ALTERNATIVE ELECTRICAL ENERGY SOURCES FOR MAINE

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Appendix L
ENVIRONMENTAL IMPACTS

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This appendix is one of thirteen volumes; the remaining volumes are as follows: A. Conversion of Biomass; B. Conservation; C. Geothermal Energy Conversion; D. Ocean Thermal Energy Conversion; E. Fuel Cells; F. Solar Energy Conversion; G. Conversion of Solid Wastes; H. Storage of Energy; I. Wave Energy Conversion; J. Ocean and Riverine Current Energy Conversion, and K. Wind Energy Conversion.

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Appendix C Geothermal Energy Conversion - A. Waterflow

Appendix D Ocean Thermal Energy Conversion - M. Ruane

Appendix E Fuel Cells - W.J. Jones

Appendix F Solar Energy Conversion - S. Finger, J. Geary, W.J. Jones

Appendix G Conversion of Solid Wastes - M. Ruane

Appendix H Storage of Energy - M. Ruane

Appendix I Wave Energy Conversion - J. Mays

Appendix J Ocean and Riverine Current Energy Conversion - J. Mays

Appendix K Wind Energy Conversion - T. Labuszewski

Appendix L Environmental Impacts - J. Gruhl

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Preface

The Energy Laboratory of the Mass. Inst. of Tech. was retained by the Central Maine Power Company to evaluate several technologies as possible alternatives to the construction of Sears Island #1 (a 600 MWe coal fired generating plant scheduled for startup in 1986). This is an appendix to Report MIT-EL 77-010 which presents the results of the study for one of the technologies.

The assessments were made for the Central Maine Power Company on the basis that a technology should be:

1) an alternative to a base-load electric power generation facility. Base-load is defined as ability to furnish up to a rated capacity output for 6570 hrs. per year.

2) not restricted to a single plant. It may be several plants within the state of Maine. The combined output, when viewed in isolation, must be a separate, "stand-alone", source of power.

3) available to deliver energy by 1985.

APPENDIX L

ENVIRONMENTAL IMPACTS

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1.0 INTRODUCTION

One of the most difficult aspects of assembling data on the environmental impacts of alternative technologies is the uncertainty associated with their eventual commercial form. This uncertainty gives rise to numerous assumptions which unfortunately are not consistent across all the technologies. As a result, comparisons drawn directly from individual assessments are at best confused and at worst completely misleading. This appendix presents the results of several large research efforts which have attempted to assess environmental impacts using a common set of assumptions.

The reader will find more specific discussions in each of the appendices on individual technologies.

The environmental impacts of alternative energy sources are, in general, difficult to assess because of the lack of operational scale systems. Before systems of a size appropriate to environmental evaluations can be built, a number of non-environmental barriers must be overcome, such as:

(1) resource limitations,
(2) underdeveloped technology, and
(3) economic disadvantages

Another generalization that can be made about alternative energy sources is that they all have environmental impacts (see Table 1.1). Many of these impacts occur in a very visible way, associated with plant operations. The other impacts are those implicit in the materials and construction of the facilities. Some of the alternative sources generally considered to be free of environmental impacts actually cause significant pollution from the cement, steel, transportation, and other supporting industries that have a part in making up these facilities. Data on these invested impacts are not currently available for these sources, and thus, operational impacts generally dominate in discussions of consequences of exotic energy sources. Perhaps, in the early 1980's, these invested impacts will be identified and quantified.

One mechanism under construction to perform the quantification of invested impacts, and other tasks, is the SEAS, Strategic Environmental Assessment System, at EPA. This SEAS program contains input/output modeling of the entire U.S. economy and can thus be used to calculate major and minor perturbations in all industries from unit demands of, say, steel or cement. Emissions information is to be tabulated in a separate, but coupled, module. In the absence of these kinds of data now, a crude measure of these indirect effects can be found in the capital expense of a facility. The field of economics offers some standard procedures that can be useful in comparing these investment environmental costs and operating environmental costs.

The most attractive feature of the so-called alternative energy sources is their more or less renewable character. Table 1.2 shows fractional resource depletions from lifetimes of 1000 MWe facilities.

Land use for transmission needs is surprising large, about 26.85 square miles per 1000 MWe distribution (CEQ, 1973). This number has been calculated by summing the entire transmission line land use in the U.S. and dividing by number of 1000 MWe of capacity in the U.S. (other computations show about 20% decrease in this figure.) Fuel cells, if they are small and distributed in nature, would gain some advantage over this number, but, on the whole, transmission line land use would be the same for the alternative sources. Excluding these transmission requirements, land use required by the exotic sources is shown in Figure 1.1.

Table 1.1

Some Environmental Aspects of Alternative Energy Sources

Energy Source	Characteristics Major Resource Impacted	 Major Environmental Impacts	 Possible Disasters
Geothermal Energy	Stored Heat.	Land use, noise, and release of heat, dissolved gases, and brines.	Land subsidence, earthquakes, uncontrolled blowouts.
Solar Energy	Land.	Land use, invested impacts, thermal effects (for solar thermal), aesthetic intrusion.	None.
Biomass	Land.	Land use, sludge, ecological disruption, air pollution.	Explosions, fires.
Solid Waste	None.	Air pollution, odors, wastes.	None.
Ocean	Sea.	Potential massive marine disruption, invested impacts.	Shipping collision, working fluid release.
Wind	Land.	Land use, invested impacts, aesthetics.	Aircraft collision, structure failure, broken blade pieces.
Waves and Currents	Sea.	Siltation, invested impacts, aquatic disruption.	None.
Fuel Cell	Fossil fuels.	Fuel extraction, trace pollutants, invested impacts.	None.

Table 1.2

Consumption of Resources by Alternative Sources

[(Beall, et al., 1974, p. 118) and other refs.)]

Energy Source	National Resource Availability	Amount of Resource for 30 yrs of 1000 MW plant
Geothermal (range)	(2 to 132 x 10^3MW)[a]	(1% - 50%)
Steam	5 x 10^3 MW	20%
Brine	50 x 10^3 MW	2%
Rocks	50 x 10^3 MW	2%
Solar		
Thermal	Land limited	15 sq. miles
Photovoltaic	Land limited	10 sq. miles
Biomass	Arable land	500 sq. miles
Solid Waste	10^9 tons per year	0.9%[b]
Ocean	Site limited	u*
Wind	100 x 10^3 MW	1%
Waves and Currents	u*	u*
Fuel Cell	Fossil fuel limited	nil[c]

[a] From several available estimates of potential by the year 2000.

[b] Assumes a heat content of 4000 Btu/lb as received (wet) waste and an annual consumption of 9 x 10^6 tons per 1000 MWe.

[c] With 2.24 x 10^{13} Btu = 1000 MW yr., 50% conversion efficiency, and 2 x 10^{19} Btu of fossil fuels.

