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ENERGY QUALITY PRINCIPLES FOR ESTIMATING THE ENVIRONMENTAL CARRYING CAPACITY FOR MAN

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Thank you for the opportunity to join you and your Queen in a common effort to find the balance of humanity and nature according to the natural laws of the biosphere. Ecology is the science of environmental systems and the relationships of their parts and processes. This field includes study of the lakes, forests, deserts, and seas but also larger systems that include man: such as regions, countries, and the whole biosphere. Ecological principles of energy flow and systems analysis give us ways of considering man's role in the environment. To help us, we use a language of energy symbols in diagrams that synthesize various aspects of our knowledge of the ecological systems (ecosystems) into an overall consideration. The relationship of man to the rest of the ecosystem is illustrated in Figure 1, where man is receiving life support services and returning work and materials to the environment in symbiotic relationships so that both parts of the system function well. So long as the life support system is healthy, humanity is secure. As in a satellite, man threatens his own existence when he injures his life support basis. Even small losses of environmental values may reduce an economy's ability to compete.

Sometimes there is a quarrel about the meaning of environmental protection and environmental health, the subject of this conference. Is environmental protection the protection of man from the environment or the environment from man? The answer is that it is necessarily both.

Given at Environmental Health Conference at Pahlavi University, Tehran, Iran, September, 1975.

Only when the two are symbiotic does the system function with full flow of energy that is possible. System designs that are less well organized are likely to be replaced in the competition among ways of life by those which are organized to process energy better.

As shown in Figure 1, the economy of man depends on the natural processes. When they supply the primary needs, the economy goes well and money circulates well. Notice in the detailed diagram (Figure 1b), however, that money circulates among people and not to the environment. Thus energy, not money, must be used to evaluate the contributions of the environment and of fuel for comparison with those of man. We may use the magnitude of energy flow to estimate the relative contributions of envinonment and economic developments in decisions about the relationship of man and environment.

Figure 1 and other energy diagrams illustrate the basic laws of energy: (1) inflowing energy flows out through the heat sink (arrow symbol pointing downward); inflowing energies must equal stored energies plus outflowing energies. (2) In energy processes and from energy storage energy is degraded into an unusable form. Used energy leaves the system in dispersed form through the heat sink. Potential energy is not reusable.

(3) A third energy principle that we believe to be the important one in understanding the design of man in nature is the Maximum power principle. This principle states that those systems which develop characteristics for the maximum energy flow are those that take over and prevail. When there are energies available for growth, that system predominates that is designed for maximum rate of growth; however, when energies are inflowing without excess, and it is not possible to grow, systems with designs for efficient existance without growth prevail and

predominate. Such existance is called the steady state.

Iran with newly developed fossil fuels is in a period of growth, but like the rest of the world may return to a steady state later when its stored reserves in the accessible part of the earth have been used. Thus two kinds of relationship of man and the environment will be in the future: one during growth and one during a more regular period of living on renewable energies later. The best patterns to be planned would be those that are effective both during growth and in the long future of steady life once again based on the energies of sun, waters, and wind through agriculture, and productivity of the seas. As we learned in the United States, people forget about efficiency and good usages during periods of excess energy and growth. They believe that they can do and design what they like. When energies again are limited, they find that their energy expensive ways of life use the environment badly, are energy-wasting, and have to be discarded and changed. Making new designs is hard to do when energies are declining. Can Iran develop its pattern so that it will not be a boom and bust pattern? What are some of the ways for fitting man and environment for effective symbiosis and thus good energy use? In Figure 1b is shown the problem of waste disposal at the same time that water and fertilizer are short. Recycle is needed. In Figure 1c is an interfac. ecosystem.

In Figures 2 and 3 are two examples of the recycling of treated sewage wastes of human settlements to the environment through semi-domesticated, interface, ecosystems so that the energy values of waste can be utilized by self-designing natural ecosystems which conserve water, improve its water quality and return the waters to the biosphere in a way that ultimately costs man's economic system little and may deliver eventually much service to the economy. One of these (Figure 2) is an experimental cypress swamp in Florida where we are adding treated sewage. In the swamp many nutrients, heavy metals, and microbes are filtered out and metabolized by the ecosystem. Much of the water is returned slowly into the ground water after its quality is improved. There it is available to the landscape or man's use later.

Another example (Figure 3) is the salt marsh and shallow estuaries at Morehead City North Carolina also receiving treated sewage. Studies were made there of the marsh and of ponds in the marsh. In three years the estuarine waters develop symbiotic ecosystems suitable as interfaces of man and nature. We sometimes call this work with interface ecosystems Ecological Engineering.

In a recent conference sponsored by the Rockefeller Foundation in Bellagio, Italy, the principle of coupling man's waste to the productive processes of the earth was recommended providing careful safeguards are built into the ecological design to insure that pathological organisms, heavy metals, or other toxic substances do not reach man's food, air, and water. The use of swamps or other ecological areas as self maintaining interfaces may be better than many current practices of releasing partly treated waters directly into ground water or directly into streams and seas. A possible interface for an arid region is suggested in Fig. 4. Since interface ecosystems may provide the water quality needs without technology, they may be expected to use less fossil fuel and make an economy more vital than one which spends large parts of its money and thus energy on technological treatments. In paragraphs below we show a procedure for estimating what use of the economy is good and what is wasteful.

