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ENERGY SYSTEMS AND ENVIRONMENTAL EDUCATION

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An overall systems view of energy flows can be used to teach the important basic principles for understanding the environment. One way of teaching energy, systems, environment, and economics as a unified whole uses energy symbols (Fig. 1). The method can be taught in a single college course, as part of more traditional courses, or in a special short course. It includes methods of energy evaluation of the environment, so the environment is given an economic value which can be compared to the values of other parts of the economic system. The textbook used is Energy Basis for Man and Nature with an Instructor's Manual by H. T. and E. C. Odum, McGraw-Hill Publ., 1976. The following are some of the points we make using energy language in our course.

ENERGY SYSTEMS DIAGRAM

To understand how energy flows in systems, we can use the energy language to describe a farm (Fig. 2).

The outside flows of the energy of rain, sun, and work interact with the soil nutrients to produce structure. This feeds back to bring in more energies for production. Some of the food produced is sold for money which is used to pay for the work and machines. However, the natural energies are free. The heat sink symbol represents the heat dispersed in the work process and depreciation of the storage.

All systems follow the first two laws of thermodynamics, conservation of energy and degradation of energy. The energy going into the system has to be accounted for going out or as storage within the

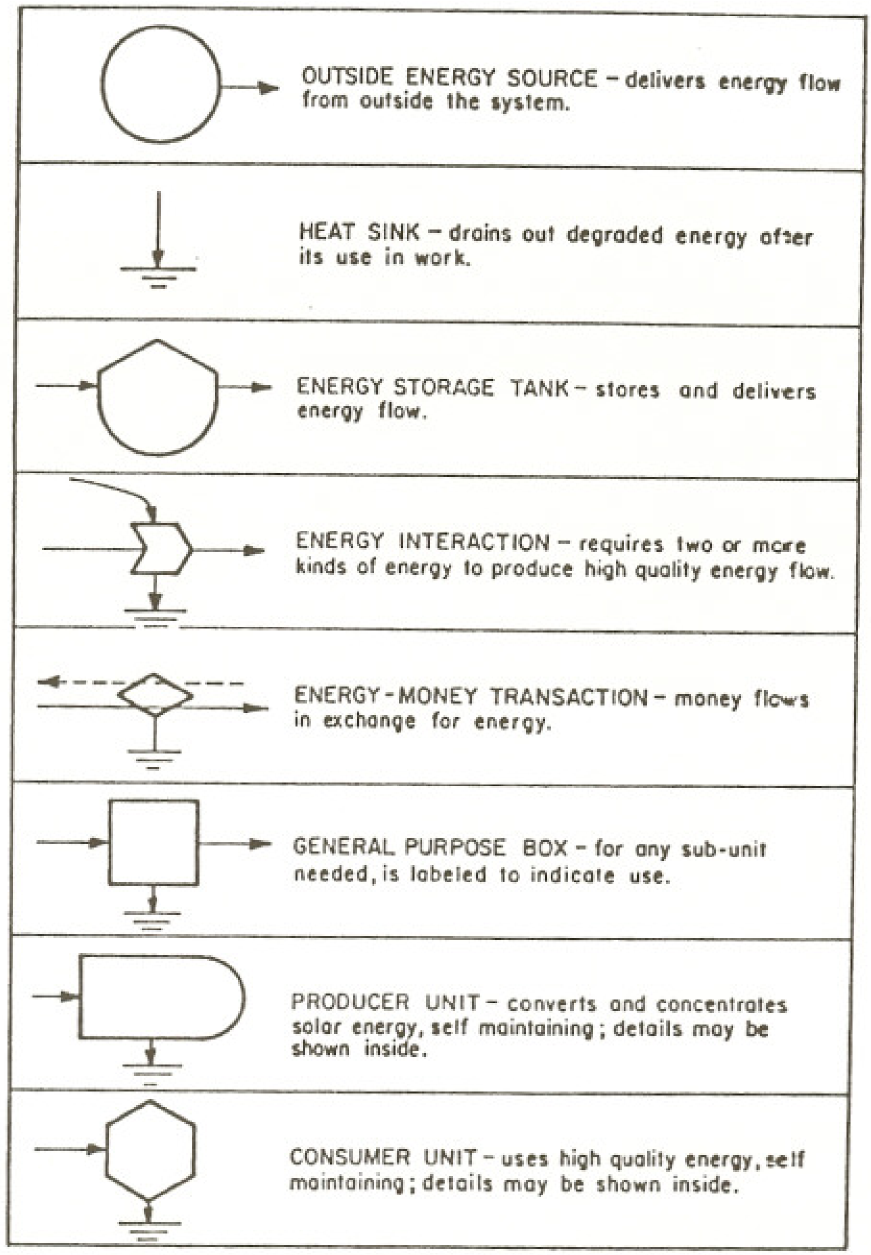

Fig. 1. Energy language symbols.