*unknown

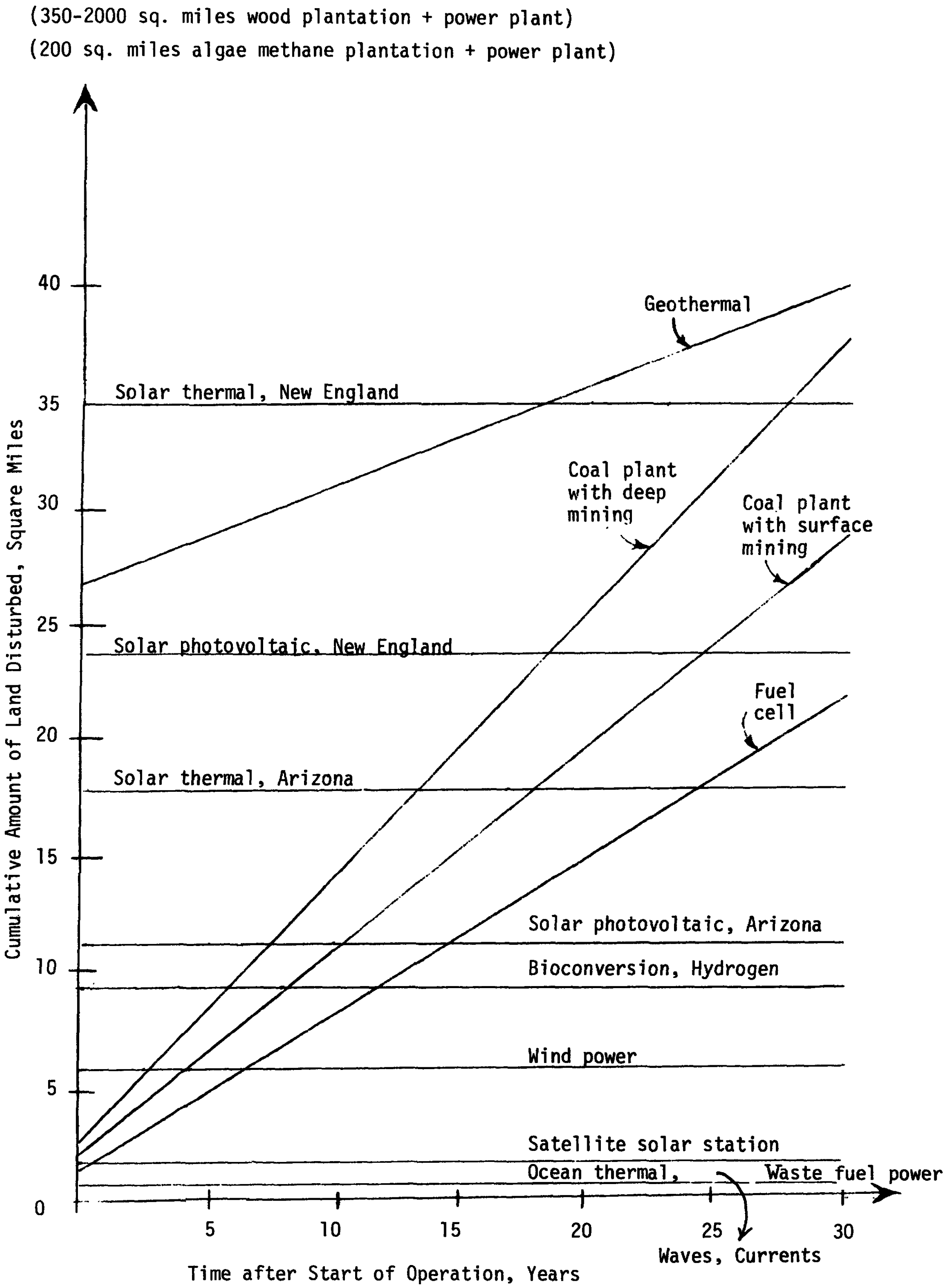


Figure 1.1 Comparison of Total Land Disturbed from 1000 MWe power plants and Fuel Extraction (Excluding Transmission)

Across-the-board comparison of the emissions from the alternative sources is shown in Table 1.3. This type of method of comparative evaluation is, of course, of limited use. It does, however, highlight some of the major differences and similarities among these energy sources. Backup information about further breakdowns of categories such as "Air, tons" is given in the following sections dealing with each of the various alternative sources.

Table 1.3 Annual Environmental Impacts from Operation of 1000 MWe Various Types of Power Plants with Load Factor of 0.75

Impact	Geothermal	Solar Thermal	Solar Photovolt.	Biomass	Solid Waste	Ocean Thermal
Land, sq. mi	72	62	37	530	28	27
Water, tons	Nil	60	u	$7.9\text{x}10^{4}$	810	u
curies	Nil	0	0	0	0	0
Btu	$1.5\text{x}10^{14}$	$1.0\text{x}10^{14}$	0	$3.1\text{x}10^{13}$+	$5.3\text{x}10^{13}$	0
Air, tons	$1.65\text{x}10^{5}$	0	0	$4.5\text{x}10^{5}$	$3.2\text{x}10^{5}$	0
curies	u[a]	0	0	0	0	0
Solid or Liquid Waste, tons	u	0	0	$2.0\text{x}10^{5}$	$3.5\text{x}10^{4}$	0
Occupational Deaths	.042+	.009+	.009+	.009+	2.3 +	u
Injuries	2.13+	1.09+	1.09+	1.09+	24.8+	u
Work-days lost	3 03+	120+	120+	120+	2500+	u

+ = summation included inknown item(s)

u = unknown

[a] Radioactive noble gases have been noted at some installations.

(continued)

Table 1.3 (continued) Annual Environmental Impacts from Operation of 1000 MWe Various Types of Power Plants with Load Factor of 0.75[a]

Impact	Wind	Waves and Currents	Fuel Cell	Coal-Deep	Coal-Surface	Nuclear (LWR)
Land, sq. mi.	38	u	45	46	54	29
Water, tons	0	u	$2.6\text{x}10^4$	$7.3\text{x}10^3$	$4.0\text{x}10^4$	$2.1\text{x}10^4$
curies	0	0	0	Nil	Nil	$2.7\text{x}10^3$
Btu	0	Nil	$2.0\text{x}10^{13}$	$3.05\text{x}10^{13}$	$3.05\text{x}10^{13}$	$5.29\text{x}10^{13}$
Air, tons	0	0	$2.2\text{x}10^4$+	$3.83\text{x}10^5$+	$3.83\text{x}10^5$+	$6.2\text{x}10^3$
curies	0	0	0	0.2[b]	4.0[b]	$4.89\text{x}10^5$
Solid or Liquid Waste, tons	0	u	$2.1\text{x}10^6$	$6.02\text{x}10^5$	$3.27\text{x}10^6$	$2.62\text{x}10^6$
curies	0	0	0	Nil	Nil	$1.4\text{x}10^8$
Occupational Deaths	.009+	u	1.76+	4.00+	2.64+	0.153+
Injuries	1.09+	u	27.7+	112.3+	41.2+	5.37+
Workdays lost	120+	u	2080+	15,300+	3090+	271+

\+ = summation includes unknown items

u = unknown

[a] Numbers from (CEQ, 1973) or documented in separate appendixes.

[b] Some Dakota coals are known to have as much as 3% uranium (Gruhl, _et al_., 1976).

The uncertainty that exists in our present knowledge of the environmental impacts of alternative sources makes the state-of-the-art of this information only a little better than subjective. Good judgment would thus necessarily require that a combination of different, small-sized, alternative sources be built rather than a single, large, alternative energy source. Other than that one generalization, there are no easy conclusions that can be made. Once all of the known data are in hand, a decision about which energy alternative is environmentally most attractive becomes a subjective judgment. Feelings about future constraints to be faced by a region and attitudes about risk-aversion are major components of this decision-making process. There have been a number of attempts to assign severity weightings to different types of pollution: (Babcock, 1972), (Beall, et al., 1974), (Shupe, et al., 1975), (Reiquam, 1972), (Shultz and Beauchamp, 1973), (Elsinghorst, 1975), and (Hall, Choi, and Kropp, 1974), and in this way produce rankings of energy technologies on overall environmental attractiveness. One of these subjective rankings, unfortunately based on comparatively little data, is shown in Table 1.4. Such rankings are of limited usefulness because decisions should never be based solely on environmental effects information. Economics should always be the primary focus because, even from a strictly environmental viewpoint, there are often far better opportunities for use of capital.

