Energy Systems in Ecology

The earth, like the universe as a whole, is composed of interconnected systems which can be represented in diagrams that show parts, processes and relationships. Because energy accompanies all flows, forces, storages and information, energy flow is a common denominator for representing and understanding systems of nature and of humanity. Symbols are used that have both energetic and kinetic meaning.

1. Energy Flows

An example is given in Fig. 1a, a diagram of the system of the world showing the energy flows and processes aggregated into three sectors: the natural life-supporting environment, the yield systems of agriculture and forestry and the consumer centers of industry and human settlements. The symbols used are explained in Fig. 2. Renewable energies are the sun, rain, wind and uplift of land flowing into the production of agriculture, forestry and the restoring work of the wild environments. The products of both production sectors flow into the human consumer sector interacting with fuels and minerals to produce goods and services which are sent out to agriculture and forestry.

Money flows as a countercurrent (dashed lines) in the opposite direction from the energy that accompanies the food and fiber moving from agriculture to the city and the goods and services moving from city to farms. Often unnoticed and unpaid for are the life-support services of the fallow lands, wilderness and oceans which maintain soils, land form, clean air and aesthetics. From each process some used energy flows out of the system at the bottom of the diagram, indicated by a "heat sink" symbol. The energy systems overview shows that a decline in energy flow while money is circulating reduces the buying power of the currency, causing inflation.

More detail can be diagrammed within the human sector as given in Fig. 1b. The assets of the city are in storages of transportation, industry, housing, people, government and information. All of these feed back to interact with incoming resources from outside the city to generate production within the city, some of which is used in exchange for food and fiber.

