PRINCIPLES OF EMERGY ANALYSIS FOR PUBLIC POLICY[1]

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This paper explains EMERGY concepts for maximizing public wealth, and gives explanations for why the principles are valid. The viewpoint is that the world economy, the nations, and states increase their real wealth and prevail according to these principles.

A new quantity, the EMERGY, spelled with an "M" measures real wealth. Here we are using "wealth" to mean usable products and services however produced. Maximizing the EMERGY is a new tool for those making public policy choices among alternative programs, resources, and appropriations. Choosing actions and patterns with the greatest EMERGY contribution to the public economy maximizes public wealth. EMERGY analysis is not advocated as a tool for estimating market values. This paper explains EMERGY evaluation and its use to improve public policies.

Human Choices Consistent with Maximum Sustainable Wealth

Many if not most people of the world assume that the economy is not subject to scientific prediction but is a result of human free choices by businesses and individuals motivated by their individual needs. A different point of view is that the human economy, like many other self-organizing systems of nature, operates according to principles involving energy, materials, information, hierarchical organization, and consumer uses that reinforce production.

If those human choices that lead to successful, continuing wealth fit principles of larger scale self organization, then the economy ultimately uses human choices to follow the scientific laws. The human free choices are the means for finding the maximum public wealth by trial and error. Choices that do not contribute to the public wealth are not reinforced in the larger scale. Eventually patterns that do develop more wealth take over and are sustained.

However, if the designs of society that maximize wealth can be determined from scientific principles, then better choices are possible with less trial and error. EMERGY evaluations and designs based on unchanging physical measures may provide an efficient and predictable means for achieving public wealth and sustainable economic patterns.

Scientific Basis for Economic Vitality

More in the education of scientists and engineers than in that of journalists and business people is the recognition that resources and products are wealth. An economy is vital when it has abundant goods and resources and uses them to reinforce productivity. Energy, minerals, and

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1 Chapter 1. from "EMERGY AND POLICY," J. Wiley

NOTE TO READER
September 1, 2006

This document was included as an Annex to Emergy Analysis of Shrimp Mariculture in Ecuador, printed in 1991.

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EMERGY ANALYSIS OF SHRIMP MARICULTURE IN ECUADOR

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information are the real wealth. It takes energy to concentrate the minerals needed by an economy. It takes energy to maintain and process information. When resources are abundant and cheap, there can be abundant wealth and a high standard of living. If resources and basic products are imported cheaply, abundant wealth is imported.

The Irrelevance of Market Prices to Wealth

Although the market value of products and services is important to individuals and business budgets, it is largely irrelevant as a measure of wealth. A tank of gasoline drives a car the same distance regardless of what people are willing to pay for it. A day of summer sunlight generates so much corn growth regardless of whether a human thinks it's free or not. A nugget of copper concentrated by geological work will make so much electric wire regardless of its price.

When resources are abundant, wealth is great, standard of living is high, and money buys more. But when resources are abundant, market values and prices are small. Prices are not a measure of resource contribution to wealth.

When resources are scarce, prices are high not only because shortages affect demand, but because more human services are required to mine, transport, or concentrate scarce resources. By the time the resources have been collected and used, the net contributions of the resource have been diminished by the extra efforts to process the resources.

Figure 1 shows the economic interface between a typical environmental process that generates the resources and the human economy. Money circulates through the people involved in processing the resources, but no money goes to the works of the environment. The money paid is not a measure of the wealth that comes from nature's work on the left. In other words, prices are not only not a measure of the contribution of resources and commodities to an economy, they are inverse, being lowest when contributions are greatest. Another kind of measure is required for evaluating contributions to public wealth.

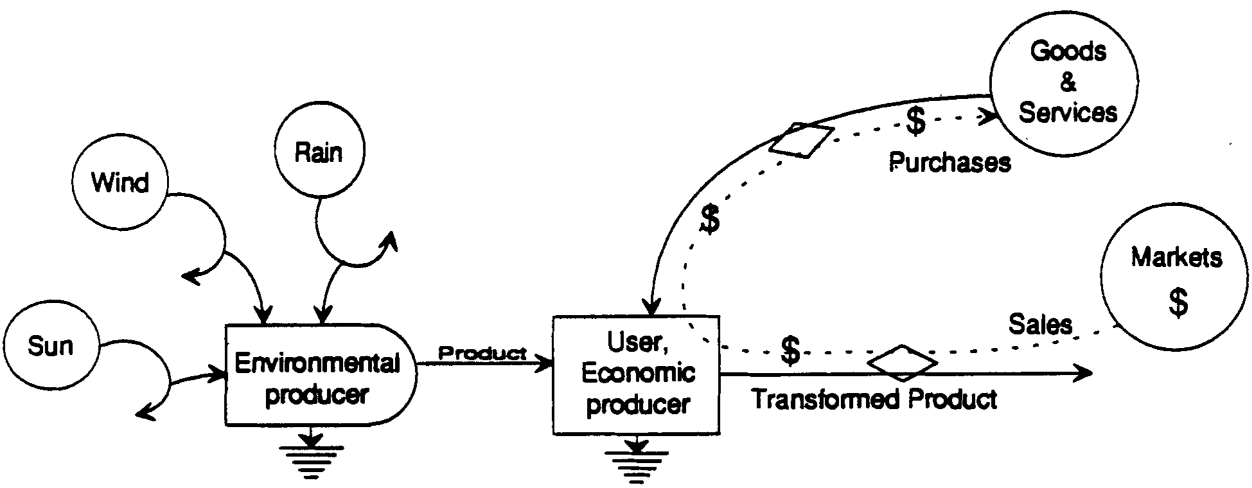


Figure 1. Environmental production process and an interfacing economic user which is also a human-paid economic production process. Notice absence of reinforcement from user to environment producer.

EMERGY Definition

EMERGY of a product is the work which went into making it expressed in units of one type of energy. The unit of EMERGY measure is the emjoule.

For example, a cubic meter of rain water over land has a solar EMERGY content of 7.5 E10 solar emjoules. This means that 7.5 E10 solar joules directly and indirectly were involved in bringing this much rainwater to the land.

EMERGY and Sustainable Uses

Because EMERGY measures what went into a product, it is also a measure of what that product should contribute to the economy if its use is to justify its production.

In the self organizational process of economies and of environmental systems, products that require more work in their manufacture either contribute more to the system commensurate with what was required to make them, or the production is discontinued.

Thus, EMERGY is not only a measure of what went into a product, it is a measure of the useful contributions which can be expected from that product as an economy self organizes for maximum production.

EMERGY goes with a product as it is processed and transported. It is like a memory, since it records what went into that product.

Reinforcement of Production Required for Sustainable Uses

Whereas individualistic human-centered concepts of economic benefit view production as directed to benefit the human consumer, real self organizing systems develop with a different consequence. All uses (by consumers) reinforce production processes or are displaced by those which do. Economies which allow allocation of resources to wasteful luxuries are not sustainable, being displaced by those with better reinforcement of their productive basis. This viewpoint contrasts with the economic view that any expenditure of money is good whether it be for unnecessary products and services or not.

Consumers that use products without contributing to production processes elsewhere in the system divert resources, reducing the wealth of the system below its potential. For example, consumers that use larger cars than necessary for their maximum service to the economy reduce the potentials for economic reinforcement inherent in the products they consume.

Consumers that use products of nature's production such as fisheries without contributing some reinforcement to the natural production process cause that production system to be displaced by alternative systems which are not so exploited. Because marine fisheries have rarely reinforced their stock production processes, many have been displaced. In contrast, most sustainable systems of agriculture apply extensive reinforcement to their soil production processes by applying various fertilizers and other soil improvements. Figure 2 compares sustainable systems that reinforce with an unsustainable design that does not reinforce.