Table 1.4 Survey of Environmental Impacts of Alternate Energy Sources

Impact	Alternate source																	
	Solid waste			Bioconversion					Hydroelectric	Wind	Geothermal	Solar	OTEC	Waves	Coal			Nuclear
	PUROX	Garrett	fuel	gas	forest	cane	pine	other							land-based	ocean-based	liquid	
Total	28	27	40	25	38	28	28	34	19	26	38	26	28	28	39	35	33	37
Energy resource depletion	1	1	2	3	4	1	1	2	1	1	3	1	2	1	4	4	4	2
Area committed for conversion	3	3	3	2	4	1	1	4	0	3	3	4	3	4	3	2	2	3
Area committed for transmission	1	1	2	1	2	1	1	1	3	3	3	3	3	3	2	2	2	2
Water consumption	2	3	4	2	2	3	3	3	1	1	3	1	3	1	2	3	2	4
Use of air space	1	1	2	1	1	1	1	1	1	3	2	3	1	2	1	1	1	1
Air pollution	1	2	4	2	3	3	3	3	1	1	2	1	1	1	3	3	3	1
Water pollution	2	1	3	1	2	2	2	2	1	1	3	1	2	1	4	4	3	2
Construction activity	3	2	2	3	3	3	3	3	3	3	4	3	3	4	3	1	3	4
Heavy metals or toxic substances	3	1	3	1	1	1	1	1	1	1	2	1	1	1	2	2	1	2
Thermal discharge	2	2	4	3	4	4	4	4	1	1	3	1	2	2	2	3	4	4
Solid waste	2	2	2	1	2	2	2	2	1	1	2	1	1	1	3	3	2	2
Visual intrusion	2	2	3	1	4	2	2	4	2	3	3	3	1	4	3	1	2	2
Noise generation	3	3	3	2	4	2	2	2	1	2	2	1	1	1	3	2	1	1
Public health	1	2	2	1	1	1	1	1	1	1	2	1	2	1	2	1	1	3
Transportation hazard	1	1	1	1	1	1	1	1	1	1	1	1	2	1	2	3	2	4

Impact severity rating: 1 - negligible, 2 - slight, 3 - moderate, and 4 - severe.
OTEC = ocean thermal energy conversion, PUROX and Garrett are specific solid waste utilization schemes.

Source: (Shupe, et al., 1975, p. K-4)

2.0 BIOMASS PLANTATIONS - ENVIRONMENTAL IMPACTS

Unfortunately, no comparative environmental studies have considered the biomass potential of the unused parts of the forest. Our discussion must be limited, therefore, to plantation technologies. Conversion-related impacts are similar regardless of the biomass source.

Crops grown specifically for energy purposes can be converted to any of a number of usable fuels (oil, methane, ethyl alcohol, hydrogen, gas, and others) or they can be combusted directly. Impacts will be peculiar to the specific processes being considered.

Fermentation of crops to alcohol could conceivably be accomplished on 100 million acres of U.S. cultivated land, which could produce 18 billion gallons of alcohol or 12 billion gallons of gasoline equivalent (Bureau of Land Management, 1973). The environmental consequences of using crops to make alcohol are likely to be beneficial in the reduced potential for soil erosion.

The production of hydrogen directly from photosynthetic mechanisms in green plants and blue-green algae is being investigated. Hydrogen would have to be piped or transported from these remote facilities and there would be hazards to humans in this task. Otherwise, solar plantation environmental consequences are supposed (Beall, et al., 1974, p. 68) to be about the same as those experienced in large-scale thermoelectric plants. Lower energy efficiencies would increase land use considerably over the land required for a solar thermal facility, requiring at least 100 square miles per 1000 MWe for a tropical location.

Plantations specifically designed for growing wood as fuel would have considerable environmental problems. Runoff of silt and fertilizers from the tree plantation and thermal pollution (equivalent to a nuclear facility) would be the major water impacts. Air pollution would be minimal: wood is low (about 0.1%) sulfur; combustion is at low temperature (reducing NO_x), and ash and CO_2 would be useful to the plantation. Land use of between 300 and 800 square miles would be required for a 1000 MWe unit (Beall, et al., 1974, pp. 62-67). Soil control, wildlife protection, and recreation would be benefited by such an operation. Fresh-cut areas could cause small, temporary ecological setbacks and aesthetic eyesores.

Existing emissions data for biomass plantation facilities are contained in Tables 2.1 and 2.2.

Table 2.1 Annual Environmental Impacts from Operation of 1000 MWe Biomass Plantation Power plant with Load Factor of 0.75[a]

Impact	Extraction	Processing	Transport	Conversion	Transmission	Total
Land, sq. mil	500	0	0	.3	26.8	530
Water, tons	u	0	0	$7.9x10^4$	0	$7.9x10^4+$
curies	0	0	0	0	0	0
Btu	0	0	0	$3.05x10^{13}+$	0	$3.1x10^{13}+$
Air, tons	$4.6x10^3$	0	$3.0x10^2$	$4.5x10^5$	0	$4.5x10^5$
curies	0	0	0	0	0	0
Solid or Liquid Waste, tons	0	0	0	$2.0x10^5$	0	$2.0x10^5$
curies	0	0	0	0	0	0
Occupational						
Deaths	u	0	u	.009	u	.009+
Injuries	u	0	u	1.09	u	1.09+
Workdays lost	u	0	u	120	u	120+

+ = Summation includes unknown item

u = unknown

[a] Cultivation of wood as fuel driving an intermediate Btu gas to electric facility. Data from (CEQ, 1973) and (Teknekron, 1977).

Table 2.2

Solar Plantation Emissions (including transportation of fuels) per 10^{12} Btu Input Solar Energy

(All values in tons unless noted)	Cultivation (output is fuel)	Direct Combustion	Intermediate Btu Gas Conversion	Conversion to Methane
Primary Eff. (fraction)	6.0E-3*	3.4E-01	7.5E-01	6.0E-01
Acids	0	-	0	-
Bases	0	-	-	-
Phosphates	0	-	-	-
Nitrates	1.47E-02	-	-	-
Other Dis Solids	u	-	0	-
Total Dis Solids	u	-	0	-
Suspended Solids	u	-	0	-
Non-Degrad Organics	u	-	7.8E+02	-
BOD	0	-	0	-
COD	0	-	0	-
Thermal (Btus)	0	0	u	0
Total Solids + Organics	u	u	1.0E+3	u
Particulates	3.0E-02	4.14E+01	0	u
NO_x	1.9E-01	u	0	u
SO_x	2.0E-02	1.7E+02	0	u
HC	3.0E-02	0	-	-
H_2S	-	-	1.65E-02	8.6E+01
CO	7.0E-02	u	u	u
Aldehydes, etc.	7.0E-03	u		
Total Air	3.5E-01	2.1E+02	5.56E+03	2.6E+04
Solid Wastes	0	2.54E+03	2.59E+03	0
Land (acres)	4.84E+01	1.7E+01	2.0E+00	7.8E00
Water (acre ft)	6.0E+01	1.4E+04	-	2.1E+02

Source: (Teknekron, 1977). Note that cultivation must precede any of the conversion processes and direct comparison of conversion processes requires attention to efficiencies.

u = unknown

\- = unlisted

*6.0E-3 = 6.0 x 10^{-3} = 0.006

3.0 SOLAR-ENVIRONMENTAL IMPACTS

3.1 Solar Thermal-Central Power

Unless dry cooling towers are used, consumptive use of water in a solar thermal plant would be about double that used in a conventional power plant. Water contamination from leaks of the thermodynamic fluid could be dangerous (for sodium or dissolved salts) or harmless (for inert, pressurized gas or steam.) Concentrated updrafts of hot air and the possible large release of evaporated water would be the only air pollutant problems.

Land use of a 1000 MWe facility would be about 15 to 20 square miles in Arizona (Alexander, et al., 1973) or twice this in less-than-optimal areas such as New England (Meyer, Jones, and Kessler, 1975). When compared with a coal-fired facility (see Figure 3.1), land use would be comparable or less for the solar facility after 30 years. The large network of access roads would not add appreciable amounts to those land requirements. In the area underneath the collectors, winds would be slightly cooler, but predictions of the type of new ecosystem balance that would result must await experimental facilities (Beall, et al., 1974, p. 51).