Another result of the maximum power principle is the characteristic design of ecological systems. Using the energy language symbols, a typical aquatic ecosystem is shown in Figure 5. Energy flows from the sun to support a food chain at the end of which is man. The diagram shows the energy laws and the characteristic recycle of materials. Another property of systems in the chain of energy, sometimes called a food chain, by which low quality energy like the sunlight (low quality because it is so dilute) is concentrated in successive steps through the plants, microbes, herbivore carnivores, animals, and also man. The systems that maximize power and predominate are apparently those which develop the more concentrated energies of the higher forms of life and then use these components to feed back services and controls involving information and intelligence. Another property of systems is the storages (tank symbol) of energy in the various components where it smooths out variations and can exert forces for organization and control. Another property is that several kinds of inflowing energy are used so that high quality energy amplifies the low quality energy. Ecosystems develop a healthy metabolism (energy flow). In aquatic systems this is readily estimated by measuring the daily range of dissolved oxygen in the water, with suitable correction for oxygen exchange with the air. The overall reaction of metabolism is given in an energy diagram in Figure 3c in which oxygen is produced along with organic matter in daytime in photosynthesis and utilized in respiration during the day and night. In the fertilized estuarine ponds the range of oxygen was much larger than in control ponds indicating more productivity in the waste receiving ponds than in the control ponds and the marsh plant growth was much better also. However, with a large range of oxygen the diversity of animal species was restricted to those adapted to low oxygen late at night. Thus energy was channeled into fewer species but the yield of these was higher.

The situation developing in eutrophication of the Caspian Sea may be similar. Daily oxygen curves should help document the productivity.

Whereas such oxygen ranges may be all right in a special interface esosystem which is intended to interface man and the larger natural areas, one would not wish to have these conditions in the large natural areas that already have a good pattern of life to which man is well adapted. It is better to have these rich conditions in local interface ecosystems so that the waters reaching the main Caspian Sea are not so eutrophic that they inhibit the sturgeon fishery or the use of beaches in places already heavy with green algae. The oscillation of oxygen in the marine ponds was somewhat reproduced by the computer simulation of the model given in Figure 3c. This illustrates another use of the energy language, which is really another way of writing differential equations. Since each symbol has mathematical content, energy circuit diagrams like Figures 1 and 4 are also systems of equations. By representing them in the visual diagrams, they are more comprehensible to everyone including those who are used to mathematics. In Figure 3c the equations have been written on the diagrams to show how the symbols indicate relationships. More on the energy language is available elsewhere (Odum, 1971, 1972, 1975, 1976).

Energy Impact Evaluations

We also use the energy diagrams to identify main energy flows which can then be considered in evaluating proposed impacts on the environment. To evaluate the contributions of the environment for comparison with the contributions purchased from the main economy we express each energy flow in its equivalent value in the same type of energy, such as fossil fuel equivalents. Energy conversion factors are made using data from observed situations where systems are converting energy from one type to another where it is believed competition has eliminated waste. In Figure 6 are the results of such calculations (See Odum, 1976 for more explanations). Solar energy is very dilute, coal is more concentrated, the energy in the purity of water and in its elevation against gravity is higher along with electricity. Even higher yet are the energies of human service such as those of doctors. Where data are given in money, we estimate the energy involved from the general economy according to the ratio of energy flow to money flow supporting the general economy - in the United States in 1974 25,000 Kilocalories per dollar.

After the main energy flows in a situation have been evaluated and transformed into fossil fuel equivalents using the factors in Figure 5, we may estimate if the plan is a good one if the overall result increases the total power flow without waste, including that of nature in interaction with man.

Another principle is involved here. High quality energy is used well only if it can amplify and help the use of low quality energy. Thus water makes agricultural use of the sun possible, electricity makes a city more efficient through communications and lighting, and human education can make the entire biosphere operate better if it serves as more effective control in developing a symbiosis.

Given in Figure 7 is diagrammed the matching of low quality natural energy with high quality energy from man's urban economy, based there on convergence of many energies but especially fossil fuels. A system competes well and its economy flourishes when its use of high quality energies feeding back from the right is matched with as much low quality energy matching from the left as competitors. The system that gets more free energy to match develops more work, more prosperity and sells its services and products more cheaply. Its prices are better and it captures markets. In the United States the average ratio of the purchased energy to the free energy is about 2.5 to 1 where both are expressed in fossil fuel equivalents. The situation in Iran is suggested in Figure 8. If some proposed use of economic development involves a greater ratio than 2.5 to 1, it is a wasteful use of high quality energy. It is an overdevelopment, one that uses nature's energies poorly. It is detrimental to the environment ultimately by its overcrowding. For example tertiary treatment has too high a ratio of purchased energy to environmental free energy as compared to the recycling interface ecosystems that we illustrated in Figures 2 and 3. In one calculation in Florida, the use of a cooling tower for a power plant was compared with estuarine cooling and found to have a ratio of 100 to 1, much too high. It would have been a poor use of the conservation dollar, one that would overload the economy and the environment elsewhere for a meager local environmental protection effect that would hinder the economy and thus the survival of the plan.