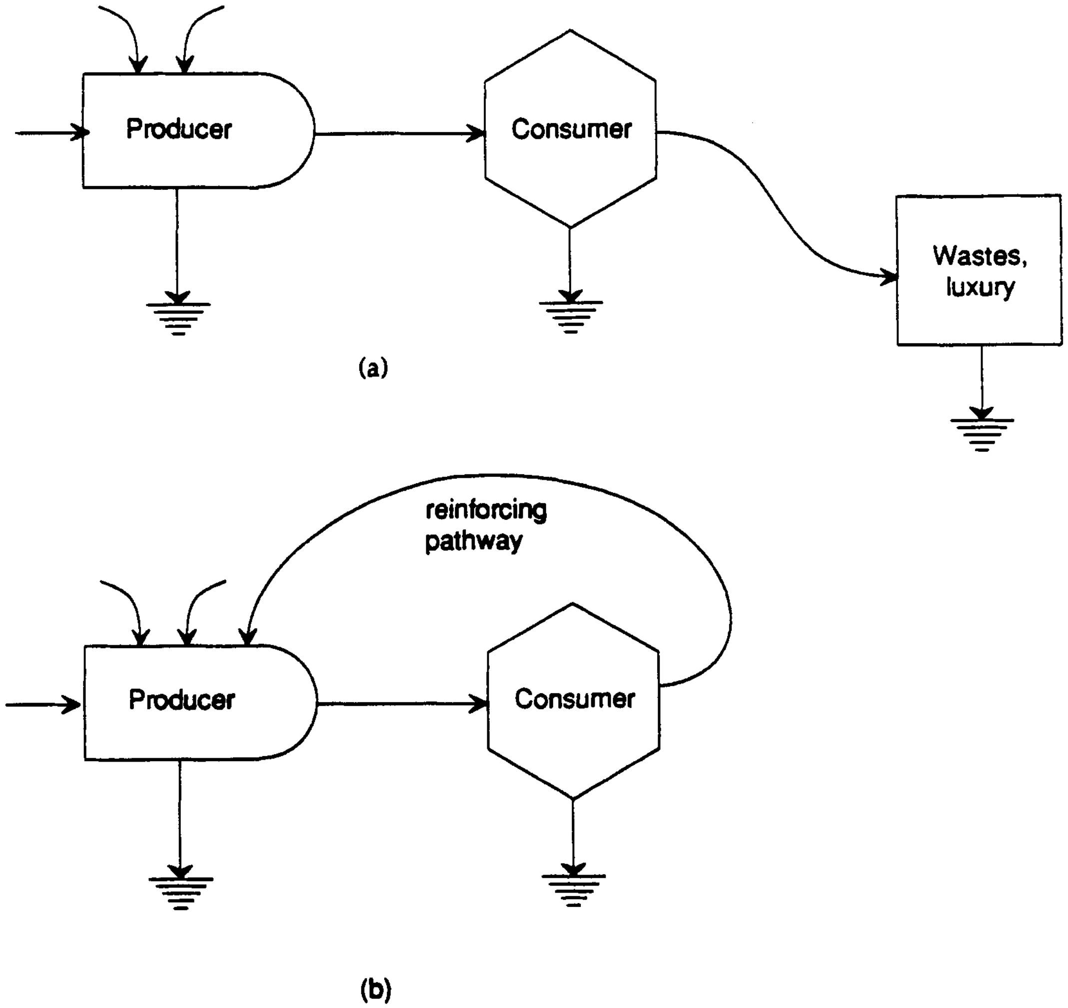


Figure 2. Comparison of consumers which reinforce production with those that don't. (a) Environmental production and consumption with consumer outputs of materials and services that don't reinforce; (b) economic production and consumption with consumer output reinforcing production.

Some of the production processes are those of environmental work such as that of forests, farms, fisheries, and mineral forming processes (geological processes). Other production processes are those within the human economic system of industries. Both kinds of production processes require reinforcement with services and other inputs from the consumers to be sustainable. For example, means for reinforcing fisheries production include release of hatchery stocks, fertilizing food chains, selective removal of competing species, and chumming with extra food suplements.

The circulation of money helps insure that human producers receive reinforcement for their contributions, but the production processes of nature cannot accept money. As Figure 1 shows, money paid to humans to process environmental products with market pricing does not lead to reinforcement. Maximizing human incomes does not include any reinforcement to the environmental systems necessary for sustainable production.

Public Policy to Maximize EMERGY Input and System-reinforcing Uses

From the preceding explanations of EMERGY we conclude that greatest public wealth can be achieved by policies that bring in the most EMERGY and allocate it to uses that reinforce production, including environmental production processes on which the human production systems depend. For example, policy to maximize agricultural production of wealth includes reinforcing natural soil maintenance processes, even if profits are less.

Maximizing EMERGY Is the Old "Maximum Power Principle"

The principle that greatest wealth is achieved by maximizing input and reinforcement may be recognized as a statement of an old concept: "the maximum power principle" sometimes attributed to Lotka (1924). The concept has its roots in writings of theoretical scientists and economists in the last century (Martinez-Alier, 1987).

EMERGY-based Evaluation of Contribution to GNP

The total annual EMERGY use by a nation measures its annual wealth. Many people are used to thinking of national economic vitality in terms of money circulating in that country measured by the gross economic product. However, in different countries money buys different amounts of real wealth even when the currencies are compared on a current international exchange basis. The amount of real wealth that circulating money buys is indicated by the EMERGY/$ ratio. Table 1 has the gross economic products and solar EMERGY budgets of several nations. The last column is the solar EMERGY/$ ratio for each country.

Rural countries have higher EMERGY/$ ratios because more of the wealth goes directly from the environment to human consumer without money being paid. For example, a family in remote rain forest gets most of its food, clothing, shelter, recreation, etc., directly from nature without money being involved.

If some change in global environmental processes reduced the EMERGY budget of a country by 10%, the real wealth would be reduced by 10%. The same money circulation would buy less. This is inflation.

Since public policy people already have values of gross economic product in their minds, it is sometimes useful to express EMERGY in dollars of gross economic product. If one is given a solar EMERGY value, the equivalent gross economic product is found by dividing the solar EMERGY by the solar EMERGY/$ ratio (Table 1).

The dollars of gross economic product estimated from EMERGY evaluation of a product is usually much larger than the money first paid for the product (Figure 1). Sometimes we call the EMERGY-based GNP evaluation "macroeconomic dollars".

Using Diagrams to Visualize Sustainable Systems

For many people the principles already stated for maximizing wealth can be understood better when the self organizing systems of environment in the economy are represented with network diagrams. These are a pictorial way of representing production, consumption, and pathways of input and reinforcement. Figure 3 shows a systems network in which all uses reinforce other parts of the system with materials or services.

Table 1. National Activity and EMERGY/$

Nation	U, ENERGY used/year E20 sej/year	GNP E9$/Year	EMERGY/$ E12
Liberia	465.	1.34	34.5
Dominica	7.	.075	14.9
Brazil	17820.	214.	8.4
India	6750.	106.	6.4
Australia	8850.	139.	6.4
Poland	3305.	54.9	6.0
World	188000.	5000.	3.8
Soviet Union	43150.	1300.	3.4
New Zealand	791.	26.	3.0
USA	66400.	2600.	2.6
West Germany	17500.	715.	2.5
Netherlands	3702.	16.6.	2.2
Spain	2090.	139.	1.6
Switzerland	733.	102.	0.7

The special set of symbols and conventions for drawing a web (Figure 4) has been used for two decades to represent systems networks, gain overview perspectives, and explain concepts. The networks of symbols connect flows of materials, goods, service, and information. These diagrams are an "energy systems language" because all pathways have some flow of energy. Even flows of information have the tiny energy content of the paper, computer disks, electrical currents, sound wave, light waves, etc., that carry messages. Flows of minerals or other materials that are more concentrated than in the surroundings contain the small energy content inherent in being concentrated. As we explain below, the importance of any flow is measured by its EMERGY content, whether the energy flow is large or small.

The second law of thermodynamics requires that any process have some of its available energy be dispersed in degraded form leaving the system unable to do more work. This law also requires that any stored material, energy, goods, or information, depreciate, losing its concentrations (because its energy is dispersing). The flows of used energy leaving the system are shown in the diagrams by pathways that go downward (into the "heat sink"). These pathways represent only degraded heat energy. Any dispersing materials, commodities, services, or energy still concentrated enough to do work are shown leaving the system by other pathways.

Money is exchanged as a counter current to the flow of commodities and services where humans are involved. Money is only paid to people and thus does not flow over environmental pathways. As already said, money flows are not proportional to the input of EMERGY wealth to the human economy.

Note that the designation of producer and consumer is relative. Things on the left are producers passing products to consumers on the right. A consumer in the center of the diagram uses products incoming from the left, but is also a producer passing its products to the unit next on the right.