The collectors, large power plants, cooling towers, and overhead transmission systems would all be aesthetically displeasing.

Significant amounts of resources would be required to build these facilities. These have their implicit environmental consequences which, outside of land use, would be the primary adverse consequence of solar thermal power.

Data on emissions from solar thermal plants are contained in Tables 3.1, 3.2, and 3.3.

3.2 Solar Photovoltaic - Central Power

Manufacture, use, and disposal of either cadmium sulfide or gallium arsenide cells would be dangerous unless strict measures were taken to prevent releases of these toxic substances to the environment. Careful planning might also help to alleviate the significant aesthetic problem posed by solar panels and their transmission equipment.

A solar-cell plant of 1000 MWe capacity would require between 7.5 square miles (FEA, 1974) and 30 square miles (CEQ, 1975) of land (1.4 square miles for a satellite facility's collector). Physical and ecological effects would be similar to those of the solar thermal facility, except water runoff could be a greater problem and defoliants might be necessary to keep vegetation from growing large enough to shade the solar panels.

Here again, the high capital cost of these solar-cell power plants indicates that there is a great deal of pollution implicit in the building of these facilities, including resource upgrading, fabrication, transportation, and so on.

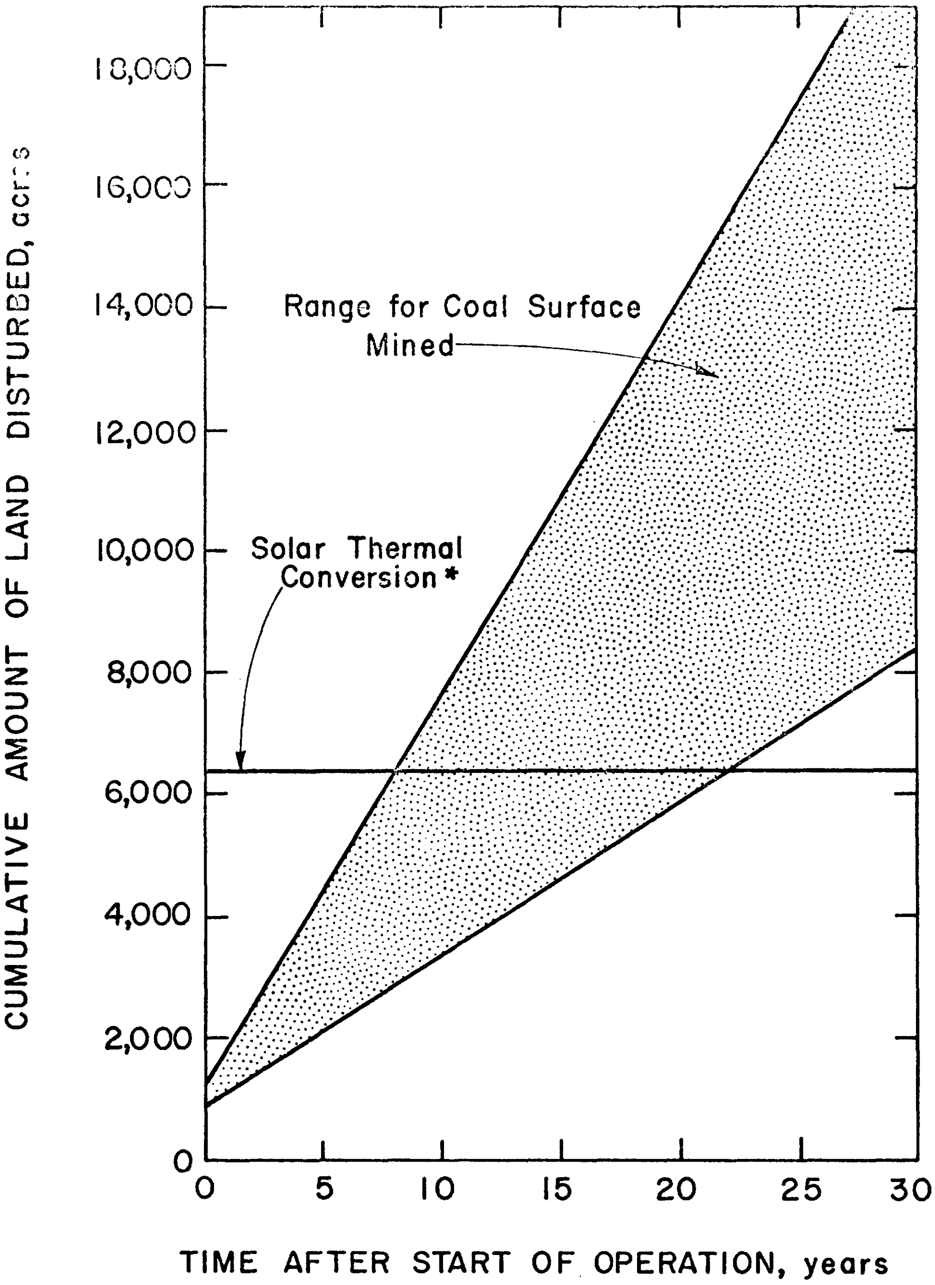
Microwave transmission of power from satellite photovoltaic systems to earth could pose a hazard to human health. Man's tolerance of microwaves has been estimated at between 100 mW/cm^2 (in the U.S.) and 0.01 mW/cm^2 (in the U.S.S.R.) with present conceptual designs for the satellite-to-earth power beam at 30 mW/cm^2 (Michaelson, 1971).

Some data about the effects of photovoltaic systems are contained in Table 3.4

3.3 Solar Heating and Cooling - Single Users

The principal impact of the collectors required by a solar heating and cooling system would be aesthetic, and this tends to be very type- and site-specific. Redistribution of heat would be small. Accidental release of toxic cadmium during a home fire where $CdS\text{-}Cu_2S$ cells are in use might be a problem with about 12.4 kilograms of cadmium being released from such an incident (FEA, 1974, Solar Report, p. VII-20).

Figure 3.1



Comparison of Land Disturbed from
Surface-Mined Coal and Solar Electric 1000-Mwe Power Plant

Source: (CEQ, 1975)

* In Southwestern U.S.

Table 3.1 Annual Environmental Impacts from Operation of 1000 MWe Solar Thermal Power Plant with Load Factor of 0.75[a]

Impact	Extraction	Processing	Transport	Conversion	Transmission	Total
Land, sq. miles	0	0	0	35[b]	26.8	62
Water, tons	0	0	0	60[c]	0	60
curies	0	0	0	0	0	0
Btu	0	0	0	10×10^{13}	0	10×10^{13}
Air, tons	0	0	0	0	0	0
curies	0	0	0	0	0	0
Solid or Liquid Waste, tons	0	0	0	0	0	0
curies	0	0	0	0	0	0
Occupational Deaths	0	0	0	0.009	u	0.009+
Injuries	0	0	0	1.09	u	1.09+
Workdays lost	0	0	0	120.4	u	120.4+

+ = Summation includes unknown item

u = unknown

[a] Figures are from (Beall, et al., 1974, 115) unless otherwise noted.

[b] For New England, see text.

[c] Assumed amounts of anti-fouling and anticorrosion materials from cooling towers.