Models like that in Figure 8 may be considered on a larger scale for whole countries. Simulation may suggest what kind of overall future trends will follow for postulated energy conditions. Simulation of energy patterns like that in Figure 7 provide a characteristic rise, decline and leveling at lower energy level, one that the United States seems to be passing through now - showing the world what is ahead for them soon too.

Many hope that alternative energy sources such as nuclear energy, solar technology, or others will provide high quality flows of energy as fossil fuels decline. We and others have used energy diagrams to calculate the net energy of proposed energy sources. Net energy is the energy resulting after one subtracts the energy fed back from the economy to get the energy. This is a very controversial and active research subject and there is much confusion when discussions are made without clear energy diagrams. So far, there is little evidence that these other energies will be major. Solar energy is inherently too dilute and its concentration yields the familiar efficiences of unsubsidized agriculture. Nuclear energy of present processes has no more fuel lifetime than fossil fuels and yields much less net energy per unit energy invested. Fusion is an uncertainty but it appears to be too intense. It is very concentrated energy and may require too much energy reducing its temperature and holding it under control to yield much at the energy level of man and the biosphere. More on these arguments is given in a book (Odums, 1976).

In the euphoria of using one's fossil fuels, countries need to make their plans for the 25 year period to include designs of man and nature effective in use of renewable energy without much technological subsidy from the soon disappearing fossil fuels.

The principle of matching energies suggests a utopian plan for worldwide good use of energy - one fair to humanity, effective for general survival, and without local energy excesses that favor flash growth, war, and other unstable regimes. If the fossil fuels of the world could be allocated in matching ratio to the energies of the natural areas (sun, wind, water, waves, tides, etc.) as estimated in fossil fuel equivalents, there would then be an equity of distribution and a maximizing of the world's total use of all energies. Something like this may be happening now anyway without our consciousness of it. It might be a principle for international organizations and treaties to consider in fitting man into the biosphere with the human in his highest role as the servant of nature.

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Figure Legends

Figure 1. System of man and nature.

Figure 2. Experiment in progress in Florida in Rockefeller and National Science Foundation (RANN Division) project recycling waste waters through cypress swamp.

Figure 3. Recycling wastes through marine marsh and ponds in North Carolin on project of Sea Grant program.

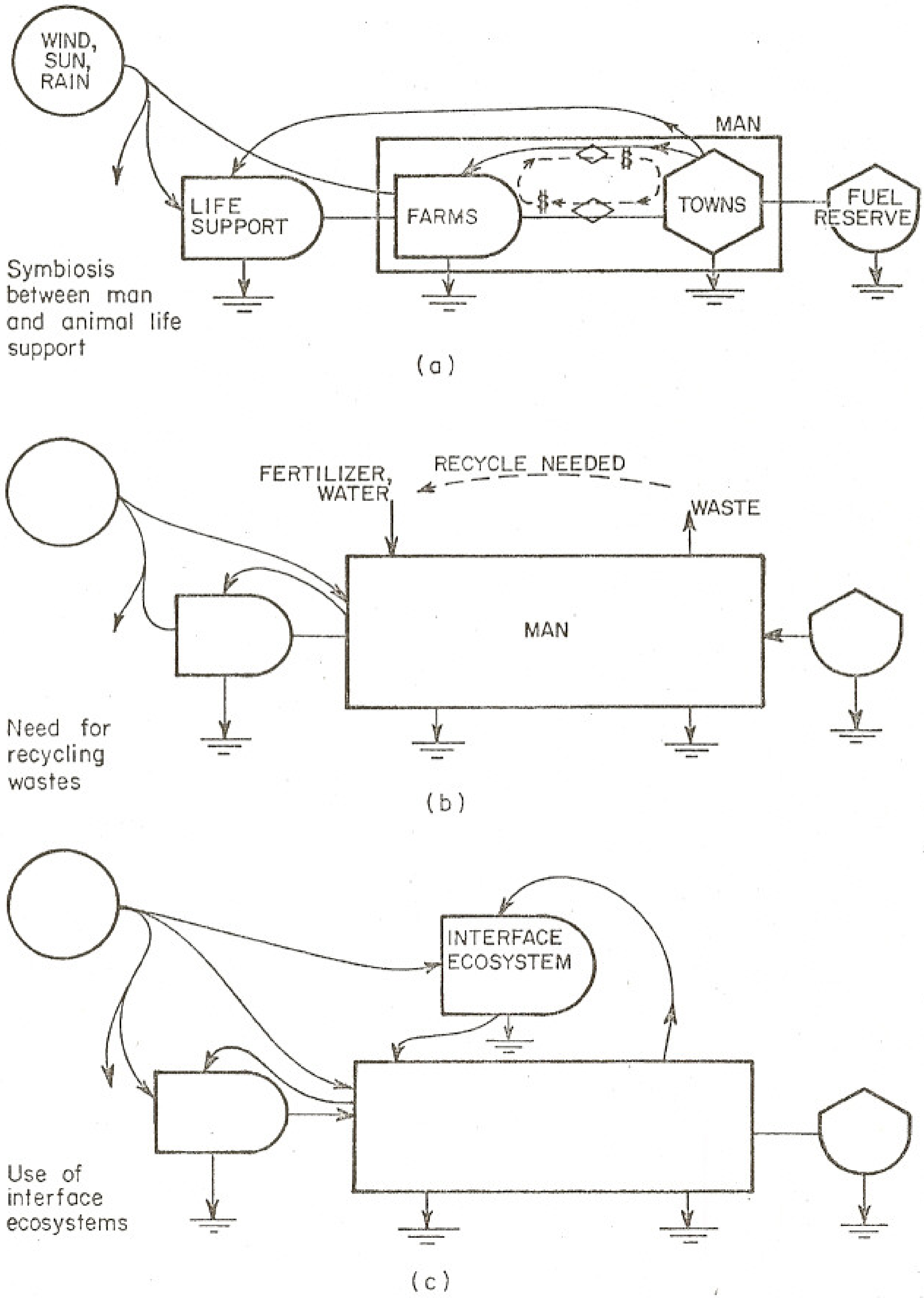
Figure 4. Interface ecosystem in arid area.