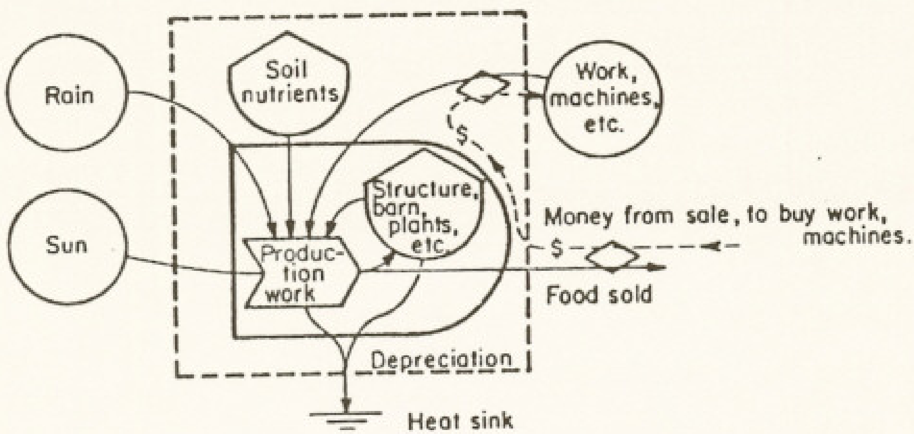

Fig. 2. Energy diagram of a farm.

system. As the low quality energy of the sun and rain are transformed into higher quality storage of foods and goods, much energy is used and becomes dispersed heat. The depreciation of all materials is also shown by the heat sink. A third energy principle is the maximum power principle first formulated by Lotka in 1922. It states that a system survives in competition with other systems which maximizes its energy flow. Surviving systems do this by using some of their energy to feedback and pump in more energy. Examples of competition for maximum power are natural selection in evolution and economic competition in human affairs.

NATURAL SYSTEMS

The basic pattern of a natural environment system is the photosynthesis-respiration diagram (Fig. 3). The natural energies interact with CO_2, H_2O, and nutrients (P, N, K, etc.) in photosynthesis which produces O_2 and organic matter. These interact in the respiration of animals, microorganisms, and the plants to produce CO_2, H_2O, and nutrients which recycle to the producers. In a closed-to-matter system, like an aquarium, only light enters and degraded heat is emitted. Most natural systems like streams and forests have inflows and outflows of nutrients and organic matter (Fig. 4).

UNDERSTANDING COMPLEXITY OF ECOSYSTEMS

The language of symbols helps students see complexity and component relationships at the same time. In the terrestrial ecosystem (Fig. 5) the student sees readily the relations of sun, wind, water, nutrients, food chains, diversity, structures, function, genetic information, etc. The lower quality energy is on the left, higher quality to the right, degraded outflows at the bottom and curving loop backs for material cycles, control works and information. Production is the output of the processes that have interaction of more than one type of energy and feedback of stored assets.

ECONOMIC SYSTEMS

To understand environmental problems, we must consider the economic value of the systems. The world runs on both natural renewable energies (sun, rain, wind, earthquakes) and nonrenewable fuel energies (gas, oil, coal, uranium) as shown in Figure 6. They interact to produce assets which include farms, industries, people, education, government, etc. These assets are used to bring in more outside renewable and fuel energies. Money flows around in the opposite direction from energy and materials. The relationship (ratio) between the money flow and the energy flow is the price.

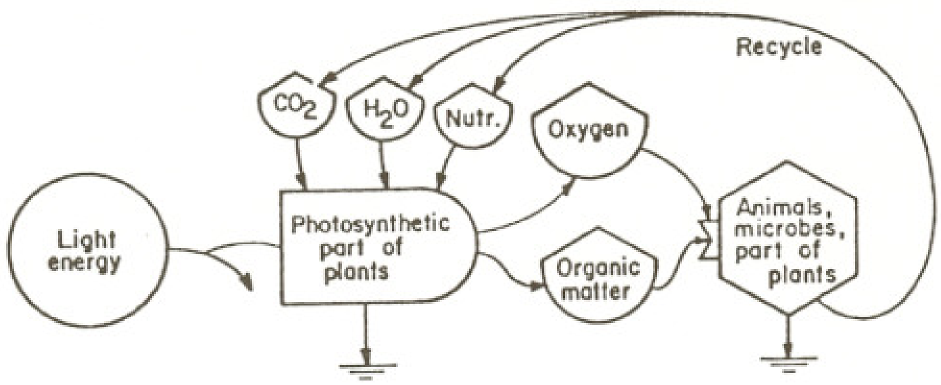

Fig. 3. Basic plan of closed ecosystem. Nutr. = nutrients such as phosphorus, nitrogen, and potassium.

