcox, K. 1977. Ecological considerations of the solar alternative. Report LBL-5927. Springfield, VA: National Technical Information Service.

De Angelis, D. G., Ruffin, D. S.; Peters, J. A.; Reznik, R. B. 1980a. Source assessment: residential combustion of wood. Report EPA-600/2-80-042b. Springfield, VA: Technical Information Service.

De Angelis, D. G.; Ruffin, D. S.; Reznik, R. B. 1980b. Preliminary characterization of emissions from wood-fired residential combustion equipment. Report EPA-600/7-80-040. Springfield, VA: National Technical Information Service.

Environmental Science and Technology. 1978. "EPA's emission offset policy." Vol. 12: 1007-1011.

Flaim, S. 1979. Soil fertility and soil loss constraints on crop residue removal for energy production. Report No. SERI/RR-52-324. Springfield, VA: National Technical Information Service.

Foster, K. E.; Wright, N. G. 1980. "Constraints to Arizona agriculture and possible alternatives." Journal of Arid Environments 3:85-94.

Harte, J.; El-Gasseir, M. 1978. "Energy and water." Science 199:623-634.

Harte, J.; Jassby, A. 1978. "Energy technologies and natural environments: the search for compatibility." Annual Review of Energy 3:101-146.

Hertzmark, D.; Ray, D.; Parvin, G. 1980. The agricultural sector impacts of making ethanol from grain. Report No. SERI/TR-352-554. Springfield, VA: National Technical Information Service.

Holdren, J. P.; Morris, G.; Mintzer, I. 1980. Environmental aspects of renewable energy sources. Report ERG 80-1. Energy and Resources Group. Berkeley, CA: University of California.

Hollowell, C. D.; Berk, J. V.; Lin, C.; Nazaroff, W. W.; Tranor, G. W. 1979. "Impact of energy conservation in buildings on health." R.A. Fazzolare and C.B. Smith, eds. Changing Energy Use Futures. Volume III. New York, NY: Pergamon Press. pp. 638-47.

Johnson, J. D.; Hinman, C. W. 1980. "Oil and rubber from arid land plants." Science 208: 460-464.

Larson, W. E. 1979. "Crop residues: energy production or erosion control?" Journal of Soil and Water Conservation 34: 74-76.

Lawrence, K. A. 1979. A review of the environmental effects and benefits of selected solar energy technologies. Report No. SERI/TP-53-114R. Springfield, VA: National Technical Information Service.

Likens, G. E.; Wright, R. F.; Golloway, J. N.; Butler, T. J. 1979. "Acid rain." Scientific American 241(4): 43-51.

Lipinsky, E. S.; Kresovich, S. 1979. "Fuels from biomass systems for arid land environments." J. R. Goodin and D. K. Northington, eds. Arid Land Plant Resources. International Center for Arid and Semi-Arid Land Studies. Lubbock, TX: Texas Tech University. pp. 294-306.

Neff, T. L. 1979. Social cost factors and the development of photovoltaic energy systems. Report MIT-EL 79-026. Cambridge, MA: Massachusetts Institute of Technology.

O'Brien, K. M.; Euser, B. 1980. "Solar energy and the search for emission offsets: a proposal." Solar Law Reporter 1:1077-1093.

Patten, D. T. 1978. Solar energy conversion: an analysis of impacts on desert ecosystems. Report COO-4339-3. Springfield, VA: National Technical Information Service.

Phillips, P. D. 1979. "NEPA and alternative energy: wind as a case study." Solar Law Reporter 1:29-54.

Pimentel, D.; Chick, S.; Vergara, W. 1979. "Energy from forests: environmental and wildlife implications." Transactions of the 44th North American Wildlife Management Institute. Washington, D.C.: pp. 66-79.

Rogers, S. E.; Cornaby, B. W.; Rodman, C. W.; Stocksel, P. R.; Tolle, D. A. 1977. Environmental studies related to the operation of wind energy conversion systems. Report COO-0092-77/2. Springfield, VA: National Technical Information Service.

Romney, E. M.; Wallace, A.; Hunter, R. B. 1979. Revegetation studies pertinent to the Barstow 10 MW_e pilot solar thermal power system and to potential power plant sites elsewhere in the Mojave Desert. Report UCLA 12-1224. Springfield, VA: National Technical Information Service.

Schwab, C. 1980. "Energy from vegetation: legal issues in biomass energy conversion." Solar Law Reporter 1:784-810.

Sengupta, D. L.; Senior, T. B. A. 1978. Electromagnetic interference by wind turbine generators. Final report. Report TID-28828. Springfield, VA: National Technical Information Service.

Solar Energy Intelligence Report 6(26): 254-255.

Stang, L.; Dienes, M.; Bohning, D.; (eds). 1980. Health effects of photovoltaic technology. Report BNL 51118. Springfield, VA: National Technical Information Service.