Figure 5. Typical ecological system with chains of increasing energy quality to the right.

Figure 6. Chain of energy transformations showing increased energy cost and energy quality from left to right.

Figure 7. Diagram showing matching of purchased high quality energies in interaction with free natural energies. Ratio is from the U.S.A. (2.5/1

Figure 8. Energy flows in Iran and the shape of the future if new types of energy are not rich in net energy.



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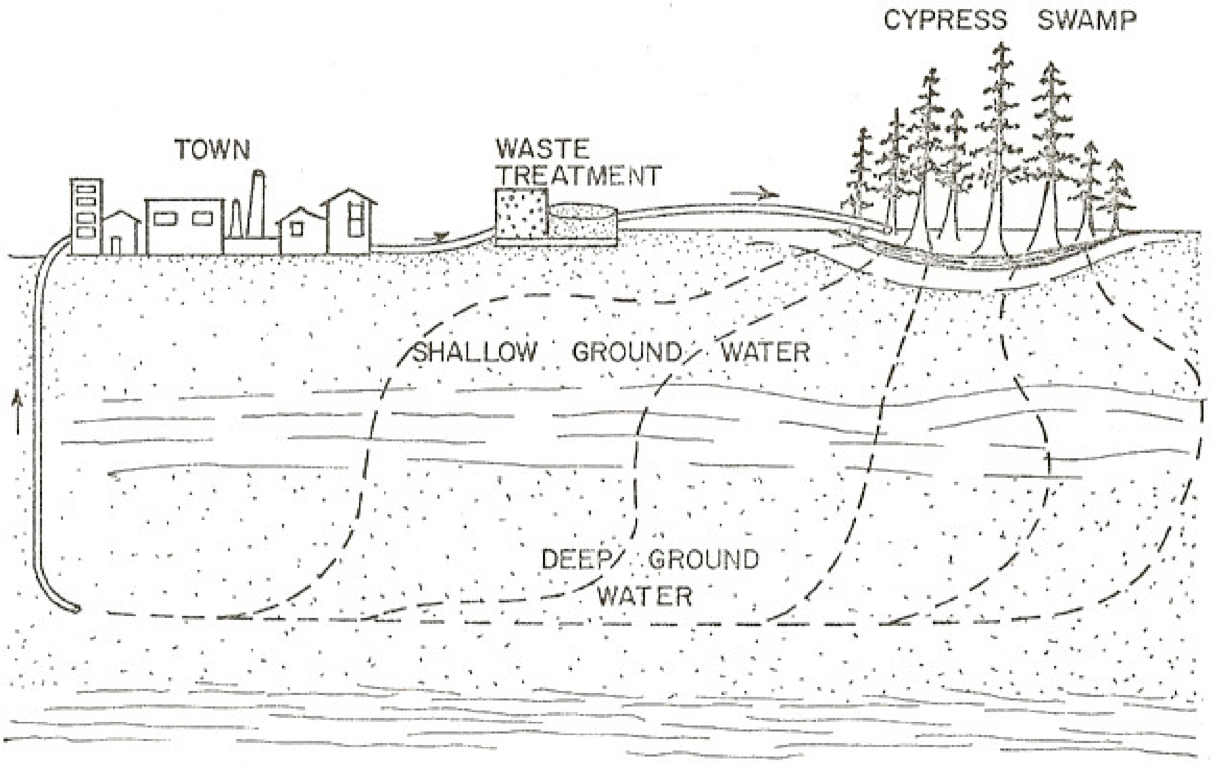