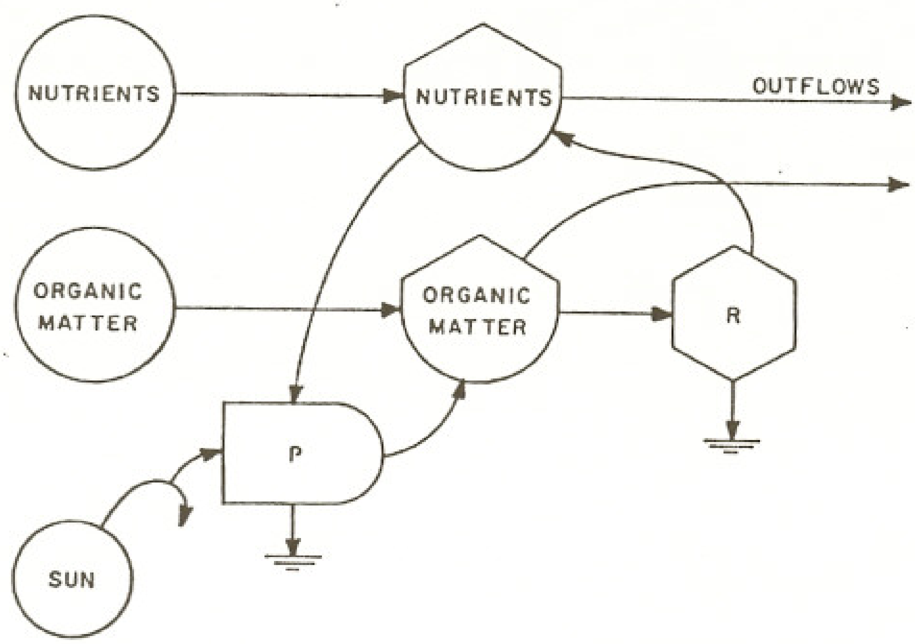

Fig. 4. Open ecosystem, such as a stream or a forest.

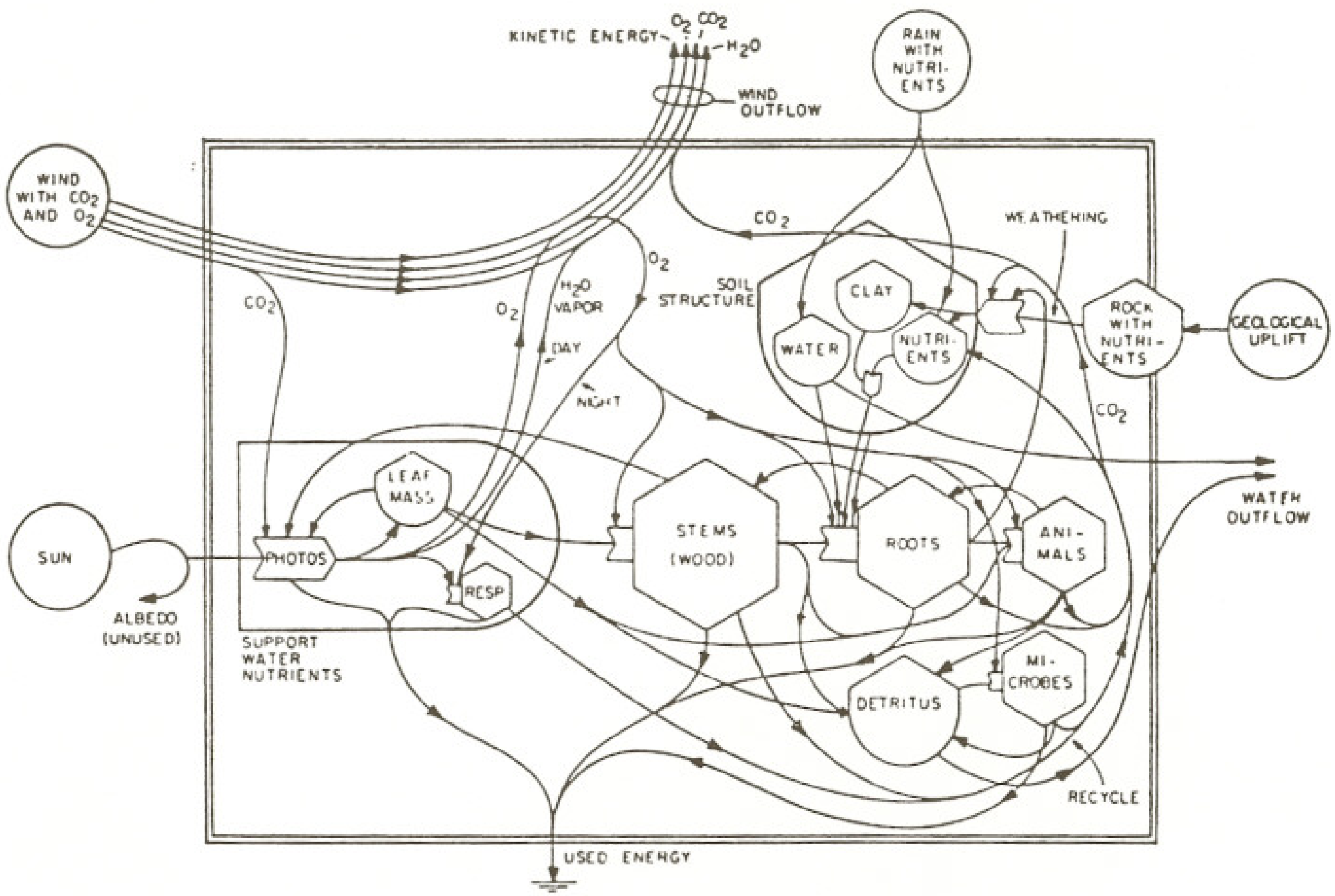

Fig. 5. Typical terrestrial ecosystem.

