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ASSESSMENT OF THE SOCIO-ECONOMIC AND ENVIRONMENTAL ASPECTS OF THE CENTRAL RECEIVER POWER PLANTS*

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The central receiver concept[1,2,3] for a solar thermal power plant is presently being pursued by ERDA. There are several aspects of this concept of an environmental or ecological nature which will be discussed here. A severe, direct environmental implication of this technology appears to be destruction of the local ecosystem at and near plant sites. Another significant problem is the water necessary for plant cooling and construction in arid locales. The power plants could modify local and regional climate, but this subject is complicated by many factors and no credible model has as yet been developed to analyze it. Material requirements for these plants, at a level of construction of 8 gWe per year, would appear to have only minor effects on the economy.

Land Requirements: For intermediate load power plants, various estimates of land requirements suggest approximately 2 Km^2 per 100 mWe. For base load plants this number would be 3-4 Km^2 per 100 mWe. These numbers do not include secondary effects such as road construction, increased population, new land devoted to meeting water requirements (i.e. desalinization, canals, dams, etc.), or land affected by storage facilities (i.e. hydroelectric reservoirs). The total mirror area of a 100 mWe intermediate load plant (6 hours of storage) is expected to be about .9 Km^2.

Material Requirements: Material requirements vary greatly with design scheme. The estimates of Table I for steel, glass, and concrete are based on private communications with several ERDA contractors for heliostat design. They are not official and improved estimates may show considerable change.

We have used these material requirements in an input/output model to analyze the effects on the economy and also the effluents produced. Although our results are quite preliminary, we find that for a construction rate of 8 gWe annually the impact on the U.S. economy is relatively small. The steel requirements would be about 2.5% of 1972 output. The cement requirements about .4% of 1972 output, and the glass requirements about 4.5%. All major air pollutants from producing these materials appear to be less than 1% of national totals.

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Ecology: Solar plants will most likely be constructed in arid regions where the ecosystem is certain to be affected. Some effects may be similar to off-road vehicle traffic in deserts[4,5] since much transporting of equipment will be necessary. For example, burrowing animals will be destroyed in large number during the construction period. This effect is a concern since most desert animals spend many of the sunlit hours underground, where it is cooler and moister than the hot arid surface. The magnitude of this effect will depend on intensity of construction and location. Locations near waterholes are highly populated, whereas desert playas (saline remnants of ancient lakes) are sparsely populated.

Fine materials are abundant in the desert but these are usually formed into a thin carapace or crust of the surface which is strong, dense, relatively impermeable, and protects the underlying fines from erosion, especially wind erosion[6]. This crust can be up to 3mm thick and may be promoted by algae or lichen growth at the surface. The main cause for the formation of the crust appears to be compaction resulting from rainfall. In addition to the solar plant itself, increased population in a region, resulting from the presence of solar plants, may lead to increased disruption of fragile desert crusts. Since the crust acts as a sealant for the fines beneath the surface, when it is broken an increase in turbidity can be expected. With increased wind erosion, degration of soil quality can occur which could reduce the flora and fauna populations supportable by the region.

Over a period of many years, many areas of deserts have developed a surface of fairly densely packed pebbles and stones. This surface is called desert pavement[7]. It forms from gravels, cobbles, and stones accumulated on dry land as a result of wind or water carrying away the finer particles of sand, silt, and clay. The pavement is naturally cemented together with various salts, gypsum, lime, and silicate; and it retards water runoff and erosion. When it is broken by off-road vehicles or by construction activity, considerable erosion and runoffs can result.

If central receiver plants are built in basins or playas where significant evaporation of ground water occurs, then they will reduce the evaporation rate and thus raise the water table to some extent. The magnitude of this effect will depend on the evaporation rate of the particular site, the fraction of the basin or playa covered with the heliostats and, possibly, the design of the helrostats. The reduced evaporation rates and, possibly, raised water table may alter the local ecosystem.

The glare from heliostat fields in the flight paths of birds may affect their ability to fly and navigate. Some birds may venture close to the central receiver and be burned or blinded by the intense radiation. Site specific experiments must be performed to analyze this possibility adequately.

Water Requirements: Water supply could be a serious problem for central receiver power plants. Evaporative cooling devices are probably ruled out because of water scarcity in the southwest. Table II shows the 1968 water supply in the southwest together with expected deficits for the year 2000.[8] Even with dry cooling towers, construction and increased population will place increased demand on the already scarce water supply.

Climate Effects: Questions of climate may be roughly classified into three general categories: local (a scale of several to tens of kilometers), regional or mesoscale (a scale of hundreds to thousands of kilometers), and global. Global questions are currently the least ambiguous since well thought-out general circulation models may be used to study them. Often, back of the envelope calculations may be used to give a rough idea of the magnitude of an effect. We will attempt such a calculation here for the question of global average temperature change induced by solar energy utilization.

