G. Pillet and T. Murota (eds)
ENVIRONMENTAL ECONOMICS – The Analysis of a Major Interface

ENERGY AND EMERGY

by

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ABSTRACT. This paper is an accidental byproduct in the search for a comprehensive policy for a Scientific Party, which will require a major input from environmental economics. Owing to great confusion in the scientific literature, and in order to clearly distinguish the theories of H. T. Odum, new concepts – energy memory, emergy, transformity, informity, empower, emtropy, emformation, emtelligence, emprice, emdollars, emtrons and soals – are introduced, plus their appropriate units. Because economics (monomics), political science and the humanities are very liberal-arts oriented, new scientific disciplines of emonomics, politology and humology are proposed, to include energy analysis and emergy synthesis.

I. *INTRODUCTION*

A Policy For A Scientific Party. In a world already dominated by scientific achievements and problems, but containing vast numbers of people with a scrap or more of scientific training or knowledge, nowhere is there a political party called a Scientific Party, although at various times most political parties have claimed to be scientific. However, the principal political parties of the contemporary world were basically conceived or launched, on average, well over 100 years ago, long before most modern scientific knowledge or methods even existed. For example, the USA Republicans and Democrats were launched about 1820, and the Communist parties of the world (frequently claiming to be scientific socialism), owe their basic ideology to the work of Karl Marx of around 1840. Furthermore, there does not seem even mention of the subject "Scientific Party" anywhere in the literature, except now

for the preliminary basic themes of Scienceman and Caldwell [1].

Environment, Power and Society. Central to our theme of a Scientific Party, was the opinion that the members and leaders should all be required to possess a certain specified minimal modern general scientific education, sufficient at least to understand the big public issues and problems of the day, and to permit better communication between scientific researchers and the legislature. Such people could all be described as sciencemates, a non-sexist word meaning a scientifically oriented person of public affairs, possibly a member of a Scientific Party, to contrast with the more scholarly or laboratory practitioner of science, the scientist, and with the public generally. Many science textbooks were examined, but all found far too narrow or specialised, until "Environment, Power and Society" by H. T. Odum [2] was accidently but fortuitously discovered in Honolulu. It contains a most appropriate scientific overview in a very modern manner, a little bit about many important sciences. A new edition is now required.

Energy Systems Diagrams. Subsequently, Odum has published a more elementary version [3], and a much larger, specialized edition for scientists [4], all based however around the original theme that when researching or discussing the affairs of people, nature or the universe, it is essential to incorporate an understanding of all available, relevant energy sources, flows and storages, and to draw an energy diagram or model tracing their entrance into and emergence from the system under review, including contributions from the environment. These energy considerations are usually ignored by most physical, biological and social scientists, as well as technologists, but probably only because of over-specialised, narrow education. Incorporated in Odum's approach is acceptance of the maximum power principle as described by Lotka [5] as a fundamental law of physics, which he indicates is basically coupled with the second law of thermodynamics [4, p.573]. These diagrams should be united with the quantum physics particle diagrams of Feynman [6].

Energy Analysis Confusion. Contrasting with this approach of Odum, is that of the conventions adopted by the workshop on energy analysis methodology convened by the International Federation of Institutes of Advanced Study [7]. The result has been very substantial confusion in the literature even among energy practitioners themselves, quite apart from the confusion which results when others, such as economists or psychologists attempt to enter the subject [8, 9, 10, 11, 12]. But nowhere is this confusion more apparent however than in the attempts by assorted authors to use the entity known as "embodied energy", it being the point and the burden of this particular article

to attempt to introduce new concepts, words and units in order to clearly distinguish the Odum variety of embodied energy from the variety used by other practitioners, and to suggest previously unknown or inaccessible implications in other sciences which have been using similar confusing concepts.

II. *ENERGY*

Energy and Work. We start with quotations containing the principal concepts of Odum [4, p.5]: "The energy language is a way of representing systems generally because all phenomena are accompanied by energy transformations. Potential energy is that capable of driving a process with energy transformation from one form to another. An energy transformation driven by potential energy is work. In most kinds of work, one type of energy is transformed into another, with some going into a used form that no longer has potential for further work. Potential energy from outside energy sources provides the means for keeping systems generating work. Storages within the system have potential energy that can drive work processes. Many forms of energy are involved in different processes. There are energies in photons of sunlight, in sound waves, in water waves, in water of rivers, in chemicals which react, in magnetic fields, and in concentrations of matter. Kinetic energy is the energy of movement, as in a spinning top or travelling car".

Heat and Power. Odum continued: "In practice, energy is defined and measured by the heat that is formed when energy in other forms is transformed into heat. All kinds of energy can be converted into heat. Heat is the energy of molecular motion. The generation of heat raises the temperature. A small calorie is the heat that raises one cubic centimeter of water one degree. A kilocalorie is 1000 small calories. The energy language keeps track of flows of potential energy from sources going into storages or into work transformations and finally into degraded form as used energy leaving the system. Pathways of the energy language are pathways of energy flow. The rate of flow of energy may be expressed in such units as calories per unit time... The rate of flow of energy into useful work is defined as power". Elsewhere, Odum [2, p.26] wrote: "In the world of science and engineering, power is defined precisely in terms of measurable units as the rate of flow of useful energy". We note the calorie is a heat unit, whereas the joule is the energy unit.