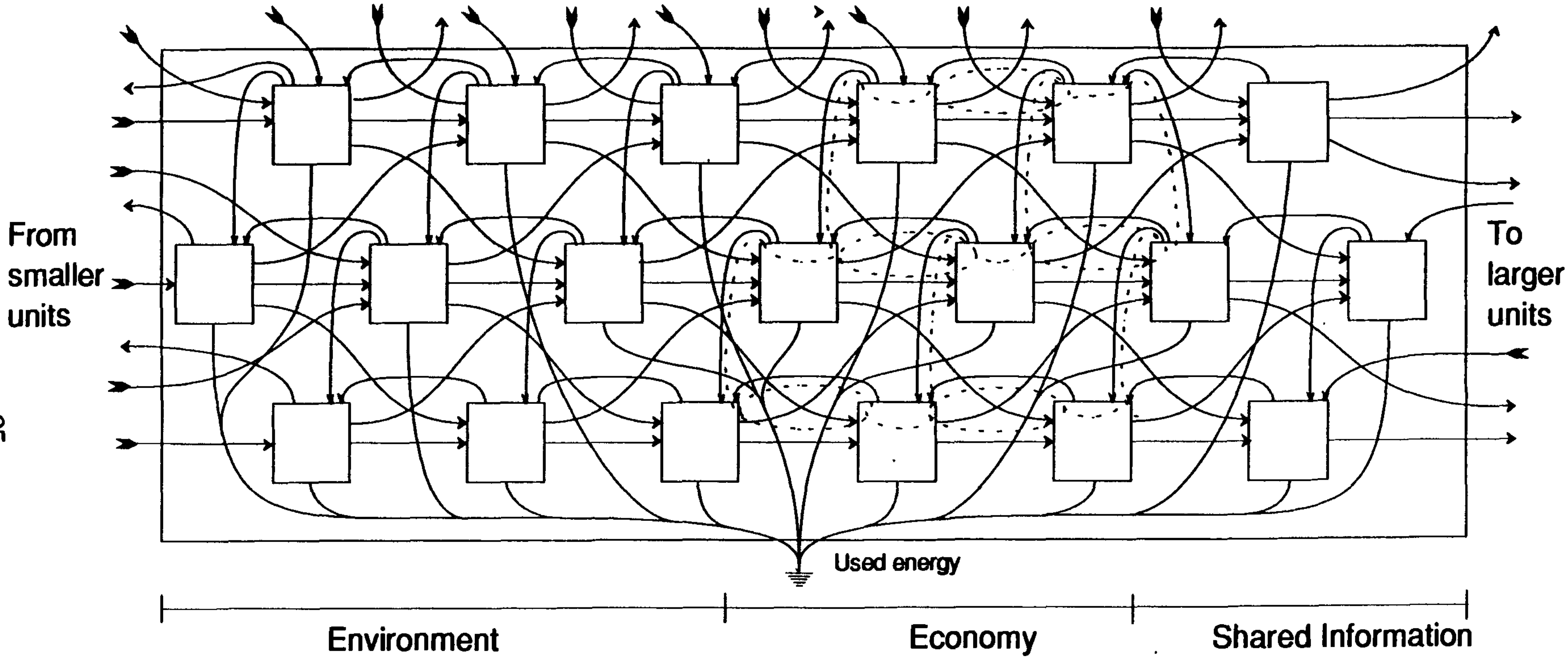
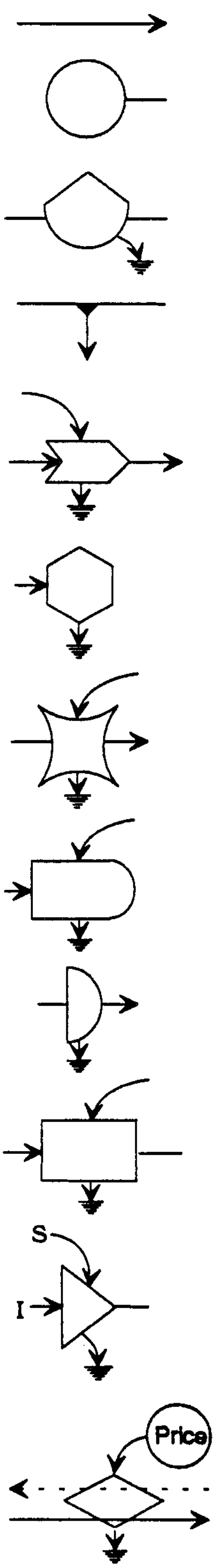


Figure 3. Network diagram of a joined system of environment and human economy. Economic sectors have circulation of money (dashed lines).



Energy circuit. A pathway whose flow is proportional to the quantity in the storage or source upstream.

Source. Outside source of energy delivering forces according to a program controlled from outside; a forcing function.

Tank. A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows; a state variable.

Heat sink. Dispersion of potential energy into heat that accompanies all real transformation processes and storages; loss of potential energy from further use by the system.

Interaction. Interactive intersection of two pathways coupled to produce an outflow in proportion to a function of both; control action of one flow on another; limiting factor action; work gate.

Consumer. Unit that transforms energy quality, stores it, and feeds it back autocatalytically to improve inflow.

Switching action. A symbol that indicates one or more switching actions.

Producer. Unit that collects and transforms low-quality energy under control interactions of high-quality flows.

Self-limiting energy receiver. A unit that has a self-limiting output when input drives are high because there is a limiting constant quality of material reacting on a circular pathway within.

Box. Miscellaneous symbol to use for whatever unit or function is labeled.

Constant-gain amplifier. A unit that delivers an output in proportion to the input I but changed by a constant factor as long as the energy source S is sufficient.

Transaction. A unit that indicates a sale of goods or services (solid line) in exchange for payment of money (dashed line). Price is shown as an external source.

Figure 4. Symbols of the energy Language used to represent systems (Odum, 1971, 1983)

Energy Hierarchy Principle

Diagramming the economies of environment and humanity in network form as in Figure 5 makes it easy to explain the important concept of energy hierarchy, which is necessary to understand how different kinds of flows have different EMERGY. Self organizing systems develop a hierarchical division of labor according to size that increases system reinforcement of production. All the processes of nature and of humans are hierarchical. Many small units converge their production flows to form a few units of larger size and territory. These larger units converge flows to fewer units of even larger size and territory. For example, grass is converged into sheep and sheep to the shepherd and shepherd's products to the village and the village products to the town.

As shown in Figure 5, we arrange the hierarchy with converging from left to right (by convention). Items on the right are fewer, have larger size, and take longer to grow, depreciate, or turn over (are replaced). Each use is an energy transformation, changing the form of energy from one unit to the next.

As already explained, consumers of sustainable systems have pathways reinforcing other units of production. In Figures 3 and 5 these reinforcement pathways are the services and materials that consumers on the right pass to the producers they use on the left. Because they go back to the left, we call them feedbacks. Many of these feedback pathways are controls with the application of useful information. Even these information flows have small amounts of accompanying energy flow, since it is not possible to store or transmit information without a small energy flow to carry the information.

Because it takes more of an item on the left to make an item on the right and because a small amount of items on the right control larger amounts on the left, we can describe the right side of the energy hierarchy as of higher quality. In sections that follow we will measure that quality.

As Figure 5c shows, the energy flows on the pathways get less as one goes from left to right in the energy hierarchy. This is because of the second law which requires that some potential energy be degraded into used energy state (no longer reusable) at each use and transformation.

Thus, it takes more energy of one type on the left to support the transformations that make a smaller amount of higher quality energy to the right. Thus, it is incorrect to use energy as a measure of work or value, except where one is comparing energy flows of the same type. A Calorie of sunlight does not contribute as much to the economy as a Calorie of coal. A Calorie of coal does not contribute as much to the economy as a Calorie of human effort.

Energy Flow Decrease Up the Hierarchy

The definition often used in elementary physics and engineering courses that energy is the ability to do work is incorrect. Degraded energy can't do any work. The work that potential energy can do depends on its position in the energy hierarchy (its position in the left-right hierarchy illustrated by Figures 3 and 5).

