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AN ECOLOGIST'S PERSPECTIVE ON ELECTRICAL POWER*

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The issues of the environmental crisis have been explored and re-explored in recent years to the point where it is understandable that many of my colleagues on this program express impatience with further exploration. Professor Williams' discussion of the imminent problems of the next generation of power reactors emphasizes nonetheless the need to consider again two of these issues. Williams has discussed the difficulties of regulation of atomic energy used in the production of power. There appears to be a broad consensus among those experienced with reactors that, if we follow the rules, nuclear power can be used safely and probably with less direct damage to the environment than an equivalent amount of energy produced from fossil fuels. But Professor Williams has shown that the rules are extraordinarily complex, reflecting a complex technology. There are potentially large profits to be made by violating the rules. It seems clear that we are entering the era of the breeder reactor with some assumptions, not only about the efficacy of a technology but also about the behavior of people. We assume that the reactors will work and that the

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rules we write for ourselves are also going to work. These are large assumptions. While I am convinced that we must proceed with the development of nuclear power, I am also convinced that this progress must be accompanied by an extraordinary exhibition of restraint. The need for restraint becomes clear from brief consideration of the two central issues of the crisis of environment--population and energy.

Despite some of the more flamboyant statements of this symposium there is almost no one, even the most optimistic among us, who believes that there will not be a doubling of the world population within the next 30 years and a doubling of the U. S. population within the next few decades at the most. It is also true that there are few who will deny that the problems of environment are in a large degree problems of interactions, interactions between people and between people and resources. It is elementary that as the number of people increases, the number of interactions increases. The number of interactions increases approximately as the square of the number of people, but the intensity of interactions varies in proportion to the amount of control that individuals exert over their environment. The most direct measure of the amount of control an individual has is his command of energy. Increasing the availability of energy to an individual provides him with a capacity to exploit more of the earth's resources of space, air, water, land and life. The interactions he has with others are increased in intensity and in frequency--and the need for regulation of the use of resources and of the behavior of individuals is increased. Obviously, the need for regulation is a direct function of the number and intensity of the interactions and we have seen that these rise more than exponentially. To fill this need we build governments with greater and greater complexities, piling rules and restrictions on further rules and further restrictions until the rules become so complicated that they are unworkable.

The problem of power is obviously very much larger than a series of simple technical problems that can be solved within the context of existing political and social systems. Simplifications and restraint are required if we are not to watch society crumble of its own complexity. Simplification is necessary to maintain the integrity of social systems. Restraint is necessary because the environment is no longer so large that it can be run by compromise among reasonable exploiters. We must now consider the limits of the earth's natural systems, fitting our activities into a finite world with much greater attention to basic laws of ecology. And this is the principal point I wish to address.

We build our society into a matrix of natural living systems that do a great deal toward stabilizing our environment and maintaining it as a wholesome place for man. It seems reasonable to assume that the continuance of an environment that is congenial to our interests requires the continuing function of the major living systems of the earth. How big can human activities get with respect to the rest of life before the costs become greater than man can pay and all aspects of life are progressively degraded? It seems doubtful that we will succeed in substituting energy based technologies for all of the functions of forests, for the functions of the biota of the oceans, or for the biota of coastal wetlands. These are simple systems in the limited sense that they run themselves. They do not require man-controlled energy to sustain them; they do their job in support of man without any tinkering from us. We will not succeed in building technologies that will do these jobs more cheaply. How can we measure the total function of these systems in support of man?

One of the approaches that ecologists have worked out over several years is through the flux of energy. Keeping in mind the age old principle of ecology that no single factor analysis is ever adequate, we may use as one criterion a comparison between the flux of energy through natural systems and the flux of energy through man-dominated systems to arrive at some degree of equivalence between the constructive, sun driven functions of nature and the exploitive, fossil fuel powered activities of man. How large are these fluxes and what degree of equivalence exists?

The worldwide flux of solar energy is about 1.34×10^{21} kilocalories per year, giving a density of 2.62×10^{6} kilocalories per square meter (Table 1). The flux through the earth's biota is limited by the total amount of photosynthesis. We can estimate this on the basis of the net production of the earth. Worldwide the density is 1.2×10^{3} kilocalories per square meter per year in temperate zone forests. In agriculture the range is 0.9 to 1.8×10^{4} kilocalories per square meter per year or one-half to 1% of the flux of solar energy. The flux of energy through man-dominated systems can be measured by consumption of fossil fuels. Specific data are limited; the data of Table 1 were compiled on the basis of the average energy consumption by citizens in the United States.