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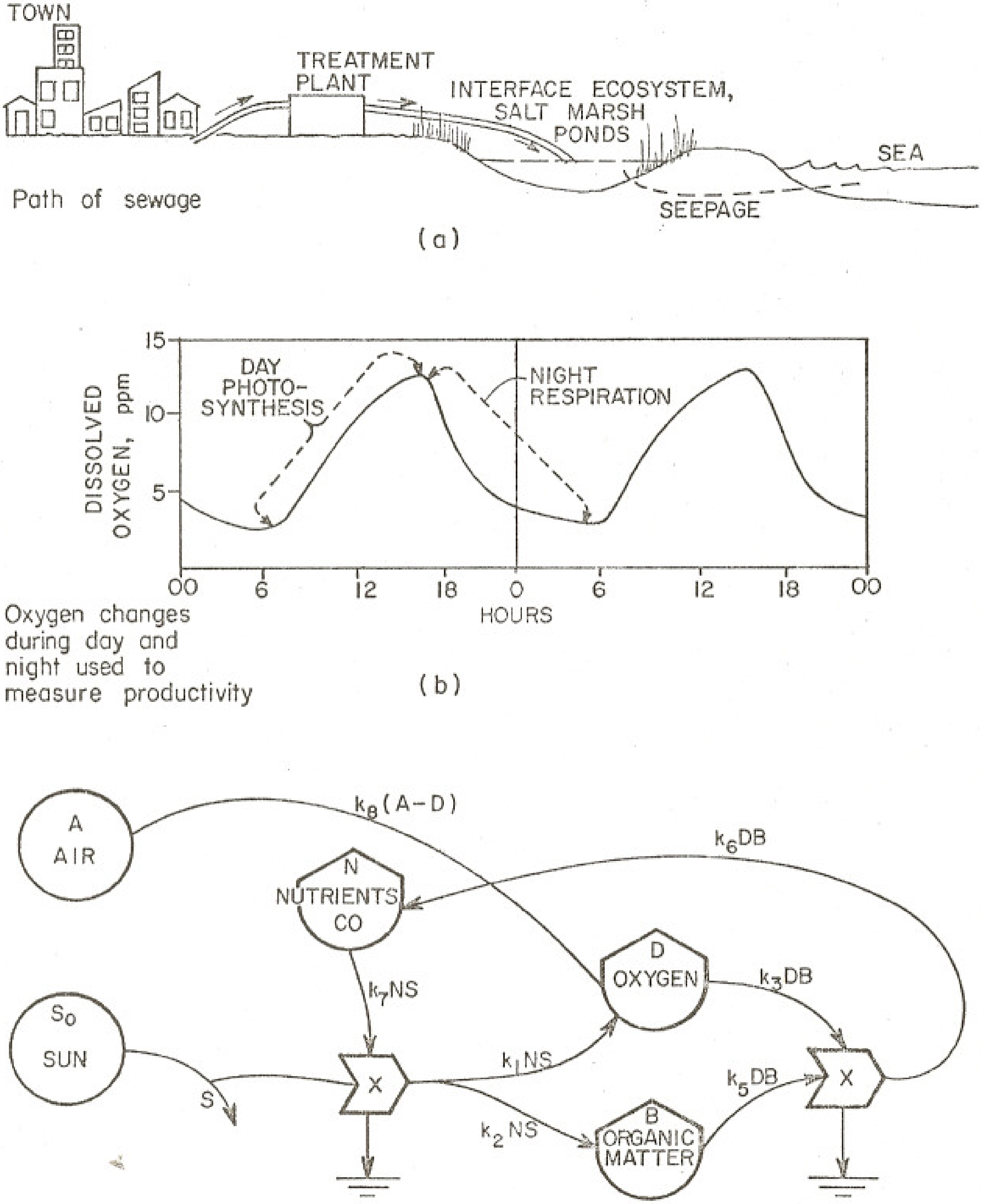