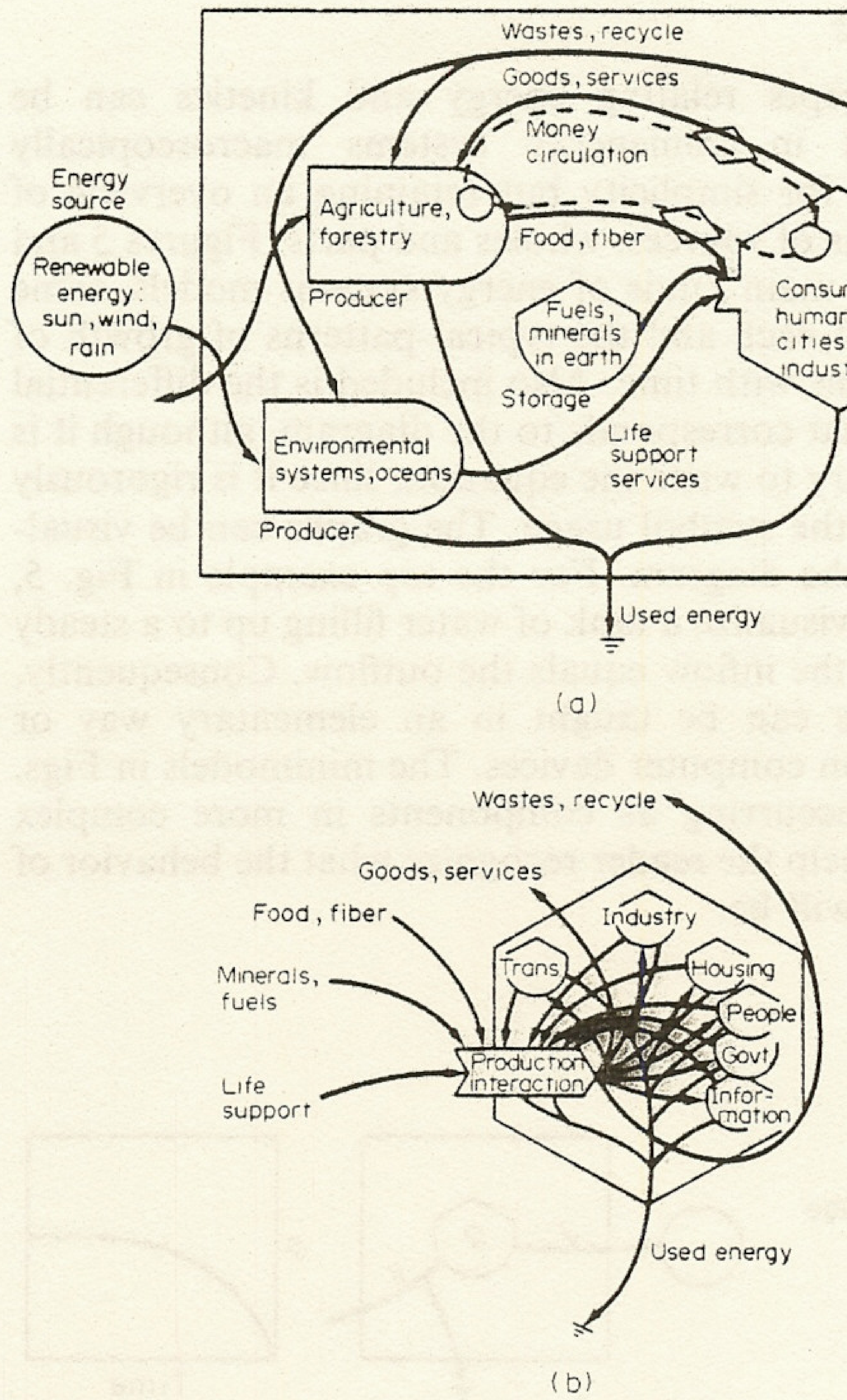

Figure 1
Energy language diagram of the overall energy system of the world of humanity and nature: (a) world energy system; (b) details in human sector (see Fig. 2 for symbols)

The example illustrates properties of most energy systems. Energy flows from sources into the system and forms interactions, processes, storages, cycles, oscillations, hierarchies and information, ultimately leaving the system as used energy which has lost its potential for work. The energy systems language shows the first energy law: that of conservation of inflowing energy in storages or outflow. The diagrams show the second energy law by connecting each storage and process to a pathway of energy degradation (called a heat sink).

Many patterns are found common to all systems and seem to be explained by the hypothesis of maximum power, which predicts that systems that maximize useful power of their surrounding system and of their own function will survive competition because they will have more energy than competitors to meet other needs.

2. *Energy Hierarchies*

Systems that survive are made of energy webs, which are progressions of energy transformations, each developing properties with higher amplifier and control effects per joule. For example, in Fig. 3a, dilute energies of sunlight and deep earth heat converge and are transformed to generate mountains and human activity at the right-hand end of the energy chain. Fig. 3b shows the spatial converging observed in energy chains. The higher-quality energies are at the focus of converging pathways; they feed back their control effects in pulsing and divergent patterns. Included in these patterns are recycling of materials, storage of more materials at low energy than at high energy, a matching of high-quality energy feeding back in amplifier relation to interact with larger quantities of low-quality energy, and interaction of energies of different types rather than use in separate processes. These patterns also appear in Fig. 1. Other examples of webs with a convergence of energy are given in Fig. 4: an ecological system and an agricultural one.

The calorific content of each type decreases when transformed into the next type in an energy chain. The energy required to make a transformation of one kind of energy to another under competitive surviving conditions is called the embodied energy. Comparisons of