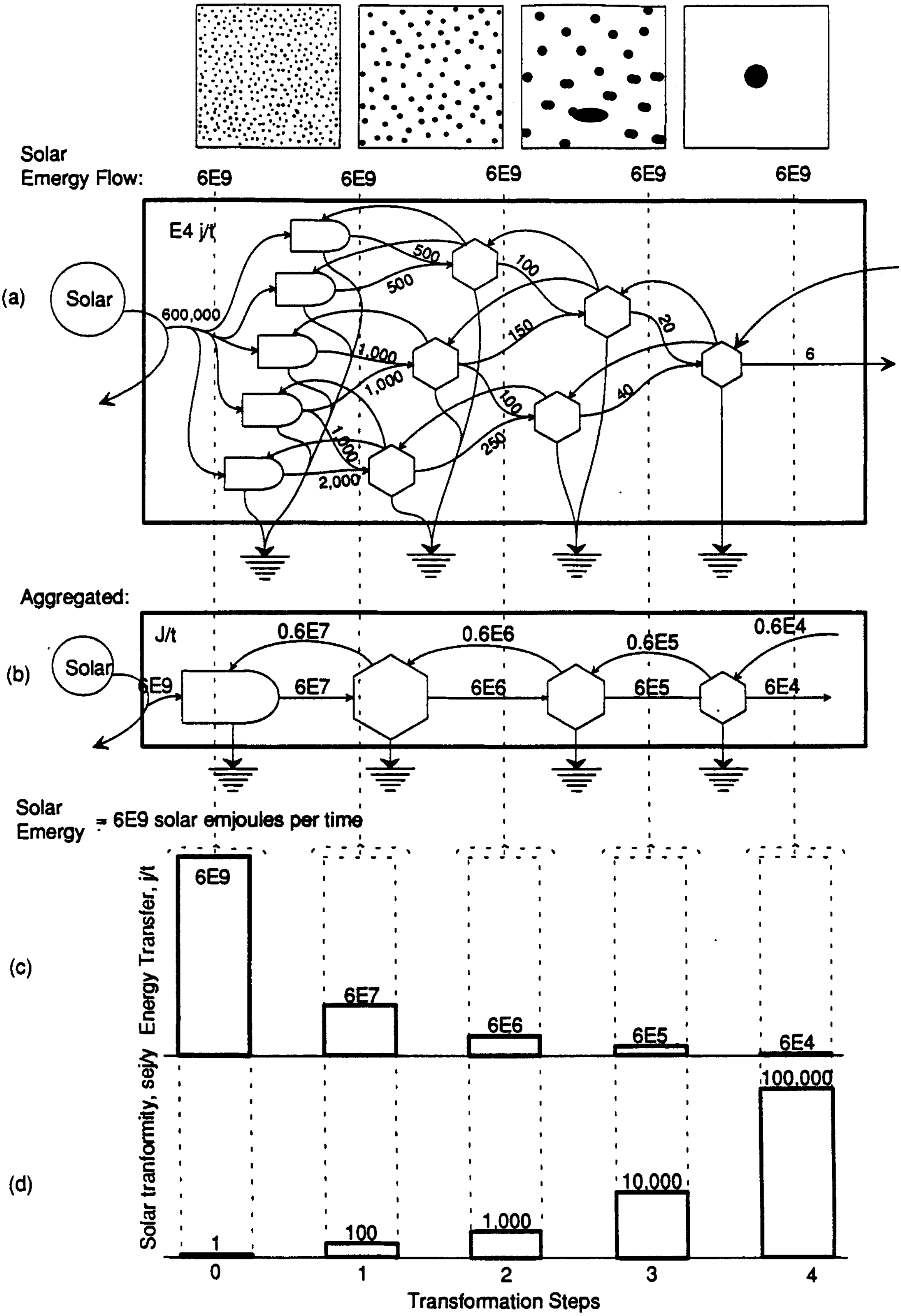


Figure 5. Energetics of a food web. (a) Energy flows on the pathways (feedback control pathways omitted); (b) the energy transformed by aggregating the web; (c) graph of energy flows by position in hierarchy; (d) solar transformity at various positions in heirarchy.

Transformities

By examining the energy transformations in networks that have been proven to be sustainable over long periods of self organization (in nature or in the economy), we can determine the energy of one form required to generate energy of another type under sustainable conditions. We introduce a new term, the "transformity" defined as the energy of one type required per unit of energy of another. For example, if 4 coal Calories are required to generate 1 electrical Calorie, then the coal transformity of electricity is 4 coal emCalories per Calorie. If one uses Joules instead of Calories as the unit of energy, then the same statement using Joules is: the coal transformity of electricity is 4 coal emjoules per Joule.

In order to make calculations easier, we have been expressing all our transformities in EMERGY units of one type, solar equivalents, as solar emjoules per Joule. Table 2 has some representative solar transformities for typical commodities and services.

Consider any product whose energy is known. Its solar EMERGY was already defined as the solar energy required to generate that product. Thus, another way to calculate a solar transformity is to divide the product's solar EMERGY by its energy. As stated before, the solar transformity units are solar emjoules per joule.

Tables of solar transformities make calculations of EMERGY easy. One has only to multiply the amount of a product by its solar transformity. If the product data are in energy units (Joules), multiply by a transformity in emjoules per Joule. If the data are in mass units (grams), multiply by the transformity expressed in emjoules per gram.

Transformity as a Measure of Unit Wealth

Notice in Figure 5 that the solar transformities rise as one goes from left to right in the system hierarchy. The larger the transformity, the more resources were required to make a unit. The further to the right, the higher the quality and the larger the control action if it is fed back to reinforce production.

Observed and Theoretical Lowest Transformities

If one evaluates the transformity of a newly initiated process, which has not been running long enough to develop its maximum efficiencies for full sustainable production, then a higher transformity (lower efficiency) may be found than later after the system is operating at highest output possible. For example, the transformity of steam engine work calculated from steam engines in 1910 was higher than for the better engines that had been developed by 1940.

There is a thermodynamic lower limit for transformities reflecting the inherent differences in quality concentration. For example, to convert dilute solar energy falling on the earth into a concentrated fuel requires that much of the energy be dispersed as part of the concentrating process. If the green plants after a billion years of evolution have achieved the maximum possible sustainable output, then the transformity we obtain from evaluating biomass conversions from solar energy will not be exceeded by new technology.

Each EMERGY analysis generates transformities. As more and more analyses are done, and we obtain many independent values for the same kinds of products, it will become clear which are the consistent lower values. Then we can judge a process to be inefficient if the calculated transformity is much higher than that found in other analyses.

Table 2. Typical Solar Transformities (solar emjoules per joule)

Item	sej/J
Sunlight	1
Wind kinetic energy	623
Unconsolidated organic matter	4,420
Geopotential energy in dispersed rain	8,888
Chemical energy in dispersed rain	15,423
Geopotential energy in rivers	23,564
Chemical energy in rivers	41,000
Mechanical energy in waves and tides	17,000-29,000
Consolidated fuels	18,000-40,000
Food, greens, grains, staples	24,000-200,000
Protein foods	1,000,000-4,000,000
Human services	80,000-5,000,000,000
Information	10,000-10,000,000,000,000+

Transformity Matching in Reinforcement

A product reinforces some other part of its system by interacting as a multiplier. For example, fuel interacts with a tractor to deliver farming work; phosphates interact with green plants to form crop products; computer programs interact with computers to generate information services. In each case something of higher quality with higher transformity reinforces its larger system by interacting with a larger quantity of lower transformity to generate new products. The principle here is that more wealth is generated by production processes that join a smaller quantity of high transformity with a larger quantity of lower transformity.

Experience shows that items with very large difference in transformity cannot interact with maximum effect directly, but need intermediate processes. For example, human bodies cannot use sunlight as an energy source directly; highly educated humans are not well used gathering sticks from the woods; high tech ships are not well used harvesting microscopic plankton; electricity is too valuable for general heating.

The transformities of products and by-products are useful guidelines for developing new systems and assigning resources.

Equivalence of Resources

Because EMERGY evaluation traces what was required for a product back to a common form of energy, it is a way of showing how the requirements for different products compare. As we discussed already, self organization finds uses for products that reinforce some part of the system commensurate with what was required in the products manufacture. After appropriate reorganization, products with similar solar EMERGY requirements can be substituted without changing the productivity of a system. The same original amount of resource is going into the same use and reinforcement.

Thus, EMERGY evaluation of a product can indicate in advance what uses and substitutions are appropriate to continued, sustainable wealth of the economy.