Useful Work. Or critical importance in these quotations is Odum's

concept of useful work. First, Odum [4, p.100] wrote: "In some sciences work is defined as mechanical work, but a more general definition is: Work is a useful energy transformation. Systems and transformations that do not contribute to maximum power tend to be eliminated in competition for energy. Useful works are transformations that feed back materials and services". Elsewhere, Odum [11, p.33] wrote, "Useful power is power that feeds back to amplify. It implies autocatalytic organisation in which energy transformations associated with gaining power feed back amplifier actions to further accelerate flow of energy of the same or different source. Or, where further acquisition of energy is not possible, existing budgets of energy feed back to maximise efficiencies through diversity, division of labor, prevention of losses, improvement of recycling, etcetera". *Useful work* can therefore include mechanical work, which is often just called *work* , and contrasts with useless work or dissipation.

Energy Quality. According to Odum [4, p.15], "The ratio of energy of one type required to develop another type of energy in a transformation is one of the useful efficiencies often calculated to describe energy patterns. It is a measure of energy since the new form of energy has abilities to amplify or control if it is fed back to interact with low-quality energies. Energy transformation ratios are derived from energy chains... If energies of different types are to be compared in regard to energies required in their formation or their effect, they may be converted into equivalents of the same type by multiplying by the energy transformation ratio which measures energy quality. For example, fish, zooplankton, and phytoplankton can be compared by multiplying their actual energy content by their solar energy transformation ratios... When one calculates the energy of one type that generates a flow of another, it is sometimes referred to as the embodied energy of that type".

Embodied Energy. Odum however, introduces the maximum power principle into his definition: "The concept here retains the meaning that the embodied energy is what is required to do the work (at maximum power). Byproducts of a work transformation have the same embodied energy because they couldn't be generated with less" [10, p.189]. Odum [4, p.266] again clarified his theory of value: "Embodied energy was defined as a way to measure cumulative action of energies in chains and webs. Embodied energy provides an alternative theory of value, is useful for tracing sources, especially net energy, determining relative importance of components, and covering free items that are not covered by money". Of critical importance, Odum [4, p.252] wrote: "An energy theory of value is based on embodied energy... The energy transfor-

mation ratio, by giving the embodied energy per unit of actual energy, provides an intensive factor for value in the way that temperature is an intensive factor for heat".

III. *EMERGY*

Energy Quality. Anyone entering this subject, however, soon finds great confusion in the literature, particularly concerning use of the phrases *useful work, energy quality* and *embodied energy*. For example, a revival of interest in old energy quality concepts owing to the "energy crisis", has resulted in development of concepts of availability, essergy and exergy, which refer however to an industrial engineering concept of energy quality, measured in mechanical quality energy equivalents, not including any maximum power considerations or environmental inputs [13, p.64]. But one of the most basic issues in physics is that "Variables may be either quantitative or qualitative... A quantitative variable is one for which teh resulting observations can be measured because they possess a natural order or ranking... Observations on quantitative variables may be further classified as continuous or discrete (discontinuous)... A qualitative variable is one for which numerical measurement is not possible... Observations can be neither meaningfully ordered nor measured, only classified and then enumerated" [14, p.9].

Transformity. It is therefore proposed that the phrases energy quality, energy quality factor, and energy transformation ratio, all used by Odum, be replaced by the word transformity, a quantitative variable describing the measurable property of a form of energy, its ability to amplify as feedback, relative to the source energy consumed in its formation, under maximum power conditions. As a quantitative variable analogous to thermodynamic temperature, transformity requires specification of units. In a comparable manner, Soma [15, p.19], has introduced an entire range of names for units of exergy, such as the Geu (after Gibbs) analogous to the energy unit, the joule. Soma describes exergy as generalized free energy, or perishable energy. His Soma number, exergy over enthalpy, suggests entities extensity or entensity of energy. The word *transformity* is due to H. T. Odum, amending our word "transformations". Transformity therefore introduces a new basic dimension into physics.

Form Energy. But the entire issue under review now, the implications of transformity, refer to the measurements of the transformation of energy from one type, kind, or form to another type, kind or form.

Odum uses these three words quite interchangeably [4, p.5-6], but since we must now introduce rigorously defined concepts, we select the word "form" as being most appropriate for a transformation of energy. We must therefore in future always clearly specify the form of energy, as well as its quantity, so the phrase "form energy" must be used in general, with special cases such as coal energy or heat energy, with an International System of Units [16, p.7] nomenclature (f)J. This eliminates confusion surrounding such pharses as "calorie per calorie" as used by Odum [4, p.252], which should now be written consistently as "form A calorie per form B calorie". Note that Odum [4, p.102] considers that using mechanical energy units instead of heat energy units to measure forms of energy may prove unfortunate.