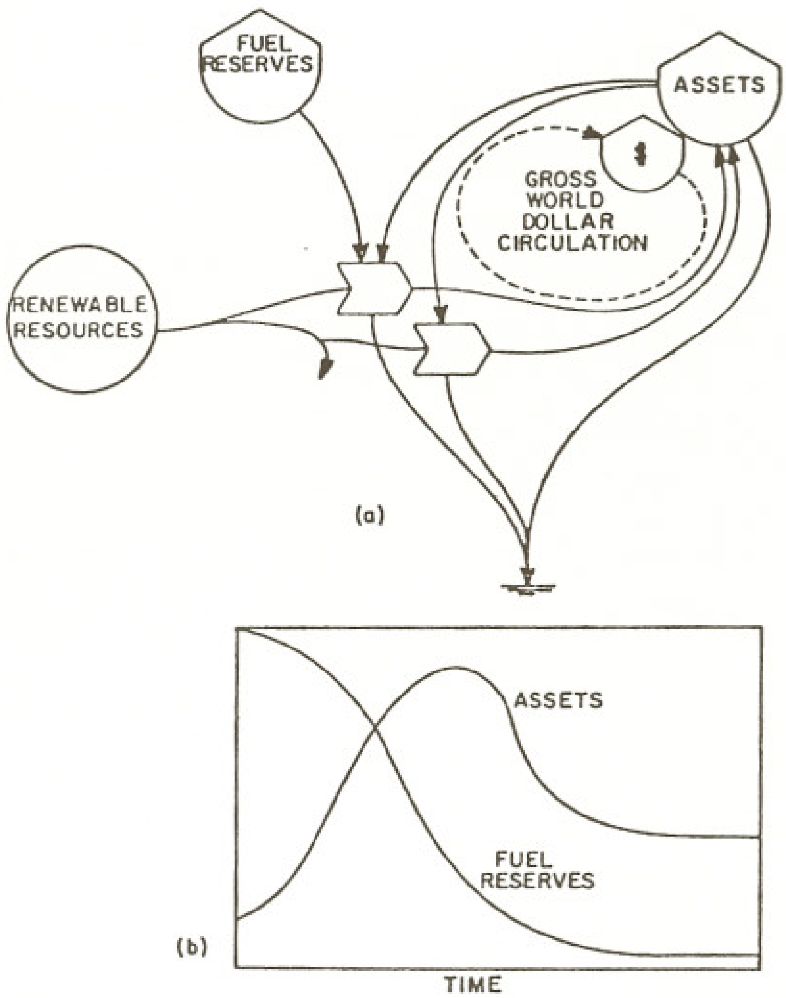

Fig. 6. Model of assets generated from fuels and renewable resources. It shows circulation of money in relation to energy.

(a) Model diagram;
(b) Graphs that result.

Therefore, if the energy flow slows down or gets less and the money flow stays the same, prices will go up. This is inflation. In most of the world today fuels are being found deeper in the ground and farther out in the sea, and so more and more energy assets are used to produce them.

NET ENERGY OF ENERGY SOURCES

Many alternative energy sources such as nuclear fission, fusion, solar technology, and wind are proposed. In order to evaluate the usefulness of an energy source, we calculate its net energy. This is the energy left for use after the resource is processed (Fig. 7). The energy of the technology from the economy is put into units of the same type of energy as the yield, and then the two are compared. Figure 8 shows the relative net energies of various sources as calculated from on-going processes. As you can see, most of those which have high net energies are fossil fuels which we are using up rapidly; solar energy has little remaining after it is concentrated and in solar technology devices takes more than it yields; and the energy from nuclear fusion may take too much energy to cool. This analysis leads to the conclusion that there will be a lower energy world based on renewable energies. Temporary changes in economic and political power will occur first as the West uses up its fossil fuels before the Middle East.

The diagrams help teaching about future possibilities. A graph of the world's economy is shown in Figure 6(b). It shows growth, peak, and decline to a steady state. The growth uses renewable and nonrenewable energies; when the nonrenewable fuels are no longer net energy there will be a steady state using renewable natural energies.

THE LOWER ENERGY WORLD

Let us consider how this lower energy world will affect the environment. As less fossil fuel is used for industry and cars, there will be less pollution. However, in the transition when more coal will be used, there may be more pollution in some places. Some anti-pollution devices will be found to cause more pollution in the areas where they are manufactured than they alleviate where they are used.

There will be more human power used as there is less fuel to manufacture and run machines. Agriculture will use more land and human labor, with less fertilizer, fewer tractors, and fewer genetic varieties. Intensive high energy agriculture will no longer be possible; the "green revolution" can work only in a high energy world. There will be less unemployment, but there will be fewer high-energy executive jobs.

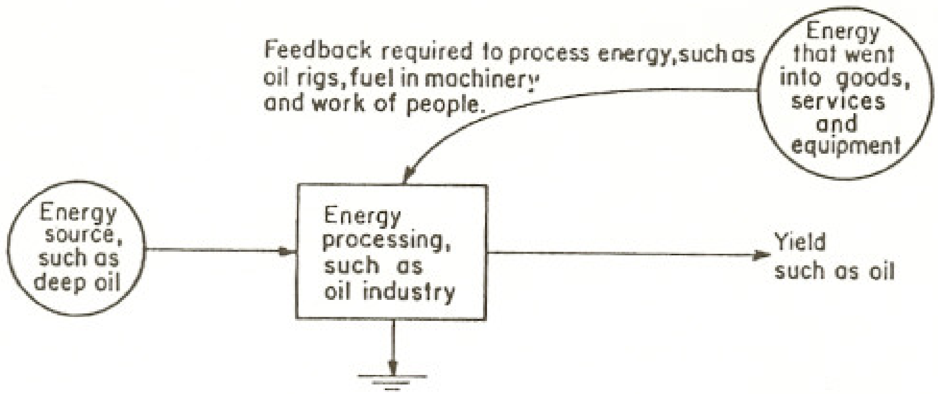

Fig. 7. Diagram of net energy. Net energy = yield minus feedback.