Evaluating Human Services

The average EMERGY/$ ratio for a nation (Table 1) can be used to evaluate the typical services. Data on costs in $ are multiplied by the EMERGY/$ ratio to estimate the EMERGY contribution from the paid services. This method omits the many unpaid services. It probably does not appropriately represent information services. For example, it does not evaluate mothers raising children.

Individual human services have a very wide range of transformities from that of an uneducated youngster to national leaders who have become symbols in the whole population. Some efforts have been made to evaluate EMERGY per person for categories of education and occupation.

Procedure for Making an EMERGY Evaluation Table

The EMERGY flows of a country, city, process, storage, or whatever may be evaluated by the following procedure for making an EMERGY evaluation table. See example in Table 3. It may be convenient to use a computer spread sheet.

1. Assemble people knowledgeable about a system to be analyzed. Together diagram the system, thus identifying the main inputs, system parts, processes, and products yielded.
2. Make an EMERGY analysis table with one line in the table for each input or product to be evaluated. Number the lines, using the same numbers for the footnotes that give the sources of data, references, calculations, or other details.
3. In the first column of data put raw data for each line in Joules, grams, or dollars.
4. Put the appropriate solar transformity in the next column.
5. In the third column multiply data from column 1 by the solar transformity from column 2, thus obtaining solar EMERGY values.
6. In the fourth column divide the solar EMERGY values by the solar EMERGY/$ ratio for a particular economy for a particular year in order to express EMERGY in equivalents of gross economic product (for perspective).
7. Calculate totals and indices for recommending public policies (see below).

Evaluation of Environmental Resources

Decisions on the use of environmental resources cannot be made correctly using money because money is only paid for services, but an EMERGY comparison can be prepared for choosing among environmental alternatives. The management with the largest EMERGY may be chosen to maximize the economy.

A use that fosters environmental EMERGY production also maintains the area's ability to attract more EMERGY from outside sources. The environmental EMERGY contribution serves as an attraction for economic investments that bring in fuels, goods, services, technologies, etc., from outside. Purchased inputs interact with the environmental resource in new production processes. One can multiply the environmental EMERGY by the EMERGY investment ratio of the region (see below) to estimate the potential the environmental use has in attracting the additional EMERGY of outside purchased resources.

Table 3. Emergy Evaluation of Texas Cattle, Grain, and Vegetable Production in 1983*

Note	Item	Raw Units J,g,$	Transformity Sej/unit	Solar EMERGY E20	Macroeconomic 1983 US E9 $/yr
1.	Cattle and Calves	2.98 E16 J/y	1.73 E6	515	19.8
2.	Grains	1.49 E17 J/y	8.6 E4	128	4.9
3.	Vegetables	4.29 E15 J/y	2.6 E5	11.1	0.43

Notes:

*. Odum, Odum, and Blissett (1987)

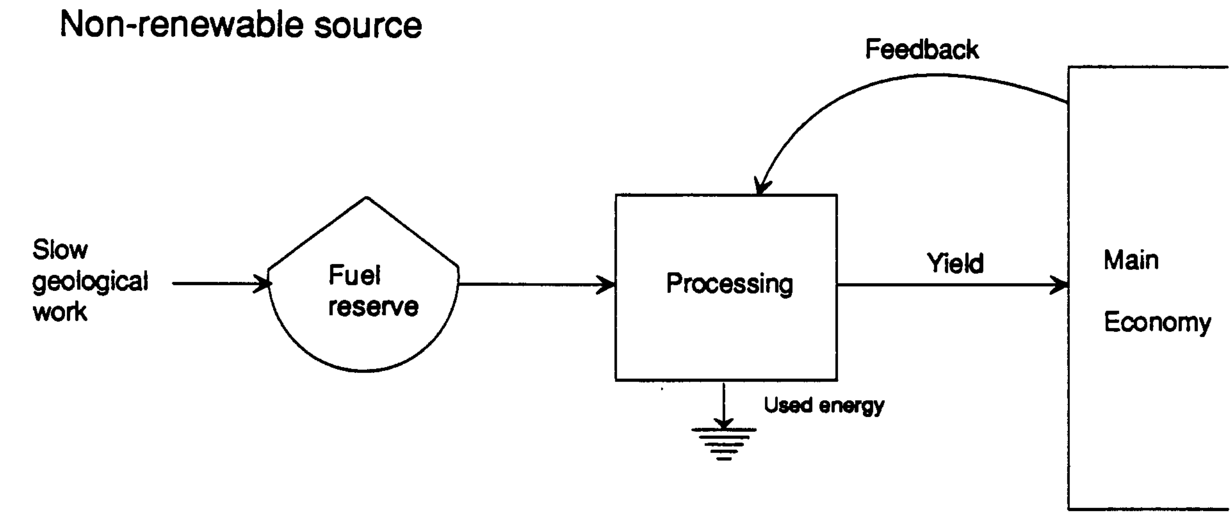
1. Cattle and Calves 1983; 5.555 E9 pounds production (Texas Livestock, Dairy, and Poultry Statistics for 1983, Texas Department of Agriculture, 60 pp)
(5.555 E9 lbs)(454 g/lb)(2.82kcal/g)(4186 J/kcal) = 2.98 E16 J/y
Transformity of beef products estimated from Appendix 35 as ratio of 0.89 of the solar emergy inputs (beef 89% of yield emergy) to energy in products:
(0.89 *(1132 + 291) E12 sej/yr)/(7.3 E8 J/yr) = 1.73 E6 sej/J

2. Grains, corn, 104,760,000 bushels; barley 2,476,000 bushels; oats 10,730,000 bushels; rye 450,000 bushels; winter wheat 161,000,000 bushels; sorghum 10,730,000 pounds CWT; rice 13,805,000 pounds CWT. (Texas Field Crop Statistics for 1984, Texas Department of Agriculture, 100 pp.)
(11.95 E12 grams/year)(0.9 dry)(13826 J/gram) = 1.49 E17 J/y

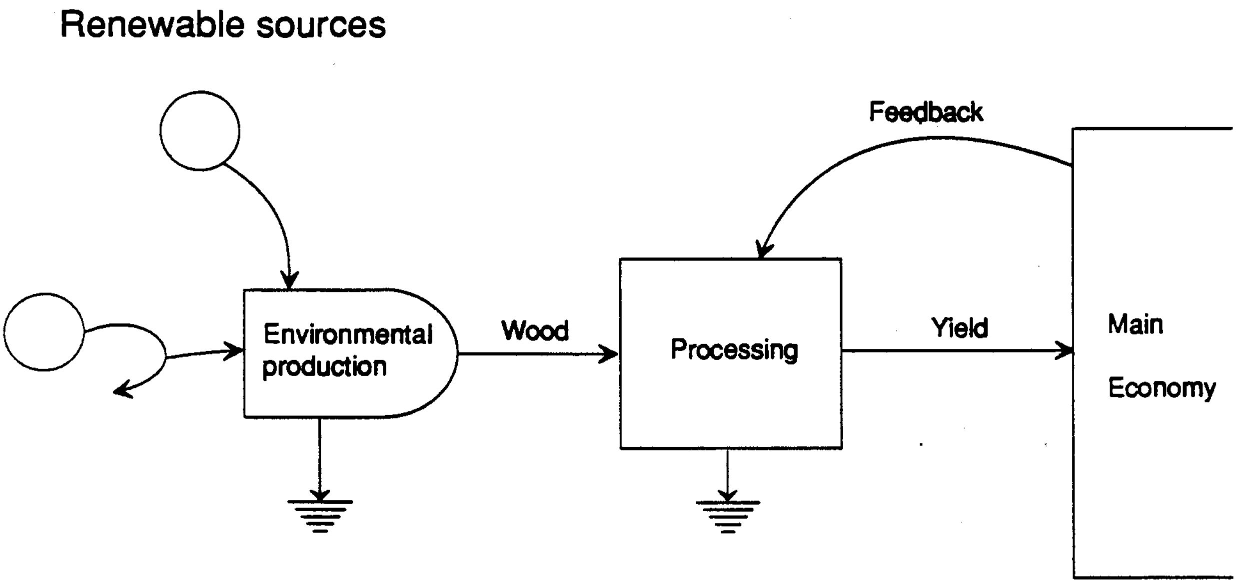
3. Vegetables, fruits: production in 1982, 1.74 E9 pounds/year (Texas Vegetable Statistics for 1985, Texas Department of Agriculture, 44 pp.)
(2.82 E9 lb/y)(.2 dry)(454 g/lb)(4 kcal/g)(4186 J/kcal) = 4.29 E15 J/y
Transformity estimated as solar emergy in rain on acreage:
(301,800)(2.1 ft/y rain)(1233 m^3/ac-ft)(1E6 g/m^3)(5 J/g) = 4.29 E15 J/y
(3.9 E15 J/y)(1.54 E4 sej/J) = 0.6 E20 sej/y
plus services estimated from cash receipts (1982): $4.07 E8)(2.6 E12 sej/J) = 0.6 E20 sej/y
Emergy inputs (0.6 + 10.5) E20 sej/y = 11.1 E20 sej/y
Solar Transformity = 11.1E20 sej/y/y/4.29 E15 J/y = 2.6 E5 sej/J.