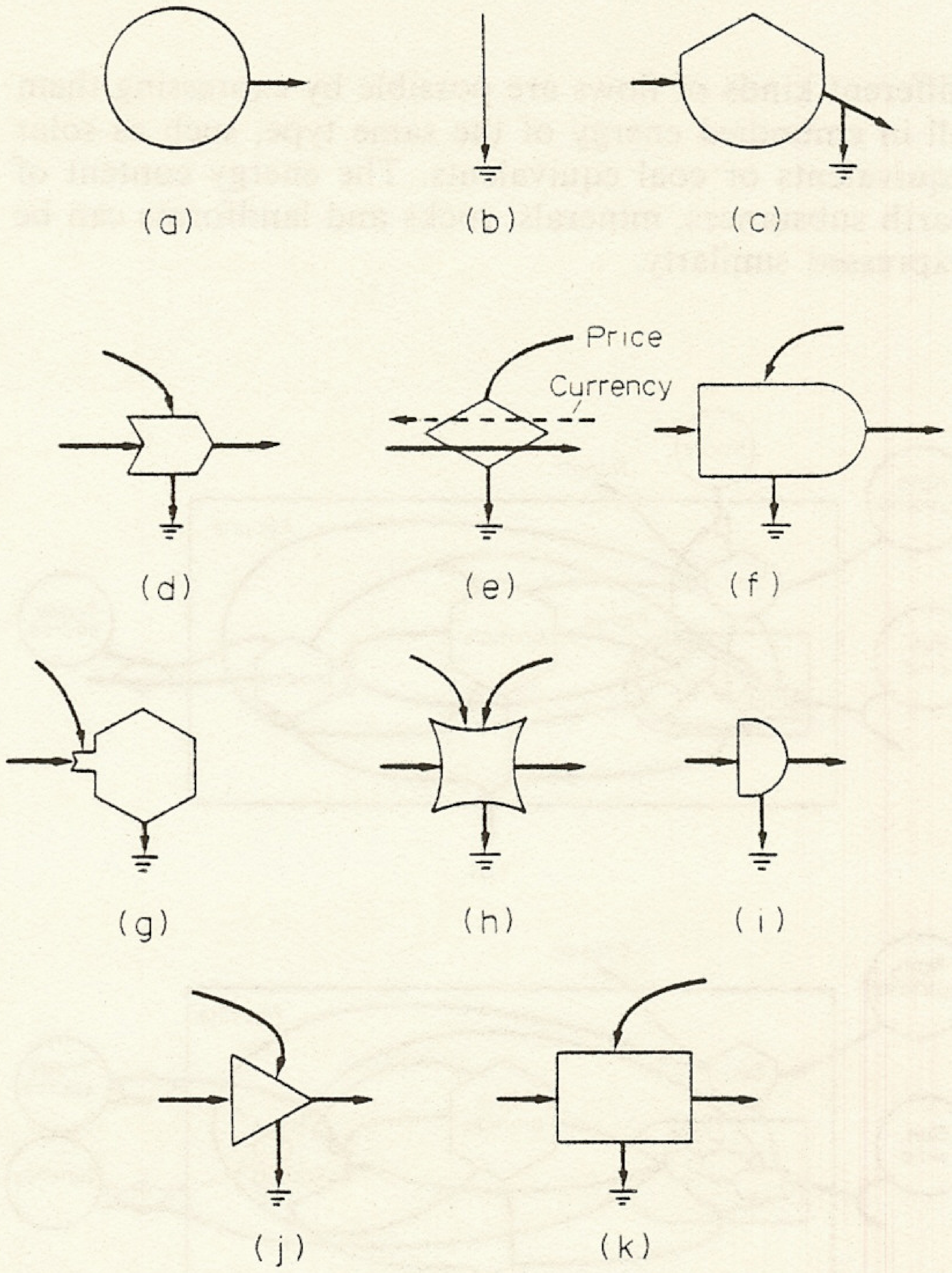

Figure 2
Symbols of the energy language: (a) source; (b) heat sink; (c) storage; (d) interaction; (e) money exchange transaction; (f) producer; (g) consumer; (h) switching subsystem; (i) cycling receptor; (j) constant-gain amplifier; (k) miscellaneous symbol for subsystems

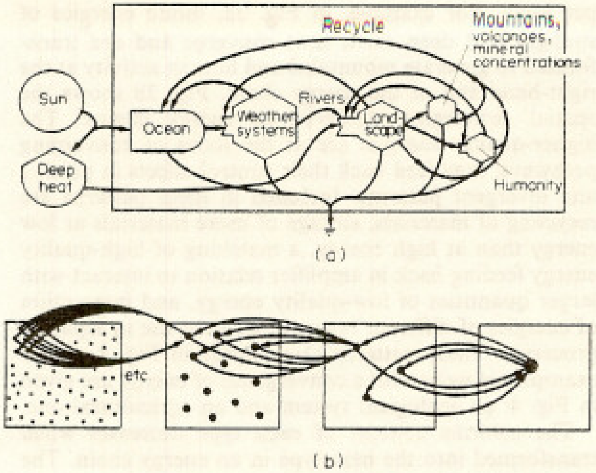

Figure 3
Aggregated energy diagram of the energy system of the earth: (a) energy web; (b) spatial hierarchy with many small units being transformed and converging to a few of high quality

different kinds of flows are possible by expressing them all in embodied energy of the same type, such as solar equivalents or coal equivalents. The energy content of earth substances, minerals, rocks and landforms can be expressed similarly.