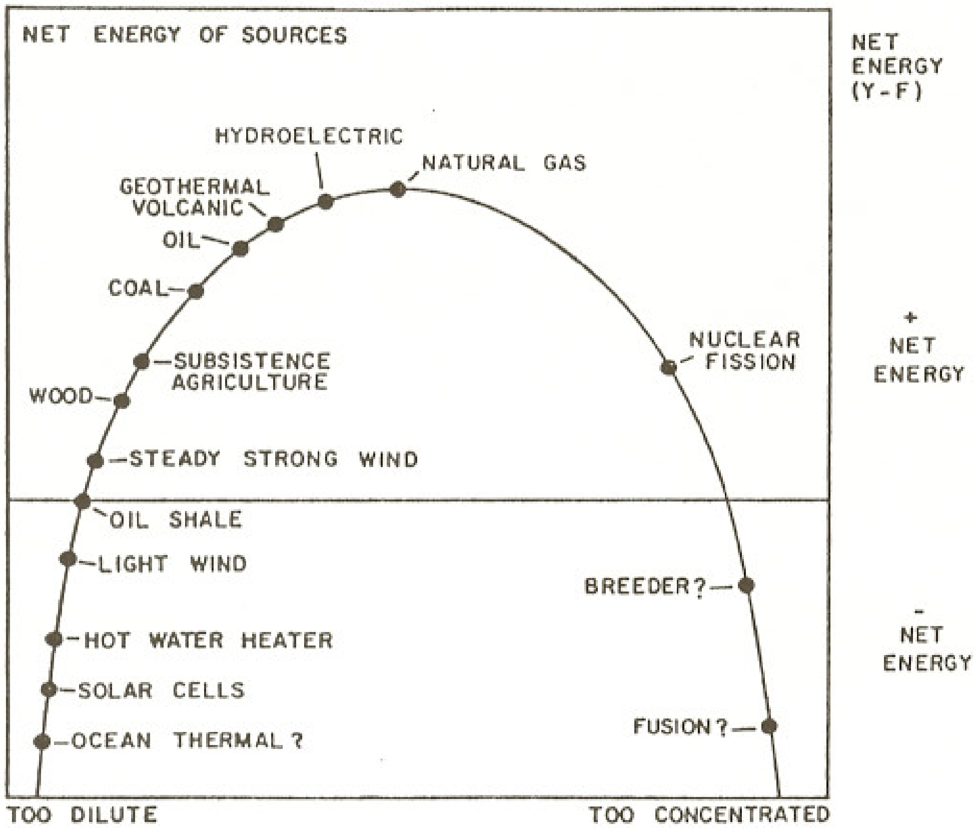

Fig. 8. Relative net energy yields of existing and proposed energy sources.

MAN-NATURE INTERFACE ECOSYSTEM

The coming of the lower energy world may be a spur to cooperation between man and the environment. Our high energy technology has been separating man from the natural ecosystems. Sewage is an example. Chemical tertiary treatment breaks the cycle of feedback of nutrients from respiration to photosynthesis and makes the nutrients a polluting waste (Fig. 9). Sewage treatment by natural ecosystems is being experimented with in many countries. At the University of Florida secondarily-treated sewage is being pumped into cypress swamps (Fig. 10). The water recycled through the swamp into the ground water is pure enough for drinking. The trees which are growing faster from the nutrients in the sewage effluent can be selectively lumbered. We need to encourage more similar interface low-technology ecosystems that help both man's economy and natural ecosystems. Examples of recycling of wastes can probably be found in your area for field trips.

EMBODIED ENERGY AND QUALITY OF ENERGY

The energy diagrams can be used to teach new concepts of embodied energy. As shown in Figure 11, energy flows in chains of units, each step a transformation that loses energy but produces an energy of higher quality in the reuse that it has the capability of feeding back as an amplifier to facilitate the energy flow in the way that favours success in maximizing power. Since flows of energy build these webs and chains, we have to recognize that energies of different type have different energy qualities. They can be compared by relating back to the energy of one type, solar energy. The calories of solar energy required to develop a flow are called the embodied energy. The ratio of embodied solar energy to actual energy is a <u>quality factor</u> indicating the inherent worth of that type of energy as compared to solar energy. The embodied energy and the quality factors give us a way to estimate value of environment and to compare different types of things: animals, human culture, materials, information, etc.