Evaluation of Primary Energy Sources Net EMERGY Yield Ratio

The Net EMERGY of a source of energy is its EMERGY yield after the EMERGY used to process it has been subtracted. Primary sources can be evaluated with the Net EMERGY Yield Ratio, which is the ratio of the EMERGY yield divided by the EMERGY used for processing (see Figure 6). The developed countries that run on fuels at present prices have fuels available to them with a net EMERGY yield ratio of 6 to 1 or more. In other words, only 1 of the 6 is required for processing, leaving 5 to run the rest of the economy. The higher the yield ratio of an economy's primary energy source, the more can be done elsewhere in the economy besides processing its energy. Good policy selects sources with the best net EMERGY yield ratio even if they have to be bought abroad.



(A)



$$\text{Net EMERGY yield ratio} = \frac{\text{Yield EMERGY}}{\text{Feedback EMERGY}}$$

(B)

Figure 6. EMERGY yield ratio for evaluating a primary energy source. (a) Nonrenewable source; (b) renewable source.

Compare this policy with the economic view that buying fuels hurts the economy by sending out foreign dollars. The economic viewpoint underevaluates the wealth of the fuel six fold or more.

When fuels are deep in the ground and require more money and services to extract, the typical economic view sees this as more value and more jobs, whereas the EMERGY viewpoint sees less net yield and diminished wealth for everyone except those involved in extracting the resource. Good public policy for a nation is to obtain resources with the highest net EMERGY yield ratio.

Countries that sell their fuels give away their EMERGY 6 for 1 or worse. The benefits to countries that buy their fuels depend on the EMERGY ratio of their trade transaction (see below).

Selecting Taxes with Net EMERGY Yield Ratio

To maximize EMERGY availability and use, taxes should never be put on any commodity that has a net EMERGY yield. Tax tends to discourage use and the effect on the economy is amplified according to the net EMERGY yield ratio. Putting a tax on fuels that have a net EMERGY yield ratio of 7 to 1 inhibits the economy 7 times more than putting the tax on a final product, most of whose EMERGY input is service. Most raw products have high yield ratios including fresh waters, soils, wood, fish, crops, and minerals.

Wastes and luxuries that do not reinforce production are usually from highly-paid consumers. Taxes on these consumers at the top of the hierarchy (on the right side of the diagrams in Figure 3) increase productivity, whereas taxes at the other end inhibit the economy. Traditional economic viewpoints do not recognize the differences, because money is used to evaluate commodities, which it cannot do, since it is paid to the human service part of a commodity only.

When there are critical fuel shortages, rationing should be of consumer use, not of production industries.

EMERGY Investment Ratio

The net EMERGY from primary fuel sources or products derived from them are moderately high quality (high transformity). Their effective use requires that there be an interaction with lower transformity resources, as we already discussed. Typically, most of the products of urban society use fuels and electricity directly or indirectly. The fuels and their products are fed back to reinforce production processes, interacting with abundant but lower transformity environmental resources. Examples are agriculture, forestry, fisheries, and recreation. In other words, high quality products elsewhere in the economy are brought into a region to form a new economic use industry, usually through economic investment that utilizes environment. How much investment is appropriate for a given amount of environmental lands and waters?

The ratio of EMERGY brought into an area from the economy and the EMERGY of the environmental resources used in the interaction is the EMERGY investment ratio (see Figure 7). This index is useful for determining when a process will be economically competitive and at the same time how much economic activity is loaded on the unpaid environment.

If a product is not the economy's primary source it does not need to yield net EMERGY, but the EMERGY matching should be typical of the region to be competitive. If a proposed project has a lower ratio than the regional average, this means that purchase costs are less than the average economic activity in the region. Costs being less, the industry tends to sell its products for less, capture markets and grow. If the EMERGY investment ratio is higher than the typical regional ratio,

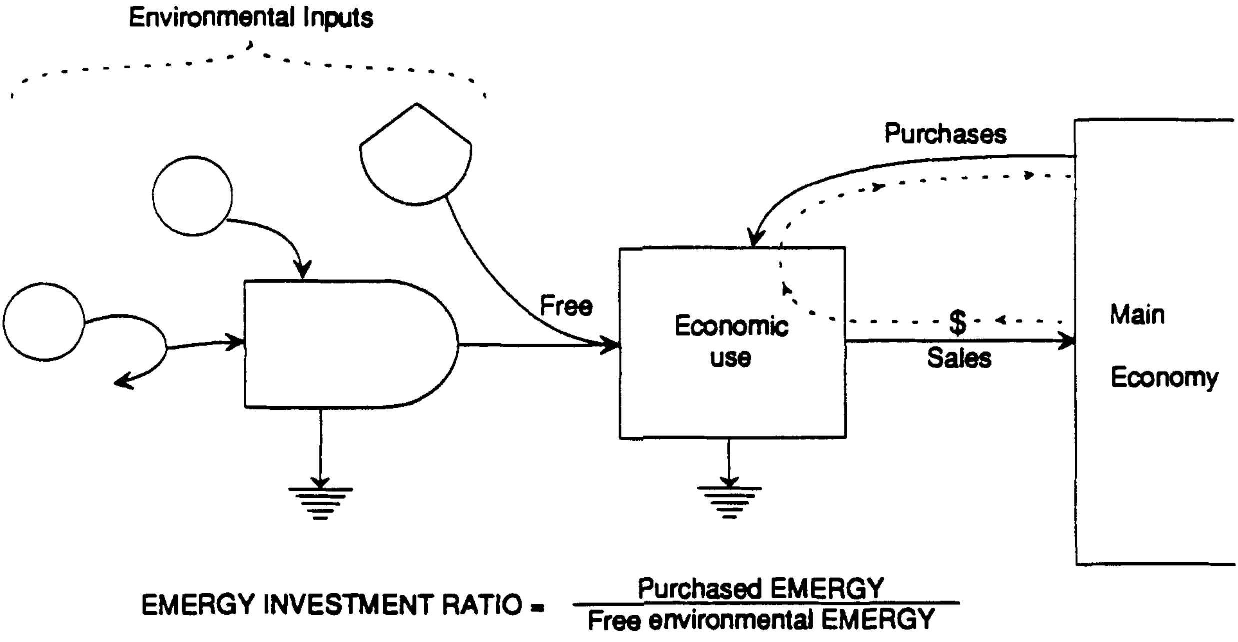


Figure 7. EMERGY investment ratio for evaluating whether an environmental use is economic and its environmental impact.

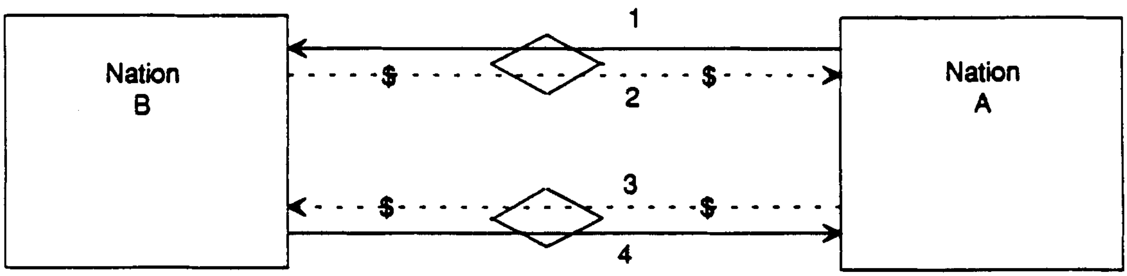
then the project may not be economic, since too much investments and costs will make the product economically uncompetitive. The worldwide EMERGY investment ratio is about 2 to 1, whereas it is 7 to 1 or higher in developed countries.