$$\mathring{D} = k_1 NS + k_8 (A-D) - k_3 DB$$

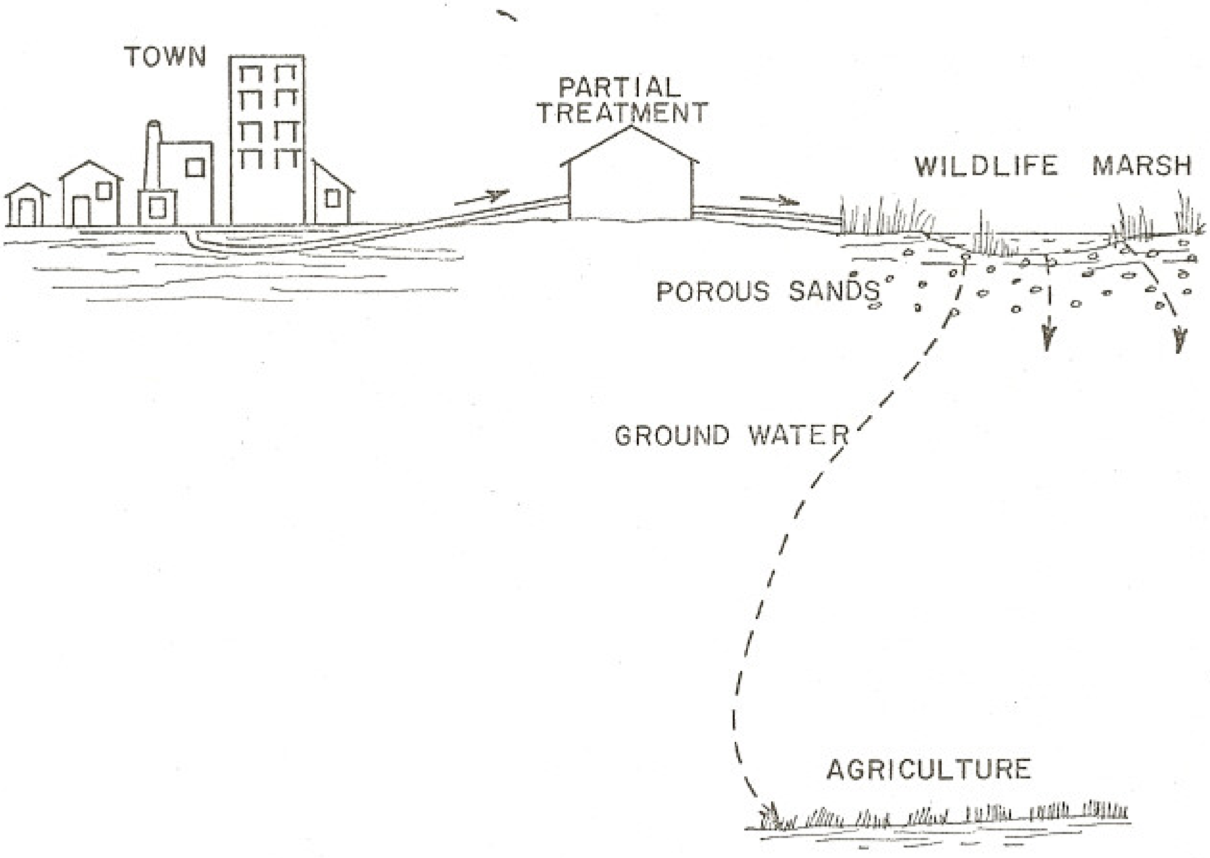
$$\mathring{B} = k_2 NS - k_5 DB$$

$$\mathring{N} = k_6 DB - k_7 NS$$

Energy diagram with mathematical characteristics shown

(c)

Figure 3. Recycling wastes through marine marsh and ponds in North Carolina on project of Sea Grant Program.



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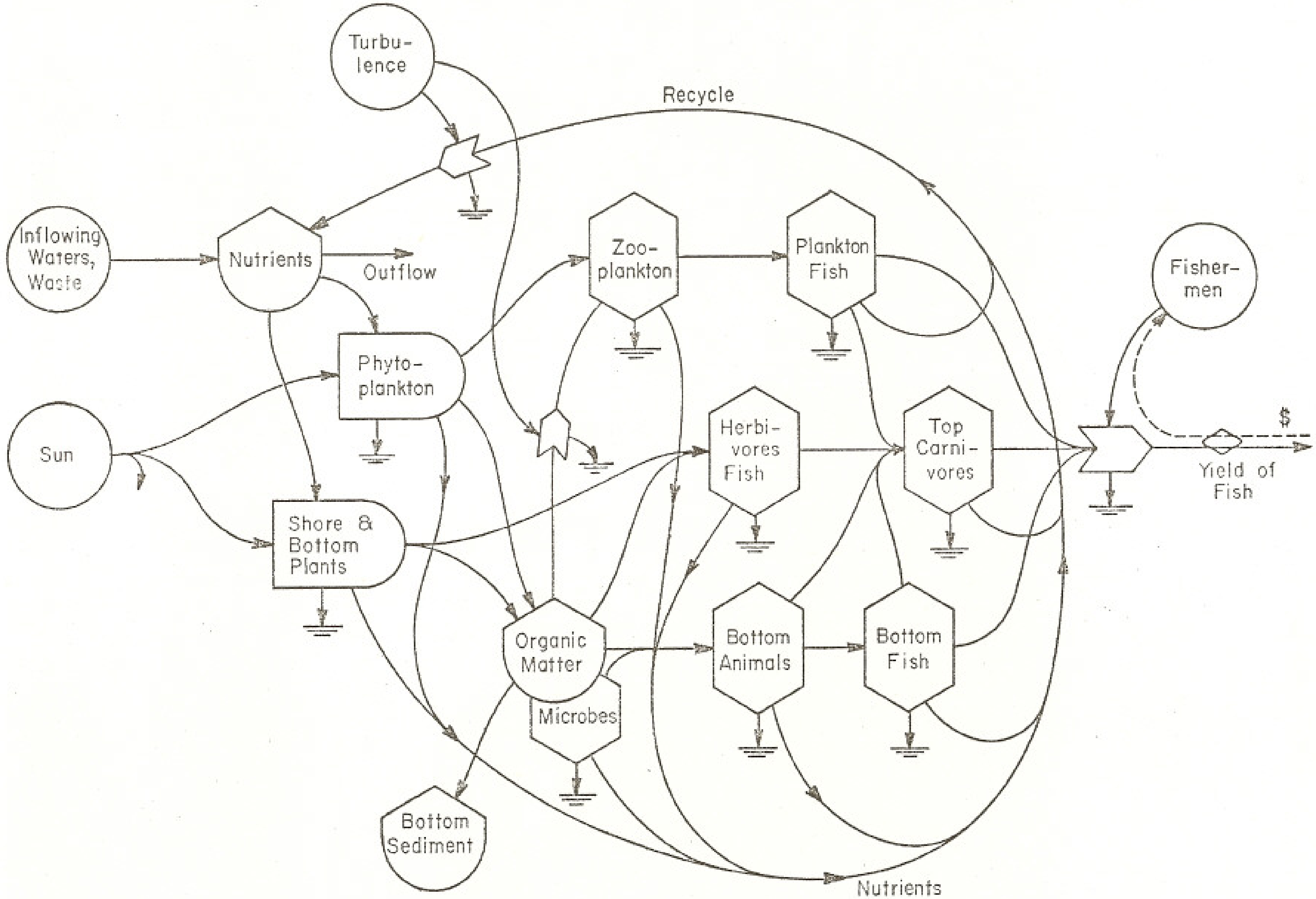