ENVIRONMENTAL IMPACT ALTERNATIVES

Many environmental questions can be understood and alternatives compared with an energy systems diagram showing existing patterns and those proposed. Figure 12, for example, is an impact diagram of strip-mining. Before mining, the water supports a grassland which yields value of wildlife, watershed control, soil building and export of water that generates economic value down stream. After and during mining the land and water are temporarily diverted as minerals are removed, and land restored to a new shape. Then the work of soil-building ecosystems resumes again, rebuilding the high quality

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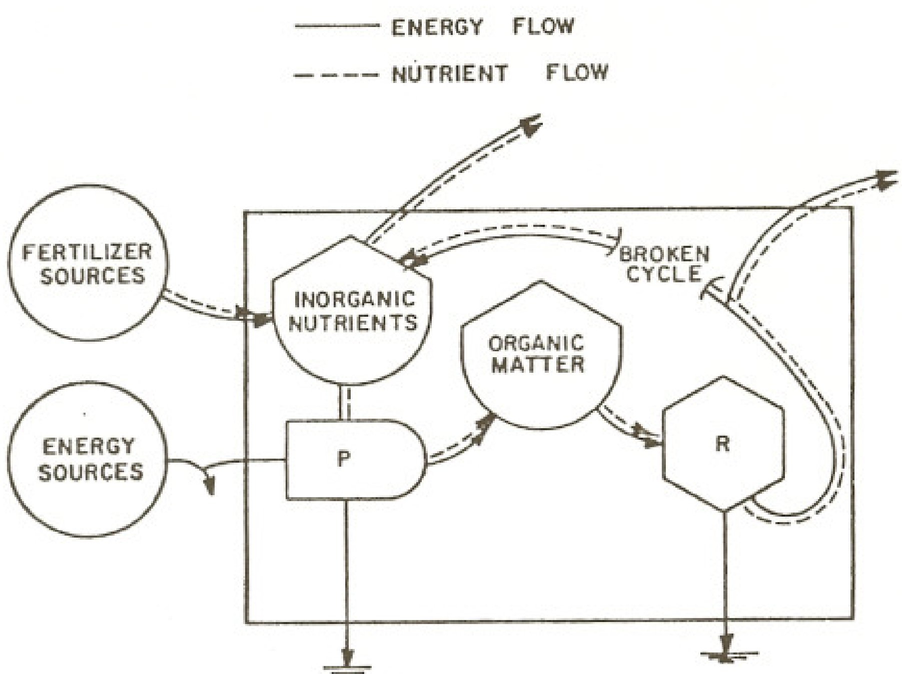


Fig. 9. Cycle of natural ecosystem broken by man's technology.

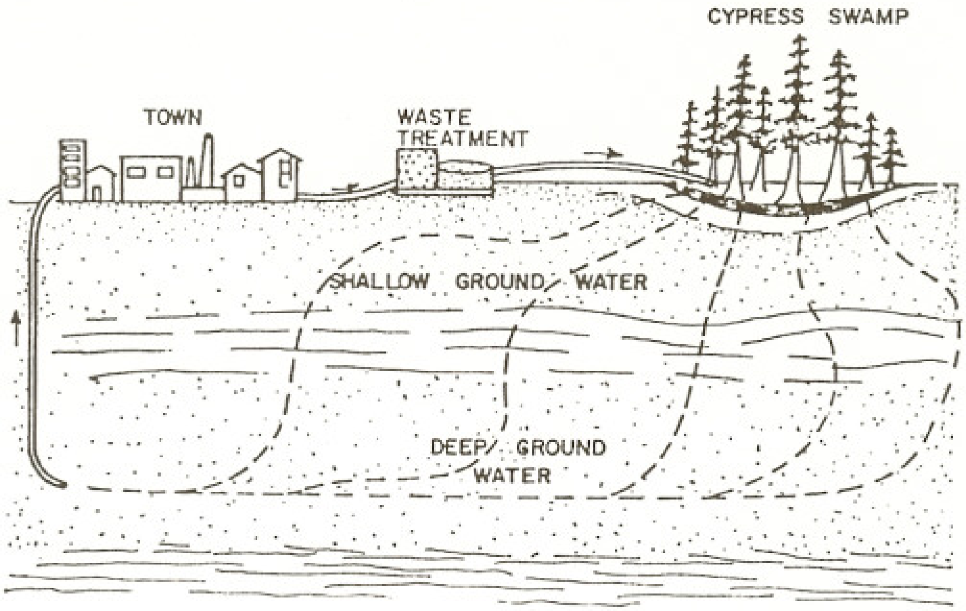


Fig. 10. Diagram of treated sewage being dumped into a cypress swamp.