As the world economy becomes more organized into one system, processes that would be competitive within their own region are forced to compete more with similar processes elsewhere. An industry with an EMERGY investment ratio of 7 may compete within the United States, but not compete with a comparable unit overseas where more free environmental resource is available with a lower EMERGY investment ratio. Planning for economic vitality now may require planning for lower EMERGY investment ratios (less density of economic developments) than a few years ago.

Areas with typically high EMERGY investment ratios have less environment to support each unit of economic activity. Thus, they are impacted more. More of their EMERGY is used up, often not reinforced. The ratio is a measure of economic loading of environment. EMERGY investment ratio is useful to plan new developments to insure that they are economically competitive and that the environmental resources are not overloaded.

Evaluation of Foreign Trade

The benefit from a foreign sale, purchase, or trade depends on the EMERGY exchange ratio of the trade. An EMERGY table should be prepared evaluating the commodities purchased or sold and the monies received (Figure 8). Generally, a country loses wealth if it sells environmental raw products because the EMERGY of nature's work to make them is high, whereas the money received is only for some services to process them. The luxury of developed countries is partly due to importing raw resources without paying anything but processing costs. For example, aluminum ingots made with New Zealand hydroelectric power were sold in Japan for 58 million dollars, even though the contribution to the Japanese economy evaluated with EMERGY methods was close to a billion dollars. For the benefit of New Zealand, the ingots should be kept at home and used to make final products for export, thus making jobs in New Zealand.



$$\text{EMERGY EXCHANGE RATIO} = \frac{\text{EMERGY received}}{\text{EMERGY sent}}$$

Figure 8. EMERGY exchange ratio for evaluating benefits of purchases and sales, foreign trade, or international loans. The ratio may be used for comparing 1 and 2, 3 and 4, 2 and 3, or all exchanges.

Another way to achieve equity in trade is to adjust foreign purchases and trades so that there is EMERGY equity. If EMERGY trade balance is uneven, the difference can be made up in education, military, or technology transfers duly evaluated for their EMERGY contributions.

Allowing individual businesses to maximize their own profits in monetary terms often imbalances EMERGY trade equity. The dollar value of profits may be small compared to the bases for public gross economic product given away to other countries.

Evaluation of Foreign Loans

The EMERGY/$ ratio is larger for rural and undeveloped countries where people are supported from the environment directly. They are using money less than those in urban areas. If one borrows money from a country, the buying power of that loan is given by the EMERGY/$ ratio of that country. When the money is paid back, the buying power in the payback is that of the borrowing country.

If an undeveloped country with 5 times higher EMERGY/$ ratio borrows from a developed country, the undeveloped country ends up paying 5 times more back than was borrowed. Much of the economic plight of undeveloped countries is due to these overpayments that come from using money instead of EMERGY as a measure of public wealth.

Guidelines for Foreign Assistance Projects from EMERGY analysis.

EMERGY concepts provide guidelines for projects from developed countries within under-developed areas. Measures that maximize the EMERGY budget are believed to maximize economic wealth and vitality. However, there are questions of scale. Figure 9 suggests there are five levels of consideration, the economy of the development project and its people, local economy of the development project, the economy of the under-developed nation, the economy of the developed nation, and the world economy. The difficult question is which economies are having their EMERGY increased. Ideally, a project should increase EMERGY of all scales. Unfortunately, past decision-making processes have not considered all these. It is not even clear that foreign aid projects have been managed for the good of the underdeveloped nations. The following are some general guidelines with do's and don'ts:

1. On the scale of the economic activity, market values will tend to guide the business managers towards project profit, but if this is the only guideline involving an environmental resource, it soon pulls down the resource, is not sustainable, and reduces the EMERGY of the local economy and of the underdeveloped country. The damage to the local economy is even worse if international sales or loans are involved as discussed in item below.

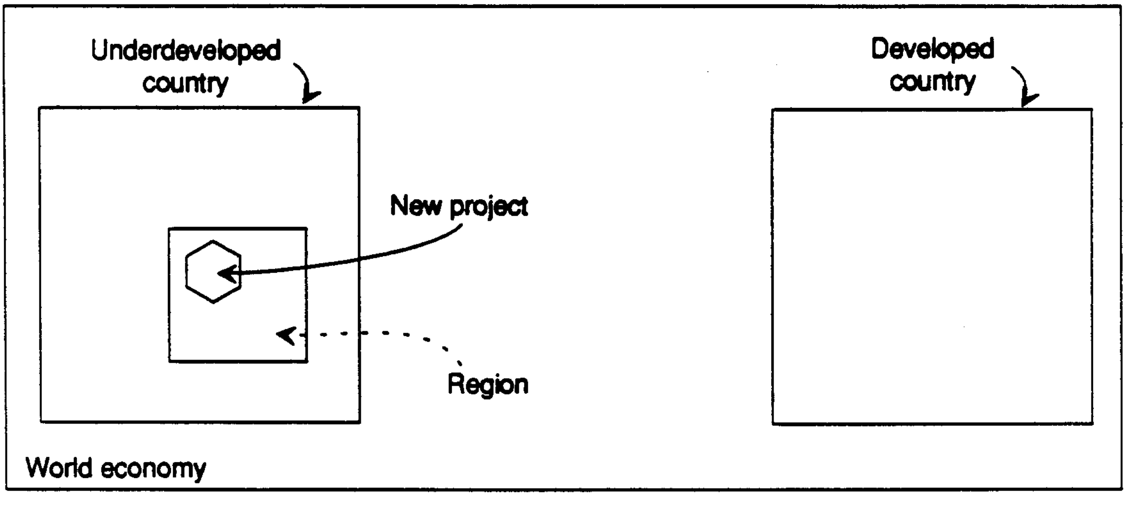


Figure 9. Scales for maximizing EMERGY.

2. On the regional scale, subsidized development of an intensive activity ahead of general development of the region is indicated by the EMERGY investment ratio being too high (higher than the regional value). As a result, the products cannot be used locally (are too expensive for the home people), and the EMERGY tends to be exported usually with less return. The situation is made worse if the profits are changed into foreign currencies because of the much higher EMERGY/$ ratios of underdeveloped currencies. Contrasts in wages disrupt other parts of the local economy, making sharper differences between rich

and poor. Pulling resources from one existing use, however indirect, to make monied income should not be done unless the total EMERGY is much increased (counting the areas disrupted).

3. On a national scale of the underdeveloped country, EMERGY benefit comes when the projects increase the total EMERGY, usually by increasing the use of purchased resources in appropriate match to the environmental resources in a sustainable way. The development must not divert resources from rural users of one region to another. Project developments should not undermine the occupations of part of the country to make profit for another area.

   On a national scale of the developed country supplying the initial funds, the project should not be a means to maintain inflated foreign interest rates. All repayments and interest rates should be adjusted for EMERGY equity, which means that repayments should remain in the currencies of the underdeveloped countries with reinvestment there. Thus, an international project to aid a country should no longer be a means for growth and profit in the developed country.
4. On the international scale, any loans or sales of products between countries should be arranged to maintain EMERGY equity so that both countries benefit mutually. Because of the different EMERGY/$ ratios, loans and sales may transfer many times more value to the developed country making the aid project an exploitation. Interest rates and repayments should be calculated in advance on an equal EMERGY basis.
5. On a world scale, projects that unbalance local economies increase EMERGY inequity between countries, do not maximize the world economy, because they leave major sectors of the world's population in poverty, essentially outside the world economy. This pattern wastes resources into luxury and excess of the developed countries, diverting the resources that used to go directly to population support (without payments). This pattern is not sustainable, does not maximize world wealth and EMERGY, does not reinforce world production, and will not last. These patterns will become discredited as world opinion changes, as revolutions occur, and worldwide resource depletion soon cuts off the largesse of the overdeveloped countries.

Controversy over Acceptance of EMERGY Wealth Concepts

General acceptance of the concepts given in this paper have been slow. Most people concerned with environment and policy have heard something about them, since there have been extensive published reports, papers, and books from time to time as the concepts have evolved.