Table 3.2

Solar Thermal Heat Conversion Using a Central Receiver

(per 10^{12} Btu Input of Solar Energy)

(All values in tons unless noted)

Primary Efficiency (fraction)	1.76 E-01
Total Air	0
Acid	u
Base	0
Phosphates	u
Nitrates	0
Other Dissolved Solids	u
Total Dissolved Solids	u
Non-Degradable Organics	u
BOD	u
COD	0
Thermal (Btu)	0
Total Solids + Organics	0
Anti-Biofouling Agent	1.8E+02
Solid Wastes	0
Land (acres)	9.6E+01
Water (acre-ft)	1.1E+04

u = unknown

- = unlisted

Source: (Teknekron, 1977, p. 217)

Table 3.3

Yearly Quantity of Solar Thermal Emissions

for 1000 MWe Facility (Boiler Blowdown)

(Teknekron, March 1975)

	Tons
Suspended solids	2490
Organics	331
BOD	12
H_2SO_4	413
Cl_2	132
Phosphates	209
Boron	1656
Chromates	12

Table 3.4 Annual Environmental Impacts from Operation of 1000 MWe Terrestrial Solar Photovoltaic Power Plant with Load Factor of 0.75

Impact	Extraction	Processing	Transport	Conversion	Transmission	Total
Land, sq. mil	0	0	0	10	26.8	37
Water, tons	0	0	0	u	0	u
curies	0	0	0	0	0	0
Btu	0	0	0	0	0	0
Air, tons	0	0	0	0	0	0
curies	0	0	0	0	0	0
Solid or Liquid Waste, tons	0	0	0	0	0	0
curies	0	0	0	0	0	0
Occupational Deaths	0	0	0	0.009[a]	u	.009+
Injuries	0	0	0	1.09[a]	u	1.09+
Workdays lost	0	0	0	120.4[a]	u	120.4+

+ = Summation includes unknown item.

u = unknown

[a] Assumed same as solar thermal.

4.0 WIND ENERGY - ENVIRONMENTAL IMPACTS

The quest for very high, multiple locations for large windmills that are near population centers makes wind energy a potentially aesthetically displeasing power source. Turbine blades would be visible for miles (Beall, et al., 1974, p. 78). Although there are no studies to confirm it, it is generally felt that a single, very large power facility is aesthetically more pleasing than hundreds of smaller sources (Börnke, 1974). This goes directly contrary to the economics which generally show that smaller-sized (about 10 MWe) windmills would be optimal. Transmission lines, unless they are put underground, are also considered quite unsightly.

The environmental problems associated with the structure itself would be very small. Although there might be considerable human risks in building and maintaining a structure in a windy environment, these would be occupational hazards. It is unlikely that these structures would be built closely enough to buildings or thoroughfares to endanger the general public. If properly sited, hazards to aircraft, both from local air turbulence and collision with the structure, should be of very low probability. Some concern has been expressed (Beall, et al., 1974) that location of windmills too close together could alter prevailing wind patterns, but again careful siting would avoid this problem. Rotating windmill blades interfere with television and navigational radio frequency energy.

No studies have been performed concerning the pollution implicit in the fabrication and transport of these structures. These effects would not be negligible judging from the high, materials-intensive capital costs of windmills. Concrete and steel used per KW would be greater than fossil or nuclear facilities (Beall, et al., 1974, p. 79).

The land use by 1000 MWe of wind facilities would be a minimum of 2.0 square miles. This is exclusion area, to protect the public from broken blades and fallen towers, and is calculated assuming a 750 ft. by 750 ft. plot at the very least would be required for a 10 MWe windmill of 250 ft. height (Meyer, Jones, and Kessler, 1975). For an 850-ft. structure (Beall, et al., 1974) with a proportionately larger exclusion area and similar 10 MWe windmills, the 1000 MWe land requirement would be 5.8 square miles. (Some structures of 1200 ft. have been proposed [REA, 1975, p. 1636].) Additional land use would result from the network of roads required for maintenance access, for heavy guying that might be needed, and by the transmission rights-of-way. No estimates have been found of these requirements. There is likely, at any rate, to be heavy dependence upon already available road and transmission systems.

Although there is no basis for assessing the magnitude of the effect, the large, rotating blades may be potentially hazardous to birds, particularly during migration.

A summary of some of these effects is contained in Table 4.1. Primary efficiency is estimated at 31% conversion of wind motion (Teknekron, 1977, p. 224).

Table 4.1 Annual Environmental Impacts from Operation of 1000 MWe Wind Power Plant with Load Factor of 0.75

Impact		Extraction	Processing	Transport	Conversion	Transmission	Total
Land, sq. mil		0	0	0	5.8	32.6[a]	38
Water, tons		0	0	0	0	0	0
	curies	0	0	0	0	0	0
	Btu	0	0	0	0	0	0
Air, tons		0	0	0	0	0	0
	curies	0	0	0	0	0	0
Solid or Liquid Waste, tons		0	0	0	0	0	0
	curies	0	0	0	0	0	0
Occupational	Deaths	0	0	0	.009[b]	u	.009+
	Injuries	0	0	0	1.09[b]	u	1.09+
	Workdays lost	0	0	0	120.4[b]	u	120.4+

+ = Summation includes unknown item

u = unknown

[a] Using 17,188 acres for transmission as from conventional facility plus amount equal to exclusion area for transmission within grid (CEQ, 1973). A value of 14,700 acres is computed in (Teknekron, March 1975).

[b] Assumed same as solar thermal station.

5.0 SOLID WASTES - ENVIRONMENTAL IMPACTS

The various proposals for the use of solid wastes as fuel have very different environmental consequences. The direct combustion of urban solid wastes has been accomplished at several locations. For a 1000 MWe power plant, the wastes of a population the size of New York City would be required (Beall, et al., 1974, p. 64). Collection, transport, and public acceptance in such a project are considered to be immense problems, environmentally and socially. Organic wastes, particulates and NO_x would be the same as for coal plants, SO_x would be decreased due to 0.23 pounds sulfur per 10^6 Btu in waste (CEQ, 1975, pp. 10-16). The St. Louis experiment in waste and coal co-combustion resulted in air emissions as shown in Table 5.1. Ash accumulation was four to seven times that for straight coal-fired ash levels, even though only 15% of the heat input was from waste. Particulate emissions increased significantly and most water effluents increased, some probably requiring additional control equipment (BOD, dissolved oxygen, and suspended solid levels). Preprocessing of the urban wastes caused noise levels in excess of OSHA standards, and caused large amounts of dust containing significant levels of bacteria and viruses (Kilgroe, Shannon, and Gorman, 1976).

Table 5.1

Stack Gas Emissions from Coal-Refuse Co-Combustion System

Component	Coal(a)	Coal RDF(b)
H_2O, percent	6.8	8.6
SO_2, ppm	943	1067(c)
SO_3, ppm	9	8
NO, ppm	298	285
Cl^-, mg/m^3	335	402

(a) Average for 3 coal tests

(b) Average for 10 coal-refuse

(c) 13% increase in SO_2 emissions during coal-RDF tests resulted from a 24% increase in coal sulfur content.

RDF = refuse-derived fuel

Source: (Kilgroe, Shannon, and Gorman, 1976).

A facility fueled by waste products from lumber harvests offers some environmental advantages. Additional land use would be small, only that necessary for the power plant itself and for storage areas. The additional runoff of silt and the removal of wildlife shelters would probably be less significant than the environmental gain from removal of diseased wood. Lower efficiencies of such facilities would produce thermal pollution comparable to nuclear power plants. Air pollution would be minimal: wood is low in sulfur (about 0.1%) and combustion at this lower temperature would reduce NO_x formation (but might increase HC emissions). Ash, although in greater amounts, could be returned to the land. Emissions from additional efforts of collection and transportation might be significant.

Organic wastes conversion into oil or gas could amount, using the 1971 collectible agricultural residues of 130 million tons, to 2000 trillion Btu (Bureau of Land Management, 1973), or enough to service about thirty-five 1000 MWe plants. Sulfur contents of various oils produced from organic wastes would all comply with federal standards (Bureau of Land Management, 1973)(Table 5.2):

Table 5.2

Sulfur Contents of Synthetic Oils from Solid Wastes

	Percent Sulfur
Pine needes and twigs	0.10
Sewage Sludge	0.64
Municipal refuse	0.13
Cow manure	0.37
Cellulose	0.003 to 0.2

Transport of these wastes could result in significant pollution from the operation of the vehicles.