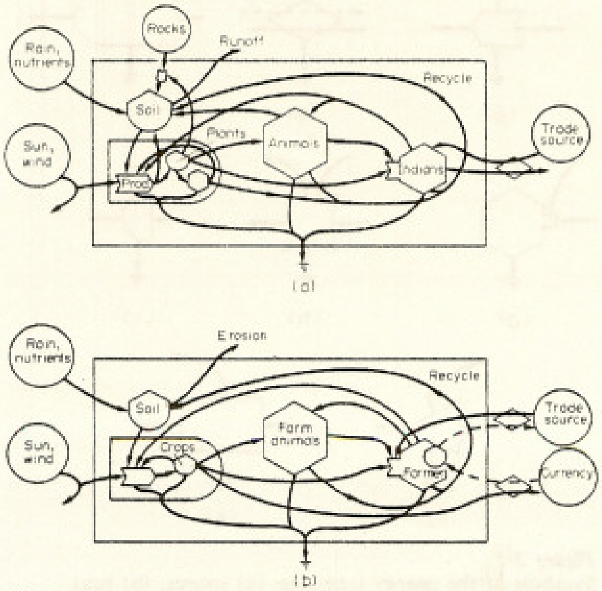

Figure 4
Environmental systems supporting human cultures on renewable energy: (a) hunting and gathering culture based on terrestrial ecosystems; (b) agrarian culture

3. Kinetics

Basic concepts relating energy and kinetics can be represented in minienergy systems macroscopically aggregated for simplicity but retaining an overview of the relations of sources, wholes and parts. Figures 5 and 6 show the main kinds of energy systems models, some examples of each and the typical patterns of growth of these systems with time. Also included is the differential equation that corresponds to the diagram, although it is not necessary to write the equation, since it is rigorously defined by the symbol usage. The graphs can be visualized from the diagram. For the top example in Fig. 5, one would visualize a tank of water filling up to a steady level when the inflow equals the outflow. Consequently, the systems can be taught in an elementary way or simulated on computer devices. The minimodels in Figs. 5 and 6, occurring as components in more complex diagrams, help the reader recognize what the behavior of the whole will be.

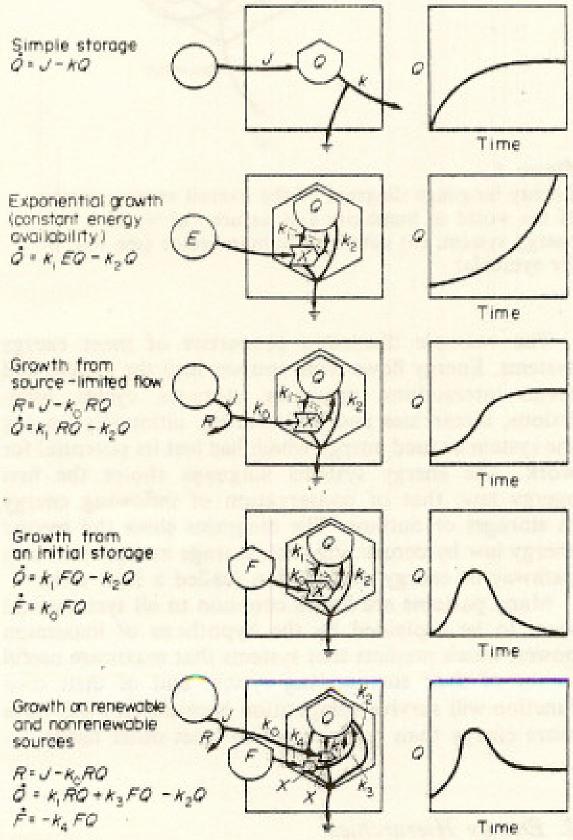

Figure 5
Basic models relating the pattern of growth to the type of energy resource available