Approximate the earth as a radiator which obeys the T^4 radiation law characteristic of a black body. It radiates energy approximately as $\varepsilon\sigma\, 4\pi\, R_e^{\,2}\, T^{\,4}$, where σ is the Steffan-Boltzman constant, T_n the average temperature of the earth's surface, ε a positive constant less than 1, and R_e the radius of the earth. The total outgoing radiation must be balanced by the total incoming radiation which is $S\pi R_e^{\,2}\,(1-\bar{\alpha})$, where S is the solar constant and $\bar{\alpha}$, the average planetary albedo of the earth, is approximately 36%.[9] The radiation balance equation is

$$S\pi R_e^{2}\,(1-\bar{\alpha}) = \varepsilon\sigma 4\pi R_e^{2}\, T_N^{\,4} \qquad (1)$$

Next, imagine modifying the radiation balance by building many central receiver power plants in desert locations. For the sake of an upper bound consider a world population of 10 billion and a per capita energy use of $10\mathrm{KW_e}$ base load power. Assuming current conversion efficiencies, the mirror area needed to generate this amount of power is from $1.5 \times 10^6\mathrm{Km}^2$ to $2.0 \times 10^6\mathrm{Km}^2$. Let us take the larger limit. At any given time, on the average, half of these mirrors will see the sun, and they will be tracking it. Approximate the actual situation by assuming that the mirror normals always point directly at the sun. This will overestimate the effect, but should not affect the result by more than a factor of 2. Let the total mirror area be denoted by $A_R = 2 \times 10^6\mathrm{Km}^2$. In this approximation a cross sectional area of $\frac{1}{2} A_R$, located in deserts, becomes essentially completely absorbing. The net radiation gain over the natural case is $S\frac{1}{2}A_R\,(1-(1-\alpha_D))$, where α_D is the albedo of the desert ($\alpha_D \simeq .25$ to $.3$). If T is the earth's temperature in this new situation we find

$$\varepsilon\sigma 4\pi R_e^{2}\,(T^4 - T_N^{\,4}) = S\tfrac{1}{2}A_R(1-(1-\alpha_D))$$

$$\simeq 4\varepsilon\sigma 4\pi R_e^{2}\, T_N^{\,4}\, \frac{T-T_N}{T_N}\,, \qquad (2)$$

this simplifies to

$$S\tfrac{1}{2}A_R\ (\alpha_D) = 4S\pi R_e^2\,(1-\bar{\alpha})\ \frac{T-T_N}{T_N}\ , \tag{3}$$

or,

$$T-T_N = \frac{1}{8}\ \frac{\alpha_D}{1-\bar{\alpha}}\ \frac{A_R}{\pi R_e^2}\ T_N\ . \tag{4}$$

Using a value of .3 for α_D and 285°K for T_N, we find

$$T-T_N \simeq .25^\circ\mathrm{K}. \tag{5}$$

This is a fairly modest increase considering the level of construction. There are natural phenomena such as volcanoes and ice ages which lead to much larger temperature changes. Burning of fossil fuels to meet this energy demand would raise the temperature of the earth approximately three times as much. Other climatic effects might be considerably more dramatic than this temperature shift. It has been suggested[10,11] that overgrazing in the Sahel region of the Sahara caused the recent drought there by modifying the local albedo. The modification that we are considering is far greater than that case. These questions ought to be examined more carefully in the context of existing atmospheric models.

Conclusion: The subject of environmental effects of solar energy is not as bland and uninteresting as one might at first imagine. The local ecological problems we have mentioned appear to be significant. The possibility that solar plants could be sited so as to increase the water table deserves further study. Climatology of solar plants is another interesting but complicated research topic which ought to get more attention. The effects of material requirements at a level of 8 gW_e construction per year appears to be a small perturbation on the U.S. economy based on an input-output model, and the effluents associated with these materials are also small (less than 1% of national production for all pollutants for which we were able to find data).

TABLE I

Heliostat Materials/m^2 of Reflector Surface

Material Contractor	Steel	Concrete	glass
Boeing	62 lb.	603 lb.	0
Honeywell	113 lb.	362 lb.	12.0 lb.
MacDonell Douglas	63.6 lb.	273 lb.	35.0 lb.
Martin Marrietta	102 lb.	N.A.	16.0 lb.
Average	85 lb.	413 lb.	16.0 lb.

TABLE II

Water Resource Region	1968 Supply*	Expected Deficit (2000)**
Rio Grande	.1	2%
Upper Colorado	2.3	2%
Lower Colorado		
Great Basin	.3	1.7%
California	6.8	1.8%

* Billions of gallons per day 90% of months.

** Assuming the 90% of months flow rate.

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