Conversion of solar energy by organic materials into methane could yield about 10^{15} Btu/year (Beall, et al., 1974) or enough to fuel about twenty 1000 MWe plants. Again, where organic materials are widely dispersed, collection and transport would involve significant environmental impacts. Explosions and fires from leaks would impose risks on the public but these are believed to be overshadowed by the general good resulting from proper waste disposal (Locke, 1970). Annual water consumption per 1000 MWe could be about 560,000 acre-ft (Oswald and Golenske, 1968) which could be a problem in a semi-arid land of the type that receives optimal quantities of sunlight. Water and sludge wastes could be a major barrier to process commercialization. As much as 40% of the starting material would require eventual disposal (CEQ, 1975, p. 10-8). Air pollutants would be in the form of CO_2, H_2O, H_2S, and NH_3. The production of methane also includes odors from the transport and storage of the necessary wastes; similar operations at sewage facilities frequently generate complaints from the nearby populace. Land use would be small.

Available information on solid waste emissions is shown in Tables 5.3, 5.4, 5.5, and 5.6.

Table 5.3 Annual Environmental Impacts from Operation of 1000 MWe Urban Solid Waste Fueled Power Plant with Load Factor of 0.75[a]

Impact	Extraction	Processing	Transport	Conversion	Transmission	Total
Land, sq. mil	0	0	0	1.1	26.8	28
Water, tons	0	0	0	810	0	810
curies	0	0	0	0	0	0
Btu	0	0	0	5.29×10^{13}	0	5.29×10^{13}
Air, tons	0	0	2.6×10^{4}	2.9×10^{5}	0	3.2×10^{5}
curies	0	0	0	0	0	0
Solid or Liquid Waste, tons	0	0	0	3.5×10^{4}	0	3.5×10^{4}
curies	0	0	0	0	0	0
Occupational Deaths	0	0	2.30	.012	u	2.3+
Injuries	0	0	23.4	1.38	u	24.8+
Workdays lost	0	0	2340	153	u	2500+

+ = Summation includes unknown item

u = unknown

[a] Data from (CEQ, 1973) coal facility and (Teknekron, 1977) data on co-combustion.

Table 5.4

Urban Solid Waste as Fuel for Power Plants

(per 10^{12} Btu Input Energy)

(All values in tons unless noted)	Co-Combustion with Coal
Primary Eff. (fraction)	3.4E-01
Acids	1.34E00
Bases	0
Phosphates	6.78E-01
Nitrates	0
Other Dis Solids	5.84E00
Total Dis Solids	7.86E00
Suspended Solids	8.08E00
Non-Degrad Organics	1.08E00
BOD	3.9E-02
COD	0
Thermal (Btus)	1.3E09
Total Solids + Organics	1.70E01
Particualtes	1.60E02
NO_x	1.50E02
SO_x	1.92E02
HC	u
H_2S	u
CO	u
Aldehydes, etc.	u
Total Air	5.02E02
Solid Wastes	0
Land (acres)	5.8E-01
Water (acre-ft)	1.52E04

u = unknown

Source: (Teknekron, 1977)

Table 5.5

Bioconversion of Wastes into Methane (per 10^{12} Btu Input Energy)

(All values in tons unless noted)	Transport of Wastes	Conversion of Agricultural Wastes to Methane	Anaerobic Conversion of Urban Wastes to Methane
Primary Efficiency (fraction)	equivalent to physical loss of 10%	1.8E-01	3.8E-01
Thermal (Btu)	-	0	0
Water (acre-ft)	0	1.5E+02	0
Total Solids + Organics	-	u	0
Particulates	7.3E-02	-	u
CO	1.3E+00	u	-
CO_2	-	8.4E+02	2.5E4
Total Air	3.8E+00	1.1E+03	2.5E4
H_2S	-	2.6E+02	-
NH_3	-	u	u
Solid Wastes	0	0	7.0E4
Land (acres)	2.3E+00	3.2E+00	3.0E1
SO_x	1.5E-01	-	u
NO_x	2.1E+00	-	-
HC	2.1E-01	-	-
Aldehydes, etc.	1.7E-02	-	-

u = unknown; - = unlisted. Source: (Teknekron, 1977, p. 230 and p. 236).

Table 5.6

Bioconversion of Urban Wastes into Clean Fuel Gas (per 10^{12} Btu Input Energy)

(All values in tons unless noted)	Pyrolysis with Air	Pyrolysis with O_2
Primary Eff. (fraction	8.0E-01	7.5E-01
Acids	u	3.22E2
Bases	u	0
Phosphates	u	-
Nitrates	u	-
Other Dis Solids	u	0
Total Dis Solids	u	3.22E2
Suspended Solids	u	0
Non-Degrad Organics	u	1.01E3
BOD	u	0
COD	u	0
Thermal (Btu)	u	u
Total Solids + Organics	u	1.32E3
Patriculates	3.33E01	0
NO_x	u	0
SO_x	u	0
HC	0	-
H_2S	u	2.2E-02
CO	u	u
Aldehydes, etc.	u	-
Total Air	u	5.56E03
Solid Waste	0	0
Land (acres)	9.0E00	2.0E00
Water (acre-ft)	6.8E04	2.5E05

u = unknown

\- = unlisted

Source: (Teknekron, 1977)

6.0 GEOTHERMAL-ENVIRONMENTAL IMPACTS

The different types and the different sites for geothermal energy present significantly different environmental problems. In general, however, effects will be limited to the area above the primary thermal cells (about 20 by 15 miles) and, more specifically, above the local thermal cells (about 5 by 6 miles) (Beall, et al., 1974, p. 22).

Utilization of hot rocks has not been investigated sufficiently to enable comment on environmental effects. For the other types of geothermal energy, the impacts begin with reconnaissance roads, blasting, and drilling. Water impacts include siltation, contamination from spills and blowouts, and degradation of springs and aquifers. Boron, fluorides, arsenic, chloride salts, carbonates, and other dissolved minerals in the water can either be reinjected or possibly recovered in ponds. Land use and possible gaseous releases from such ponds would require careful study. Because geothermal facilities operate on small temperature differences, thermal efficiency can range from 22,000 to 25,000 Btu/KWhr, or 1/2 to 1/3 the efficiency of conventional systems (Beall, et al., 1974, p. 29). With wet cooling towers at a 1000 MWe facility, this would result in the consumptive use of 60 million gallons of water per day. There may be beneficial uses for the waste heat, such as desalination of water where brines are the local fluid.

Air pollutants can include damaging amounts of H_2S, NH_3, methane, fog-producing humidity, mercury, and radioactive noble gases (mainly argon) (see Table 6.1). For a 1000 MWe plant, about 10 to 45 square miles of land would be needed for steam lines and installations, with about 12 more square miles necessary eventually (Beall, et al., 1974) for replacement wells (and this does not include the land use demands that would be made by access roads and transmission). These lands would be completely lost to recreation and partially lost to the land wildlife communities, although the major impact to wildlife would be to the aquatic communities exposed to toxic and heated effluents. Noise levels have been known to reach 65 dB at 1500 feet (Beall, et al., 1974, p. 25)(see Table 6.2).

Potential hazards of these facilities include: during development -- blowouts, brush fires, landslides and brine flow; during operation -- seismic activity from fluid withdrawal or reinjection, and ground subsidence. Some data on emissions follow in Tables 6.3, 6.4, and 6.5.