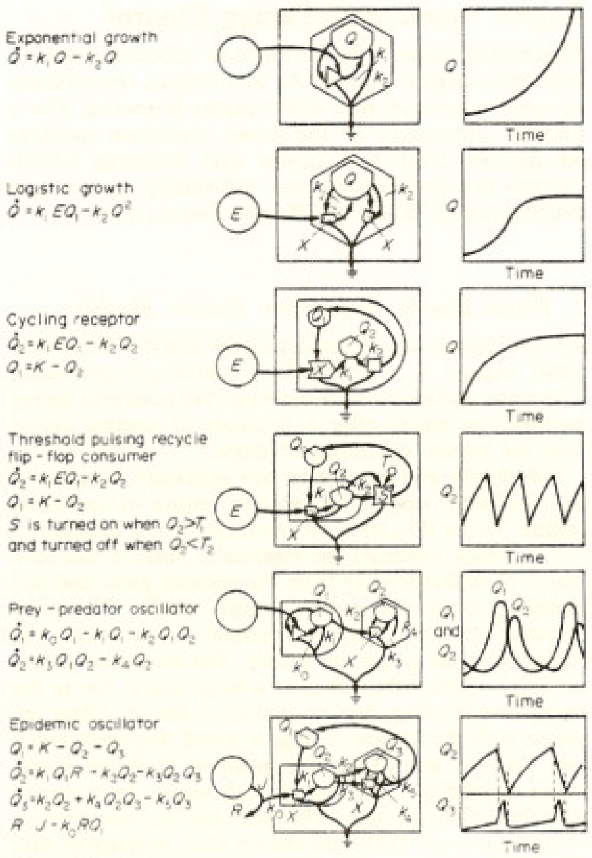

Figure 6
Additional models which are important in science teaching of ecology and other fields

4. Evaluation of Energy Sources

As supplies of fossil fuels become depleted, other energy sources are proposed. These can be evaluated by calculating their net energy, that is, whether they produce more energy than is used to process them. Figure 7 is a net energy diagram. If the yield from the process is greater than the feedback of goods and services from the economy, the source has a positive net energy, or a yield ratio > 1.

The yield and feedback must be in the same units. Coal equivalents (CE) are usually used; these are the number of joules of coal which are needed to produce one joule of the yield. For example, the CE of electricity is 3.7, since it takes 3.7 joules of coal to make 1 joule of electricity. The CE of the feedback is calculated from the energy–currency ratio of the economy. This ratio is obtained by dividing the total energy flow in the economy by the GNP for that year. In 1986 the ratio for the USA was about 75 MJ per dollar. The total energy includes the 1/7 renewable energies of the sun, rain and wind and the 6/7 nonrenewable fossil fuel energies.

Yield ratios of some positive sources are natural gas, 36; purchase exchange for US mideastern oil, 6; Alaskan oil, 6; coal transported 1600 km, 4.8; hydroelectric power at the dam site, 20; geothermal energy in a volcanic region, 13; nuclear fission, not including accidents or waste storage, 2.7; subsistence agriculture and forestry, 1.5. Two energy sources which have a negative net energy (yield ratio < 1) are 16 km h^{-1} wind (0.25) and solar electric cells (0.20). These sources are dilute and need many goods and services to process them. Since the nuclear breeder and fusion processes are not yet in operation, there can be no definite calculations; however, it can be speculated that they may take more energy to cool and contain than they will yield. This analysis of net energies leads to the prediction that as fossil fuels decline there will be no sources to take their place and therefore we will have an economy with less total energy flowing—a lower-energy world.

5. The Future

A comparison of Fig. 4 with Fig. 1 provides an overview of the historical change in our way of life from that of hunting and gathering to that of subsistence agriculture and then to the fossil-fuel-based system of cities. Population growth was one of the high-quality assets that fed and accelerated growth when energies permitted. The

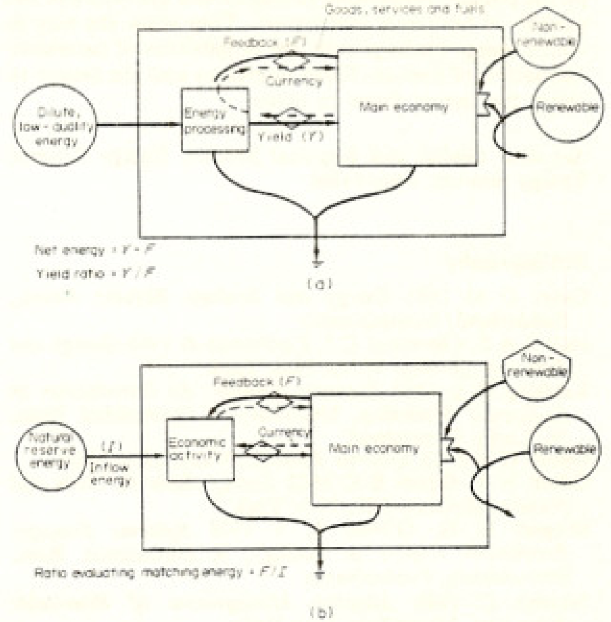

Figure 7
Energy ratios: (a) net energy evaluation of a source, yield ratio; (b) investment ratio evaluation of the contribution of environment to making an activity economic

last model in Fig. 5 has a scenario of growth and decline of assets as fuel, mineral and soil storages are used up. The last model in Fig. 6 suggests that the future could be an oscillating one.