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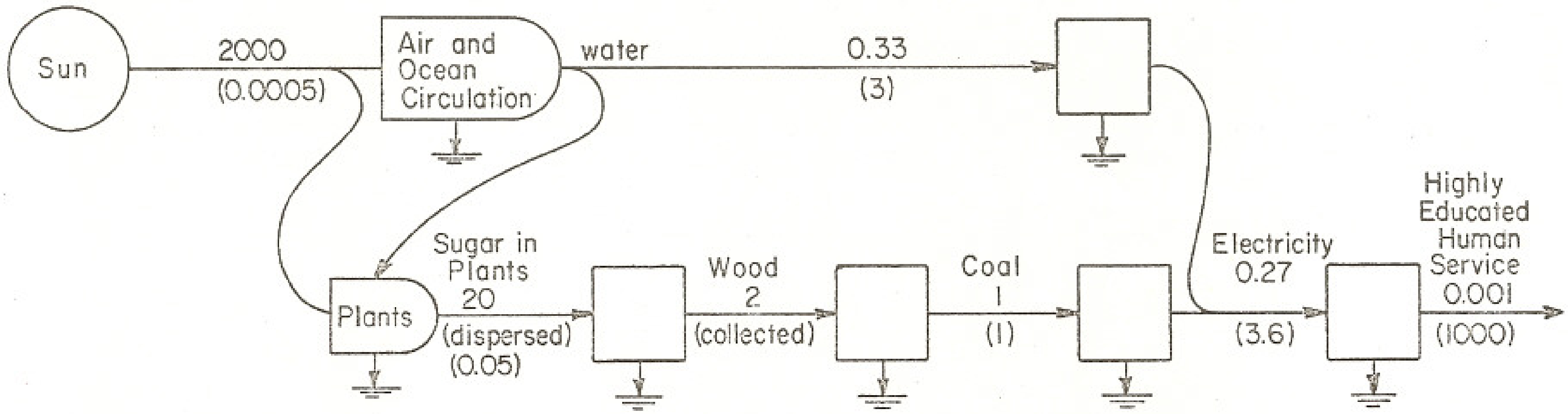
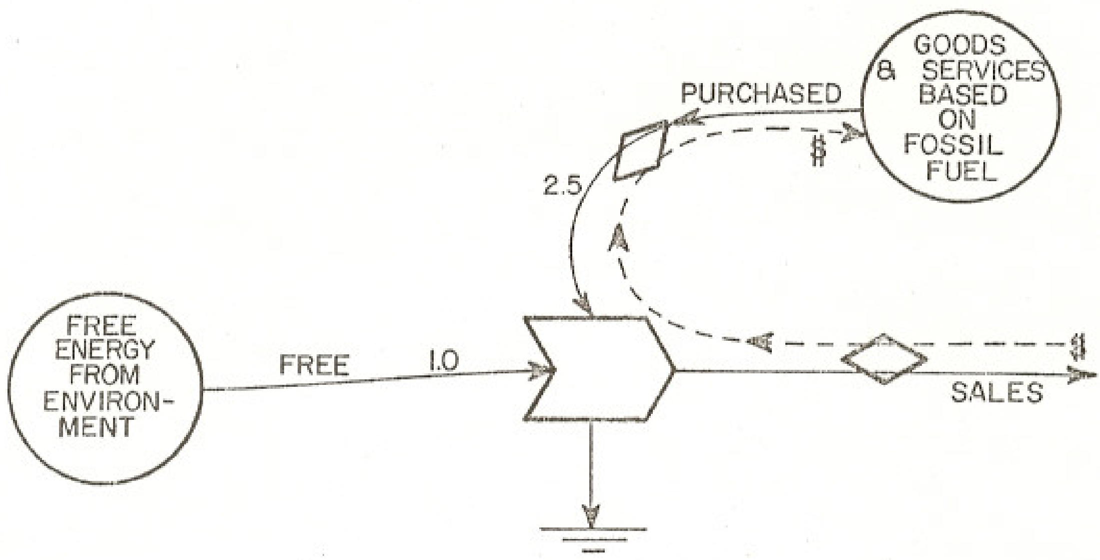


Numbers above line are calories heat equivalent.
Numbers in parentheses are calories fossil fuel equivalents.