Opposition has been severe, especially from economists. It's probably safe to say that this group with a handful of exceptions don't understand it. The concept of a donor value is so fundamentally opposite to the "human willingness to pay" concept of value, that those with that training read opposite meanings into words so that what they read seems like nonsense to them.

EMERGY value is a donor value based on invariant physical measures that accompany a product through transformation to its final use until it reinforces another production process. EMERGY only adds and subtracts when flows of products of the same kind are added or separated. When there are by-product flows, they carry the same EMERGY because that is what was required to make them. The by-product flows, while reinforcing other production processes, may come together again. In this case, the EMERGIES are not added, since they represent the same original input. Network diagrams of a larger system are required to avoid double counting the same original source.

Many economists were taught that early efforts to find an absolute basis for value failed, often citing Marx's labor theory. As several authors have pointed out, Marx's labor value concept was also a donor-value concept, using hours of labor as the measure of labor power. But what labor can accomplish depends on the EMERGY inputs of the education, the machinery used, and other aspects of labor. EMERGY measures put labor value on a more scientific basis.

Some confuse EMERGY concepts with the technocrat movement of the 1930's, which used energy as the basis of value and proposed to pay people with energy certificates in place of money. Of course this failed because energy of different types are not of equal wealth and have to be multiplied by their transformities. Technocrats wanted to substitute energy value for money, whereas EMERGY value is not meant to be used for market value, but for larger scale evaluation of the economy. Value to the person is market value. Value to the economy is EMERGY. A free functioning market economy helps to maximize EMERGY values by eliminating shortages. A dollar bill of currency represents about 2 E12 solar emjoules per 1989 U.S.$. It is already an EMERGY certificate for interhuman transactions. (An emjoule is the unit of EMERGY defined as the energy of one kind in Joules required to supply all the inputs necessary for a product or service.)

Input-output embodied energy analysts oppose the EMERGY methods because it does not fit their method which assigns the embodied energy of resource inputs to pathways with an arbitrary matrix inversion procedure according to some other variable, usually money. Assigning embodied energy according to money gives a measure that correlates with money, which is a useless tautology. The embodied energy assigned to commodities depends on the numbers of pathways used in aggregation, so that there is no one value for a commodity. Many who have criticized the input-output approach to embodied energy have assumed that EMERGY analysis was similar, which it is not.

Process analysts adding up energies that go into industrial processes have attacked EMERGY analysis because they do not want to give up the idea that energy (without using transformities) is a measure of work. Nearly all scientists and engineers were trained this way. They trick themselves into holding on to what they were taught in elementary classes by leaving out all items of large or small transformity, only adding items of similar transformity. Their methods are nearly worthless for evaluating contributions and drains to the economy. They omit the EMERGY of service, which is often the largest input.

Many oppose an energy-based theory of value because they think it refers only to medium and lower quality energy (sunlight, fuels, electricity), whereas they correctly recognize that humans, information, and scarce materials are more valuable. They don't wait to hear that transformity and EMERGY evaluation give highest values to these high quality items.

Many in government and industry who have declined to support research or use the concepts in their public policy decisions reject a method which requires that the problem under study be put into the context of the next larger system, which is required for EMERGY evaluation. Going larger puts people into conflict with decision makers on a larger scale and may bring in large scale politics to a smaller scale problem.

The whole education of intellectuals in this century is towards taking things apart, studying parts to find answers to problems. It has been left to experience, vague judgements, and adversary process to make larger scale decisions as if there were no right or wrong for that level of organization. People of wide experience and responsibility may feel threatened if scientific calculations can preempt their judgement. Since few public policy people believe there are any deterministic scientific principles at this level, any effort to provide policies through calculations is rejected as nonsense without any effort to understand it.

Thus, there are many reasons why each kind of background rejects the EMERGY approach, usually before they have heard anything but fragments of it. On any general committee there are usually a mix of backgrounds from different fields, each of which has a different objection. Thus, it is not hard to get a negative concensus. How can someone take an action when his advisory committee doesn't understand it and has members violently against it? People whose security depends on the majority have to avoid being associated with something controversial that is excluded lest he be excluded.

The general accounting office reviewing energy analysis methods said the method was interesting and declined to consider it. A recent author of a book on net energy (Spreng, 1989) referred to the methods as a valiant failed effort even though the last reference he referred to was 1976. Because transformities were not used, many inferences in that book are in error.

Many have said, let's wait and see, because the methods have been evolving, the transformities revised with new data, and new indices offered. We renamed the two main rigorous measures (EMERGY and TRANSFORMITY) in 1982 because the older names (embodied energy and transformation ratio) were being confused with other concepts.

Sometimes there are products for which we do not have a trustworthy value for transformity and must make subsystem evaluations to obtain them. Confidence in transformities comes with many determinations so that we can average values, using some to check others. Training people takes time. A new student who makes an analysis after a few months may have incorrect results because he may not know enough yet about the larger system so that important features are diagrammed incorrectly or omitted. Some have described the system as complex, but that is because the real world being evaluated is complex.

In the meantime, the method is chalking up some successes in predicting what is good public policy in energy polices and environmental development, proven after the fact, when the right answer is agreed upon following years of disastrous trial and error. Probably there will be further progress, but the EMERGY method for arriving at policies may already be the best way to develop a vital economy. It is especially useful to show what's wrong with many economic dogmas now undermining public welfare on the planet.

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An EMERGY Glossary

Dan Campbell

Available energy

Energy with the potential to do work.

Donor value

A value of a product determined by the production process and not by what a person is willing to pay (examples, mass & energy of wood).

EMERGY (spelled with an "M")

All the available energy that was used in the work of making a product expessed in units of one type of energy.

Emjoule

The unit of EMERGY which has the dimensions of the energy previously used (grams-centimeter squared per second squared).

Energy

A property of all systems which can be turned into heat and measured in heat units (Calories, Btus or joules).

Energy hierarchy

The convergence and transformation of energy from many small units into smaller amounts of higher-level types of energy (often in units of larger size) with greater ability to interact with and control smaller units.

Energy systems language or energy circuit language

A general systems language for representing units and connections for processing materials, energy, and information of any system; diagrammatic representation of systems with a set of symbols (Figure 4) that have precise mathematical and energetic meanings.

Gross national product (GNP)

The total market value of all final goods and services produced in an economy in one year.

Investment ratio (EMERGY investment ratio)

The ratio of EMERGY brought into an area from outside an economy to the local, free environmental EMERGY used in the interaction.

Macroeconomic dollar value

Dollars of gross economic product obtained by dividing the EMERGY of a product by the appropriate EMERGY/$ ratio. The dollars of gross economic product equivalent to the wealth measured in EMERGY.

Maximum power principle

An explanation for the designs observed in self organizing systems (energy transformations, hierarchical patterns, feedback controls, amplifier actions, etc). Designs prevail because they draw in more available energy and use it with more efficiency than alternatives.

Net EMERGY

The EMERGY yield from a resource after all the EMERGY used to process it has been subtracted.

Net EMERGY yield ratio

The ratio of the EMERGY yield to that required for processing.

Next larger scale

Larger territorial areas occupied by units with longer replacement times which must be considered in determining system behavior because of the controls larger units exert on smaller scale units and processes. (See Energy Hierarchy)

Reinforce

The action of a unit or process to enhance production and survival of a contributing unit or process, thereby enhancing itself; a loop of mutually enhancing interactions.

Self organization

The process by which systems use energy to develop strucure and organization.

Maximizing EMERGY

The process by which the maximum power principle operates within a system to select from among the available components and interactions the combination that results in production of the most EMERGY.

Second law of thermodynamics

Principle that energy concentrations disperse spontaneously and in all energy transfomations some of the available energy is dispersed in the process.

Solar transformity

Solar EMERGY per unit energy, expressed in solar emjoules per joule (sej/J).

Sustainable use

Resource use that can be continued by society in the long run because the use level and system design allow resources to be renewed by natural or man-aided processes.

Systems ecology

The field which came from the union of systems theory and ecology and provides a world view for energy analysis.

Transformity

The EMERGY of one type required to make a unit of energy of another type. e.g. Since three coal joules and one coal emjoule of services are required to generate one joule of electricity, the coal transformity of electricity is four coal emjoules per joule.

Turnover time or replacement time

The time for a flow to replace a stored quantity. For example, a flow of 10 gallons of water per day will replace a 1000 gallon tank of water in 100 days.

Wealth

Usable products and services however produced.