Energy use in support of the technological segment of society is indicated in the lower section of Table 1. Worldwide about 5×10^{16} kilocalories per year are used in producing a density of 9.2×10 kilocalories per square meter. In the United States, where energy is used much more abundantly than in any other countries in the world, density is about 1.7×10^3 kilocalories per square meter. In the Long Island Sound region, which includes Long Island Sound, the coast of Connecticut as far inland as Hartford, and New York City, the density of energy use is 7.7×10^4 kilocalories per square meter. Thus on a worldwide basis we have a density of energy use of about 10^3 kilocalories per square meter. In a reasonably densely settled region the flux approaches 10^5 kilocalories per square meter as it does in the Long Island Sound region. This can be compared to a world flux of net production of about 10^3 kilocalories per square meter and a temperate zone flux of about 10^4.

We can draw from these numbers some inferences concerning the effects of man and the capacity of the biosphere to repair itself. While the topic is certainly open for considerable interpretation, the consensus emerging from detailed analyses of various aspects of biospheric change seems to be that the stability of the biosphere is not immediately in question. It seems reasonable to believe that current rates of energy use can be made compatible with a stable biosphere if we are willing to apply certain restraints on technology. The biota of the earth seems sufficient to repair the damage we do on the basis of our present use of energy. The damage occurs not simply through the production of energy, but through its use. We can draw from this the tentative conclusion that the disruptive influences of 1 kilocalorie of energy flux through industrial civilization is approximately cancelled by the repair mechanisms of natural systems that leave a net production of about 1 kilocalorie.

To test this assumption we might examine several different regions where the flux of energy through technology varies greatly. The Long Island Sound region in its entirety is such a place. The flux of fossil fuel and energy through various segments of the Long Island Sound region ranges from more than 200 times 10^4 kilocalories per square meter for Manhattan Island to about 4 x 10^4 for counties such as New Haven and Suffolk. In these counties the flux approximates the net production for temperate zone forests. While both counties have conspicuous environmental problems, solutions appear possible and the stability of environment seems not to be in serious question.

If it is true that 1 kilocalorie through technology is repaired by 1 kilocalorie through the mature natural vegetation of the region, then to repair the effects of man in the Long Island Sound region, including New York City, we would have to have about 9600 square miles of rich inshore estuaries or about 10 times the area of Long Island Sound. If we were to apply this to an area of ocean, which is much less productive than estuaries, 430,000 square miles would be required. The equivalent effect could be obtained from 20,000 square miles of the Eastern Deciduous Forest.

If there is any validity in this equation of the instabilities produced by technology as measured by the flux of energy and the repair processes carried out by natural ecosystems, then it is clear that the Long Island Sound region is parasitic on a large segment of the rest of the earth. Unfortunately, this large segment is also being used to repair the damage caused by energy use through technology in areas other than the Long Island Sound region. The effect is a slow and progressive degradation of the biotic structure and progressive loss of function. The rate of change is increasing as some product of growth in population and increasing energy use.

In so far as any local or national policy on either population or energy can be identified at present, it is a policy of unlimited growth. If pursued it must lead in a time that is short to both the erosion of the efficacy of government and the progressive degradation of all life, including man's. Consideration of energy fluxes offer one further criterion for appraising both the effects of man and the resiliency of nature. On this basis at present the energy used in technology, no matter how produced, should not exceed regionally the energy available through net production of the mature natural vegetation.

References

G. M. Woodwell and C. A. S. Hall. The ecological effects of energy: A basis for policy in regional planning. In: 1st Conference on Energy, Environment and Planning--The Long Island Sound Region, Brookhaven Natl. Lab., Upton, N. Y., in press.

Energy in the Biosphere

	Flux: kcal/yr	Density: kcal/m^2
Solar energy		
World	1.34×10^{21}	2.62×10^{6}
Net production		
World	6.12×10^{17}	1.20×10^{3}
Temperate zone:		
Forest and agriculture		$0.9\text{-}1.81 \times 10^{4}$
Fossil Fuel		
World	4.69×10^{16}	9.20×10
U.S.	1.58×10^{16}	1.69×10^{3}
Long Island Sound region	1.02×10^{15}	7.71×10^{4}

Table 1. Energy flux in the biosphere (data from Woodwell and Hall, in press).

Energy in the Long Island Sound Region

County	Area (mi^2)	Density ($kcal/m^2$)
Fairfield	626	3.86×10^4
New Haven	604	3.73×10^4
Middlesex	372	8.42×10^4
New London	667	10.07×10^4
Westchester	443	6.10×10^4
Bronx	41	112.8×10^4
New York	23	207.7×10^4
Kings	70	114.2×10^4
Queens	108	54.3×10^4
Nassau	289	15.0×10^4
Suffolk	929	3.63×10^4
Total (11 counties	4172	9.42×10^4
Long Island Sound	930	
Total (11 counties and L.I. Sound)	5102	7.71×10^4

Table 2. Energy flux in the Long Island Sound region (data based on population density, from Woodwell and Hall, in press).