Turner, F. B. (ed.). 1979. Ecological base line studies at the site of the Barstow 10 MW_e pilot solar thermal power system. Report UCLA 12-1223. Springfield, VA: National Technical Information Service.

Turner, F. B. 1980. "Environmental issues and solar thermal power systems." Proceedings—Institute of Environmental Sciences, 26th annual meeting, "Life cycle problems and environmental technology." Mt. Prospect, IL: The Institute of Environmental Sciences. pp. 430-434.

Ullman, A. Z.; Sokolow, B. B. 1979. Worker health and safety in solar thermal power systems. I. Overview of safety assessments. Report UC 12/1211. Springfield, VA: National Technical Information Service.

Ullman, A. Z., Sokolow, B. B.; Daniels, J. I. 1979a. Worker health and safety in solar thermal power systems. II. Data base and methodology for the estimation of worker injury rates. Report UC 12/1212. Springfield, VA: National Technical Information Service.

Ullman, A. Z.; Sokolow, B. B.; Daniels, J.; Hurt, P. 1979b. Worker health and safety in solar thermal power systems. III. Thermal energy storage subsystems. Report UC 12/1213. Springfield, VA: National Technical Information Service.

Ullman, A. Z.; Sokolow, B. B.; Hill, J.; Meunier, G.; Busick, H., III. 1979c. Worker health and safety in solar thermal power systems. IV. Routine failure hazards. Report UC 12/1214. Springfield, VA: National Technical Information Service.

Ullman, A. Z.; Sokolow, B. B.; Pauker, S.; Robinson, D.; Busick, H., III. 1979d. Worker health and safety in solar thermal power systems. V. Off-normal events. Report UC 12/1215. Springfield, VA: National Technical Information Service.

Ullman, A. Z.; Sokolow, B. B.; Broutman, M. 1979e. Worker health and safety in solar thermal power systems. VI. Solar ponds. Report UC 12/1216. Springfield, VA: National Technical Information Service.

U.S. Department of Energy 1978a. Environmental readiness document. Large and small wind systems. Report DOE/ERD-0006. Springfield, VA: National Technical Information Service.

_________________ 1978b. Environmental Readiness document. Photovoltaics. Report DOE/ERD-0008. Springfield, VA: National Technical Information Service.

_________________ 1978c. Environmental readiness document. Solar: hot water and passive. Report DOE/ERD-0010. Springfield, VA: National Technical Information Service.

_________________ 1979a. Environmental readiness document. Solar heating and cooling of buildings. Report DOE/ERD-0018. Springfield, VA: National Technical Information Service.

_________________ 1979b. Environmental readiness document. Solar thermal power systems. Report DOE/ERD-0019. Springfield, VA: National Technical Information Service.

_________________ 1979c. Environmental readiness document. Ocean thermal energy conversion. Report DOE/ERD-0020. Springfield, VA: National Technical Information Service.

_________________ 1979d. Environmental readiness document. Biomass energy systems. Report DOE/ERD-0021. Springfield, VA: National Technical Information Service.

_________________ 1979e. Environmental readiness document. Solar agriculture and industrial process heat. Report DOE/ERD-0025. Springfield, VA: National Technical Information Service.

_________________ 1979f. Environmental readiness document. Wood combustion. Report DOE/ERD-0026. Springfield, VA: National Technical Information Service.

_________________ 1979g. Environmental development plan. Solar heating and cooling of buildings. Report DOE-EDP-0029. Springfield, VA: National Technical Information Service.

_________________ 1979h. Environmental development plan. Wind energy conversion. Report DOE/EDP-0030. Springfield, VA: National Technical Information Service.

_________________ 1979i. Environmental development plan. Photovoltaics. Report DOE/EDP-0031. Springfield, VA: National Technical Information Service.

_________________ 1979j. Environmental development plan. Biomass energy systems. Report DOE/EDP-0032. Springfield, VA: National Technical Information Service.

_________________ 1979k. Environmental development plan. Solar agricultural and industrial process heat. Report DOE/EDP-0033. Springfield, VA: National Technical Information Service.

_________________ 1979l. Environmental development plan. Ocean thermal energy conversion. Report DOE/EDP-0034. Springfield, VA: National Technical Information Service.

_________________ 1979m. Environmental development plan. Solar thermal power systems. Report DOE/EDP-0035. Springfield, VA: National Technical Information Service.

Woodwell, G. M. 1967. "Toxic substances and ecological cycles." Scientific American 216(3): 24-31.

Woodwell, G. M. 1977. "Recycling sewage through plant communities." American Scientist 65: 556-562.

World Health Organization. 1979. Health aspects related to indoor air quality. EURO Reports and Studies 21, Regional Office for Europe, World Health Organization, Copenhagen, Denmark.