Table 6.1

Yearly Quantity of Geothermal Emissions for 1000 MWe Facility

(Teknekron, March 1975)

Water emissions:	Tons
Akalinity as HCO_3^-	5070
Ammonia	1750
Sulfide	23.6
Sulfate	1549
Free Sulfur	98.6
Nitrate	1.18
Chloride	41.3
Calcium	62.6
Magnesium	11.8
Silica	44.2
Boron	202
Total Solids by Evaporation	2190
Organics and Volatile Solids	2440
Air emissions:	
CO_2	487,000
NH_3	43,900
CH_4	36,300
H_2S	12,100
N_2, A	21,800
H_2	7,250

Table 6.2

Noise from Geothermal Operations

Operations	Distance Measured (feet)	Noise Level[a] (decibels)
During air dilling of a well	25	125
	1,500	55
Muffled testing well	25	100
	1,500	65

[a] For comparison: jet aircraft takeoff noise is approximately 125 decibels (dB) at 200 feet.

Source: (CEQ, 1975, pp. 8-10)

Table 6.3 Annual Environmental Impacts from Operation of 1000 MWe Geothermal Power Plant with Load Factor of 0.75[a]

Impact	Extraction	Processing	Transport	Conversion	Transmission	Total
Land, sq. mil	12	0	0	33	26.8	72
Water, tons	Nil	0	0	Nil	0	Nil
curies	Nil	0	0	Nil	0	Nil
Btu	0	0	0	15x10^{13}	0	15x10^{13}
Air, tons[b]	0	0	0	1.65x10^{5}	0	1.65x10^{5}
curies	0	0	0	u	0	u
Solid or Liquid Wastes, tons	u	0	0	returned to reservoir	0	u
curies	0	0	0	Nil	0	Nil
Occupational Deaths	0.04	0	0	0.002	u	.042+
Injuries	2	0	0	0.13	u	2.13+
Workdays lost	286	0	0	17	u	303+

[a] Source is (Beall *et al*., 1974) unless otherwise noted.

[b] Excluding water and CO_2 (Finney, 1972).

Table 6.4

Geothermal Extraction Emissions

(per 10^{12} Btu Input Energy)

	Steam-Dominated Hard Rock	Liquid-Dominated Hard Rock	Hot Dry Rock
(All values tons unless noted)			
Primary Efficiency (fraction)	1.5E-01	u	u
Thermal (Btus)	0	0	0
Total Solids + Organics	0	0	0
Total Air	0	0	0
Solid Waste	-	-	2.4E+01
Land (acres)	1.5E+00	1.5E+00	3.3E-01
Water (acre-ft)	0	0	3.1E+02
Occupational Deaths	u	-	u
" Injuries	u	-	u
" Man-days lost	u	-	-

u = unknown

- = unlisted

Source: (Teknekron, 1977, pp. 30-37)

Table 6.5

Geothermal Power Plant Conversion

(per 10^{12} Btu Input Energy)

(All values tons unless noted)	Steam-Dominated Hard Rock	Liquid, Binary System
Primary Efficiency (fraction)	1.4E-01	1.2E-01
Thermal (Btus)	0	0
Total Solids + Organics	0	0
Particulates	0	0
NO_x	0	0
SO_x	0	0
HC	6.7E+01	0
H_2S	7.7E+01	-
CO	0	0
NH_3	6.7E+01	-
Total Air	1.34E+03	-
Solid Wastes	0	-
Land (acres)	2.36E-01	2.4E-01
Water (acre-ft)	0	3.0E+04

- = unlisted

Source: (Teknekron, 1977)

7.0 FUEL CELLS - ENVIRONMENTAL IMPACTS

Because of the efficiencies in the range of 50-55% (Meyer, Jones, and Kessler, 1975), fuel cells would consume about two-thirds of the fossil fuel of a conventional facility, thus consumptive use of land for extraction purposes would be less. Thermal pollution is thus proportionately less than at a coal facility and air pollutants are limited to CO_2 and small fractions of other pollutants (see Table 7.1).

Table 7.1

Comparative Air Pollutant Levels of 1000 MWe Power Plants at 0.75 Load Factor (Schurr, 1971)

	Gas-fired station	Fuel cells
Sulfur dioxide (lbs)	1970	2
Nitrogen oxides (lbs)	26300	1600
Hydrocarbons (lbs)	18400	1500
Particulates (lbs)	660	.2

The fuel cell power plant was originally conceived to be the answer for a "non-polluting" electric power plant. At that time a hydrogen/oxygen fuel cell was envisaged. The production and handling of hydrogen and oxygen cells presents very serious problems which are expensive to solve.

Next, fuel cells operating on natural gas and very light distillates (alcohols, naptha, etc.) were anticipated. Since the embargo of 1973/74 and the natural gas shortage of 1976/77 this type of fuel cell plant has had to be discarded.

The present thinking is that fuel cells can be made to operate satisfactorily from fuels derived from coal. The reforming of coal into a suitable fuel cell fuel means that all of the problems of mining, distribution, gasification and disposal of the solid wastes associated with the use of coal will still exist.

Other beneficial effects of fuel cells result from a quietness, size, and low waste level which enable small installations to be sited locally, reducing transmission needs to one-third or less of conventional needs.

Table 7.2 presents a general fuel cycle view of important pollutants; Tables 7.3 and 7.4 show lists of specific concerns and chemicals emitted, and Tables 7.5, 7.6, and 7.7 show quantification of effluents (Kalfadelis, et al., 1976) from a large fuel cell facility that includes a coal gasification plant.

Table 7.2 Annual Environmental Impacts from Operation of 1000 MWe Coal-Fired Fuel Cell Power Plant with Load Factor of 0.75[a]

Impact	Extraction	Processing	Transport	Conversion	Transmission	Total
Land, sq. mil	32.9	.2	2.3	.6	9	45
Water, tons	23900	2570	0	813	0	26300
curies	0	0	0	0	0	0
Btu	0	0	0	2.0×10^{13}	0	2.0×10^{13}
Air, tons	u	3200	1.8×10^{4}	870	0	2.2×10^{4}+
curies	0	0	0	0	0	0
Solid or Liquid Waste, tons	1.82×10^{6}	3.0×10^{5}	0	0	0	2.1×10^{6}
curies	0	0	0	0	0	0
Occupational Deaths	.206	.016	1.53	.009	u	1.76+
Injuries	9.3	1.7	15.6	1.09	u	27.7+
Workdays lost	330	66	1560	120	u	2080+

+ = Summation includes unknown item

u = unknown

[a] Assumed similar to a gas-fired facility in conversion aspects and to a coal facility in extraction and transport aspects.

Table 7.3

EMISSIONS AND EFFLUENTS FROM FUEL CELL POWERPLANT

Emissions to Atmosphere	Potential Concerns
Wind action on coal storage and handling	Dust, fire, odors
Wind action on ash	Dust
Water vapor from coal grinding	Dust, H_2S
Cleaned flue gas	NO_x, plume dispersion, dust, SO_x, P.O.M.
Vacuum pump on steam condenser	Minor
Air and mist from cooling tower	Plume, mist deposition, trace chemicals
Possible fugitive dust from area and iron oxide preparation	Dust nuisance
Transients due to upsets, cleaning, etc.	Dust, smoke, fumes
Potential noise and odors	Machinery, maintenance
Effluents - Liquids and Solids	
Rain runoff - coal and waste areas	Suspended and dissolved matter
Ash slurry	Ground water contamination
Slurry of waste from sulfur recovery cleanup	Ground water contamination and land use
Sludge and chemicals from water treating	Minor
Waste electrolyte	Ground water contamination
Trace Elements	
Leaching associated with disposal of ash	Soluble toxic elements
Fate of volatile toxic elements in coal feed	Contamination of local air and water; effect on fuel cell life
Emissions as gas and P.M. and P.O.M. with stack gas	Hazards to life

Source: (Kalfadelis, *et al.*, 1976)