ıWAMP

cypress

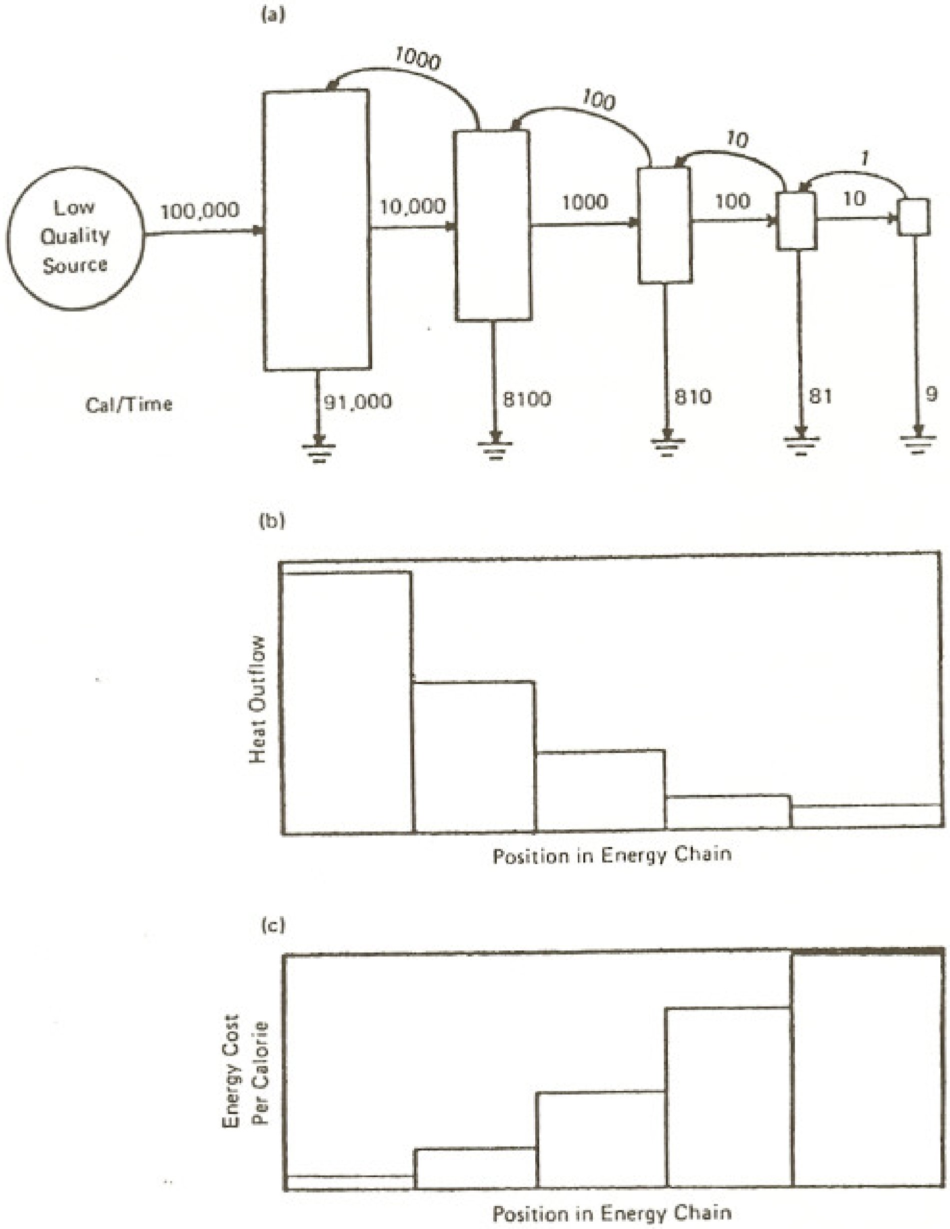


Fig. 11. Chain of energy transformations typically found in all systems of nature.