The concept of energy hierarchy (Fig. 3) suggests that high quantities of low-quality items are in steady state with the small quantities of high-quality items that they generate. Thus the proportion of high-quality and low-quality components of our civilization is determined by the energy flow. A decrease in total energy especially in high-quality energies such as fuels may cause a drop in the high-quality items such as high-technology systems, education, culture, electricity consumption, travel and communication. With a shift to lower-quality renewable energies as the main basis of human existence again, energies of the land become proportionately more valuable and cities decentralize. Human labor replaces machines in industry and on the farms, solving the unemployment problem. Ideals of growth and progress change to values of slow and careful craftsmanship and the natural environment becomes more and more valuable.

An economic activity is competitive when it has low-quality energy (*I* in Fig. 7b) to supplement and attract investment of high-quality energy (*F* in Fig. 7b). The ratio F/I is about 7.0 in the USA. Proposed economic activities with much higher ratios than 7.0 are not well matched and may not be competitive.

Energy flows measure the value of all systems, both natural and artificial. Diagrams of systems help to guide public policies concerning resources and the future of the pattern of humanity and nature. They show the way in which energy limits growth, the possibilities of successive oscillation of human–Earth interfaces and the means to relate the energy flows to value.

See also: Global and Regional Models; Energy Sources; Energy Sources, Renewable

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H. T. Odum and E. C. Odum

Engine Speed: Self-Tuning Control

This article discusses the problems of self-tuning control applied to engine systems. As an example, the problem of speed regulation of a diesel engine is studied. For a detailed description of the diesel regulation problem see Zanker (1980) and Zanker and Wellstead (1978). Further practical insights into self-tuning are given in Wellstead and Zanker (1978) and Oates (1980).

1. Diesel Engine Regulation: System Models

The traditional way of regulating the speed of stationary diesel engines is by mechanical centrifugal governors. The more sophisticated of these involve nonlinear spring mechanisms which offer a schedule of control action over the system operating envelope.

Scheduling and regulation are necessary because of the nonlinear, open-loop-unstable nature of the diesel engine. To see this, consider the simple block diagram of Fig. 1, which indicates the essentially positive feedback action of turbocharging from the exhaust gases and fuel pumping from the engine output shaft. The joint influence of these positive feedback loops makes the engine unstable at certain speeds. The nonlinear nature of diesel engine behavior is to a large extent due to the dissipative loading due to frictional losses. These increase with the square of engine speed (approximately) and tend to counteract the positive feedback loops, hence stabilizing the system at high speed. An extensive modelling (Thirurooran 1979) and identification exercise (Wellstead *et al.* 1978) has shown that, in keeping with the above arguments, the diesel engine can be modelled by a simple first-order model relating the fuel rack position $u(t)$ to the engine speed $y(t)$:

$$\frac{y(s)}{u(s)}=\frac{k}{s+\alpha} \tag{1}$$

where k is a gain term and α is a function of speed and is (a) negative at low speed (unstable), (b) zero at medium speed (integrator) and (c) positive at high speed (stable).

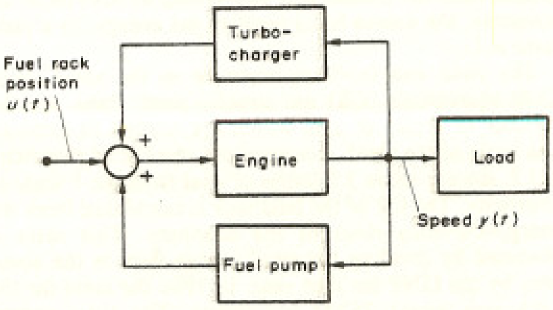

Figure 1
Engine block diagram