Table 7.4

CHEMICALS USED IN RECIRCULATIVE COOLING WATER SYSTEMS

Use	Chemical
Corrosion inhibition or scale prevention in cooling towers	Organic phosphates Sodium phosphates Chromates Zinc salts Synthetic organics
Biocides in cooling towers	Chlorine Hydrochlorous acid Sodium hypochlorite Calcium hypochlorite Organic chromates Organic zinc compounds Chlorophenates Thiocyanates Organic sulfurs
pH control in cooling towers	Sulfuric acid Hydrochloric acid
Dispersing agents in cooling towers	Lignins Tannins Polyacrylonitrile Polyacrylamide Polyacrylic acids Polyacrylic acid salts
Biocides in condenser cooling water systems	Chlorine Hypochlorites Sodium pentachlorophenate

Source: (Kalfadelis, et al., 1976)

Table 7.5

POWERPLANT PERFORMANCE SUMMARY
GASEOUS AND THERMAL EMISSIONS

	Plant Effluent	Solid Fuel Standards
SO_2, μg/J	0.32	0.52
NO_x, μg/J	<.013	0.30
HC, μg/J	Negligible	--
CO, μg/J	6.8	--
Particulate, μg/J	<0.039	0.043

Thermal Pollution

Heat Rejected - Cooling Towers	1.830 MJ/kWh
Heat Rejected - Stack	0.30 MJ/kWh
Heat Rejected - Total (1)	3.62 MJ/kWh

---

(1) Includes total plant losses

Source: (Kalfadelis, *et al.*, 1976)

Table 7.6

BASE CASE ESTIMATE OF POTENTIAL TRACE ELEMENTS DISCHARGED TO ATMOSPHERE WITHOUT SCRUBBER

Element	ppm in Coal (Dry Basis)	Average % Emitted	Emitted[b] kg/d
Antimony	0.5[a]	25	0.81
Arsenic	8 - 45	25	13 - 73
Beryllium	0.6 - 7.6	25	1.0 - 12
Boron	13 - 198	25	21 - 320
Bromine	14.2[a]	100	92.0
Cadmiun	0.14[a]	35	0.32
Chlorine	400 - 1000[a]	100	2600 - 6500
Fluorine	50 - 167	100	320 - 1100
Lead	8 - 14	35	18 - 32
Mercury	.04 - .49	90	0.2 - 2.9
Molybdenum	0.6 - .49	25	1.0 - 14
Selenium	2.2[a]	70	10.0
Vanadium	8.7 - 67	30	17 - 130
Zinc	0 - 53	25	0 - 86
TOTAL			3094 - 8373

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a. Not given in ECAS basis and therefore estimated

b. Based on a feed rate 6891 t/d of Illinois No. 6 coal

Source: (Kalfadelis, *et al*., 1976)

Table 7.7

POWERPLANT PERFORMANCE SUMMARY
LIQUID AND SOLID WASTE

Liquid		
Blowdown	152 m^3/h	0.23 dm^3/kWh
Gasifier Boiler	5.9	
Steamplant Boiler	21.1	
Cooling Tower	125.0	
Sulfur	6.1 t/h	9.1 g/kWh
Solid (Ash)	20 t/h	32 g/kWh

Source: (Kalfadelis, et al., 1976)

8.0 OCEAN THERMAL - ENVIRONMENTAL IMPACTS

An ocean thermal power plant would cause a significant warming of deep water and cooling of surface water. Although the temperature change would only be a few degrees, this kind of magnitude is currently of great concern for shoreline power plants; in addition, ocean fauna are generally more sensitive than estuarine fauna (Paskausky, 1974).

The upwelling of deep waters rich in nitrate and phosphate nutrients might lead to significant increases in useless blue-green algae populations. Algae growth could lead to unexpected events such as Crown of Thorns invasions as on Pacific reefs. Growth of reefs and reef animal populations would likely be inhibited.

On a positive side, natural upwellings occur in a few places around the world, and fish production is improved as a result (Beall et al., 1974, p. 72). Experiments (Gerard and Roels, 1970) have shown significant increases in phytoplankton production in raised water with potential mariculture of marketable products such as shrimp.

Air pollution could result from the accidental release of the inventory of working fluids. For some fluids (freon), evaporation could cause significant local contamination of the atmosphere; for other fluids (propane), explosion and fire hazards would exist. Other soluble fluids (ammonia) could be very disruptive to local aquatic life.

Experience with offshore oil rigs has demonstrated that with sufficient care, navigational hazards posed by these large, floating facilities would be minimal. Climatic and aesthetic impacts (avoiding nearshore sites in Hawaii, Puerto Rico, Florida, and California) would be minimal (Beall, et al., 1974, p. 73). About 60 square miles of ocean would support a 1000 MWe facility (Meyer, Jones, Kessler, 1975).

The arguments about the positive or negative nature of ocean thermal plant environmental impacts will persist until pilot plants are operated at the various different site types (FEA, 1974). Sites close to shores and estuaries will require particularly careful study.

Some data on environmental effects of ocean thermal plants are collected in Table 8.1.

Table 8.1 Annual Environmental Impacts from Operation of 1000 MWe Ocean Thermal Power Plant with Load Factor of 0.75[a]

Impact	Extraction	Processing	Transport	Conversion	Transmission	Total
Land, sq. mil	0	.1[b]	0	60(at sea)	26.8	87
Water, tons	0	0	0	u	0	u
curies	0	0	0	0	0	0
Btu	0	0	0	0	0	0
Air, tons	0	0	0	0	0	0
curies	0	0	0	0	0	0
Solid or Liquid Waste, tons	0	0	0	0	0	0
curies	0	0	0	0	0	0
Occupational Deaths	0	0	0	u	u	u
Injuries	0	0	0	u	u	u
Workdays lost	0	0	0	u	u	u

u = unknown

[a] Most values from (Teknekron, 1977, p. 200).

[b] (Perrigo and Jensen, 1976, p. 23).

9.0 WAVES AND CURRENTS - ENVIRONMENTAL IMPACTS

Wave power technology and ocean and riverine current technology have not been evaluated by any of the studies on comparative environmental impacts. The modification of normal wave action and current flows by these devices may have an effect on the ecosystems in the near shore areas and in the rivers.

With sufficient design it would be possible to locate these devices so as to cause minimal navigation hazards. There may be advantages to wave energy extractors which serve as breakwaters. About 40 to 160 nautical miles of wave energy devices, or 500 to 1000 current devices of 300 m^2 turbine area would be required for 1000 MWe of generation.

Some data have been generated on the environmental effects of wave energy and riverine current energy devices, as shown in Tables 9.1 and 9.2.

Table 9.1 Annual Environmental Impacts from Operation of 1000 MWe Wave Energy Device with Load Factor of 0.75

Impact	Extraction	Processing	Transport	Conversion	Transmission	Total
Land, sq. mil	0	.1	0	25-100(at sea)	26.8	52-127
Water, tons	0	0	0	u	0	u
curies	0	0	0	0	0	0
Btu	0	0	0	0	0	0
Air, tons	0	0	0	0	0	0
curies	0	0	0	0	0	0
Solid or Liquid Waste, tons	0	0	0	0	0	0
curies	0	0	0	0	0	0
Occupational Deaths	0	0	0	u	u	u
Injuries	0	0	0	u	u	u
Workdays lost	0	0	0	u	u	u

u = unknown

Table 9.2 Annual Environmental Impacts from Operation of 1000 MWe Riverine Current Device with Load Factor of 0.16

Impact	Extraction	Processing	Transport	Conversion	Transmission	Total
Land, sq. mil	0	.1	0	600+	26.8	627+
Water, tons	0	0	0	u	0	u
curies	0	0	0	0	0	0
Btu	0	0	0	0	0	0
Air, tons	0	0	0	0	0	0
curies	0	0	0	0	0	0
Solid or Liquid Waste, tons	0	0	0	0	0	0
curies	0	0	0	0	0	0
Occupational Deaths	0	0	0	u	u	u
Injuries	0	0	0	u	u	u
Workdays lost	0	0	0	u	u	u

+ = Summation includes unknown item

u = unknown

10.0 REFERENCES

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