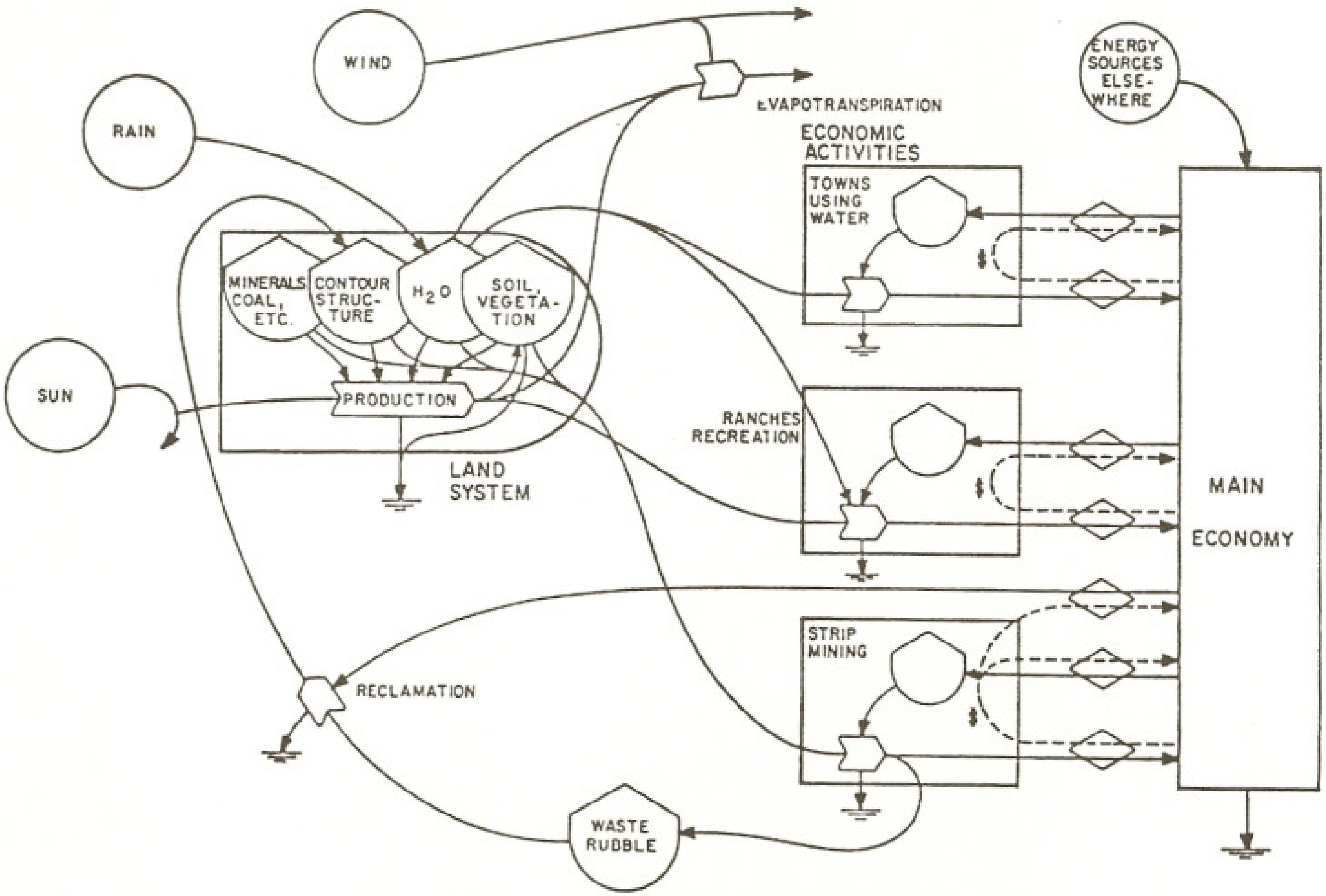


Fig. 12. Environmental input represented by a diagram. Impact of strip mining on rangelands low in rainfall.

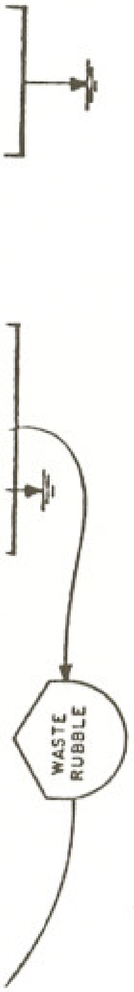


Fig. 12. Environmental input represented by a diagram. Impact of strip mining on rangelands low in rainfall.

storages of soil and vegetation. Finally, the water returns to the groundwater aquifer. The diagram is enough to explain direct and indirect effects. Estimating calorie flows and embodied energy can also be done to see whether more energy is generated before or after.

MATHEMATICAL EQUATIONS

For more advanced students or for theoretically trained people new to environment, one shows the mathematical content implied by the symbols whether one is conscious of it or not. A diagram is a set of differential equations. Having already taught how the tank symbol sums the inflows minus outflows, one can draw intuitively the graphs that result. Then one can introduce the notation of the differential equation as giving the same meaning. Then explain that integration is finding the tank storage quantity, given the initial storage, rates of inflows, and rates of outflows. In other words, the diagrams are used to teach mathematics instead of the usual way of doing mathematics first, diagramming later. Figure 13 has more examples.

SIMULATION

Most fun of all is making the diagrammed systems come alive with simulation. One way is physical simulation, arranging water reservoirs and tubes so that inflows and outflows of water can be observed to chart water levels.

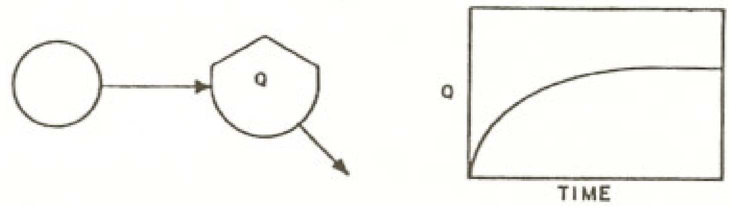
Either analog or digital computer simulation can be arranged by those who know these devices and how to go from equation to machine graphical output. For most students these details may not be necessary; they can follow the trace of the recorder or oscilloscope chart while looking at the energy diagram.

For digital simulations difference equations are written that say:

> Let Q, the quantity in the tank, become what it was (Q_t) plus the inflow and outflow in the unit time (t) since the earlier time.

$$Q_{t+1} = Q_t + \text{inflows} - \text{outflows}$$

Then let time become one unit later $t = t+1$; then go back and repeat. This one teaches the ideas of iteration. Figure 13 includes some graphs from simulation which can be visualized also.



Differential Equation:

$$\dot{Q} = J - kQ$$

Rate of change of Q — Inflow minus outflow that is proportional to quantity stored (Q)

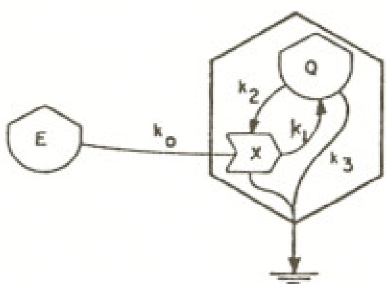
Difference Equation:

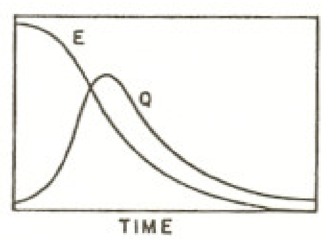
$$Q_{t+1} = Q_t + J - kQ$$

(a)

$$\dot{E} = -k_0 EQ$$

$$\dot{Q} = (k_1 - k_2) EQ - k_3 Q$$





(b)

Fig. 13. Equations and simulations for systems.

(a) Single tank;
(b) autocatalytic process on a declining storage.

Some of the main problems and misunderstandings come in thinking of the pathways as only energy, or materials, or information. Pathways all have energy content along with whatever else the pathway is. One keeps careful track of what each storage, and pathway is by using word labels; the position in the web shows the quality as high or low.

Experience shows students can learn the language quickly, learn to think visually in these terms, and can then deal with complexity of a high level. They understand the environmental systems and the interactions.

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