Figure 6. Chain of energy transformations showing increased energy cost and energy quality from left to right.



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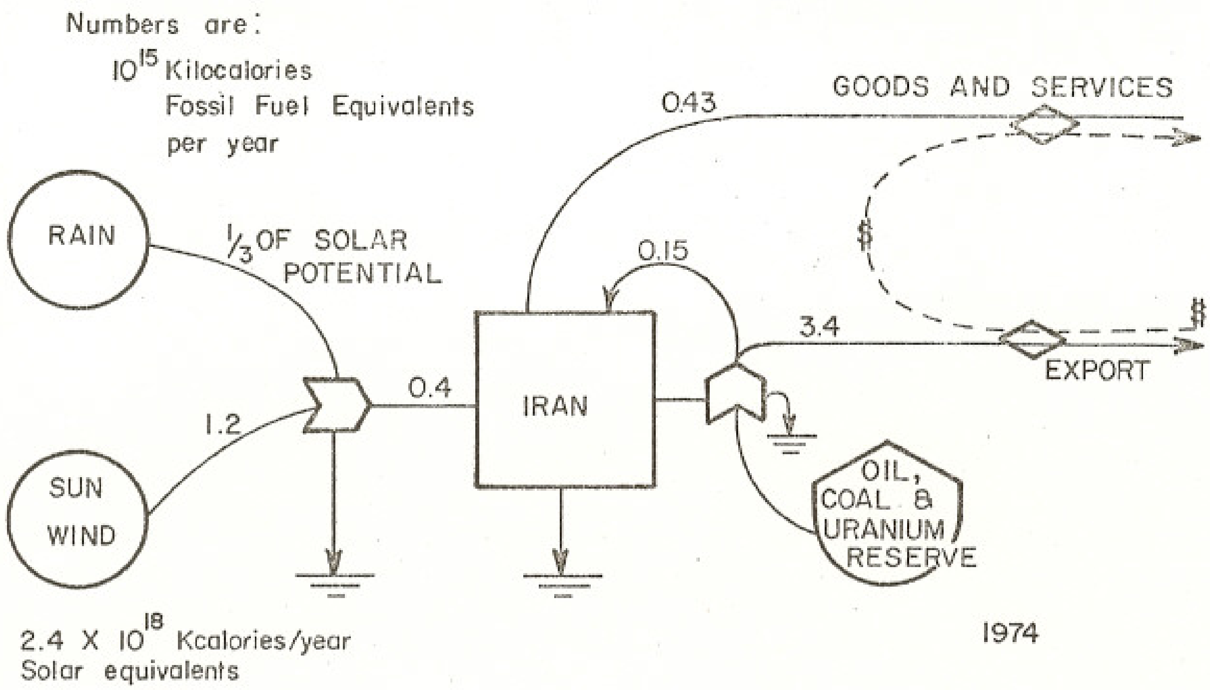

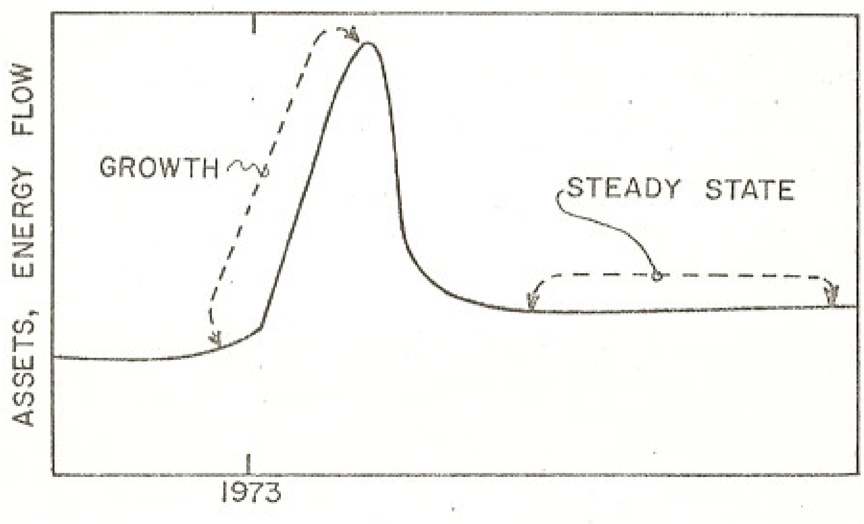

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