Emergy. We now come to the relatively new concept, "embodied energy", which has been defined differently by different authors – as summarised by Odum [4, p.264; and 10, p.189]: "Much of the confusion in the energy analysis field is because of the different concepts of embodied energy". The principal point of difference is that with one concept of embodied energy, such as that used by Costanza [17], the entity is partitioned at work intersections, and is additive just like first law heat energy. But the Odum concept is "not apportioned among pathways, and feedbacks are not additive at their amplifier intersections. This procedure partitions energy only on diverging, flexible, high-qualitiy energies that feed back" [1, p.264]. Accordingly it is proposed that the Odum variety of embodied energy be known as emergy, or source emergy when referring to any specific source. The prefix em- can, fortuitously, even be taken to indicate an energy memory property, a record of source energy transformed. The time rate of change of emergy is empower, analogous to the time rate of change of energy, power.

The Emjoule. We can now introduce a new unit in order to clearly distinguish units of emergy from other units of embodied energy concepts. The unit the solar equivalent joule used previously by Odum can now be known as a solar emjoule, the unit of solar emergy, chosen as such to always remind us that the solar emergy, say of a structure, which is a displacement from equilibrium [4, p.313], is proportional to the number of source joules required to create it. The symbol for form emergy is (f)ej; sej for solar emjoule for example, using SI nomenclature again. We can now use this new language to write Odum's equation for energy transformation as "form energy times solar transformity equals solar emergy". In symbols therefore, transformity equals the number of sej per (f)J, and can be given the symbol *tr*, or maybe even L for lotkas, after Lotka. The logarithm of transformity can be called

"informity", a continuous measure of change of form, with a unit, the soal, pronounced so/al, equal to a solar to coal energy transformation step [10, p.188].

IV. *EMTROPY*

Entropy. We turn attention to the concept of entropy, used often by Odum, but in a manner with significant additions to classical usage. The word entropy itself was apparently coined by Clausius [18, p.36], "who brought the whole science of thermodynamics – literally "the movement of heat" – to a new level of sophistication by expressing the behavior of energy in two laws. The first law of thermodynamics states that energy is conserved. It is not created or destroyed. The second law of thermodynamics says that while energy does not alter its total quantity, it may lose quality. The name Clausius gave to the measure of this loss of quality was entropy, from a Greek root meaning "transformation". Soma [15, p.18] in turn introduces another word "entrogy", "the energy associated with the entropy. To gauge the exergy change, the enthalpy change must be derated by the entrogy change, the energy unavailable to perform work".

Entropy Definition. Odum [4, p.103] wrote: "Much used in energetics is a quantity S called entropy. In an energy transformation, the change in heat divided by the absolute temperature at which the heat change occurs is defined as the entropy change. Flows of heat can be divided by their temperatures (absolute scale) to obtain flows of entropy. When heat is added to a storage, entropy increases, and when heat is subtracted, entropy decreases. The entropy content of a storage is the accumulated heat divided by the temperature at which the heat was added. It is the stepwise integral of the reversible heat changes divided by the temperatures. The integration starts at absolute zero. The heat is visualized as being added infinitesimally slowly so that there is no heat processed that does not go into the storage. State changes made in this way are said to be reversible". This is the standard classical definition of entropy.

Microscopic and Macroscopic Entropy. Later, Odum [4, p.312] wrote: "The entropy of microscopic states is many orders of magnitude larger than that entropy calculated similarly for the much fewer macroscopic states of items in the biosphere of size range of ecological and anthropological entities. For instance, 6.02 times 1E23 items of microscopic complexity are contained in one item of macroscopic realm, which is composed of one mole of matter (6.02E23 molecules). The calculated

entropy for the mole of components is 1.377 cal per degree (6.02E23 bits), whereas one item of macroscopic realm is one bit... The relationship of microscopic to macroscopic may be related as are the energy quality ratios. Consequently, there is high- and low- quality entropy that, like their energies, are related as the ratio of one inherent in the existence of the other". The implication is that entropies can only be compared if they are first multiplied by the transformity of their supporting energy flows.

Entropy and Order. Odum departs further from classical entropy thinking [4, pp.314-16]: "A general model of order and disorder is diagrammed. A source of potential energy interacts with disordered materials to generate structure. This structure is regarded as order because it was transformed by an energy flow and is a storage capable of depreciation. The storage may be low entropy or high entropy, but its state will generate an increase in entropy when it is degraded... Sometimes the word "entropy" is used to mean disorder in a vague collective sense disregarding definitions (Rifkin). The possibility that the molecular states gain functional structure as their entropy is increased (opposite from classical views) is considered... When entropy is increased, molecular complexity increases, which may be adaptive whether or not at equilibrium". The implication is that we should consider a hierarchy of entropic levels, just as we are familiar with for energy spectra.

Emtropy. We can conclude therefore that Odum is referring to some new entity, embodied entropy, which like its counterpart, embodied energy, is transformed under maximum power principles. We can call this entity *emtropy* by direct analogy with emergy; its units would therefore be source emjoules per kelvin; its symbol would be sej/K. We can also see emtropy as a method of adding together entropies of different transformity, just as emergy was used to add together the amplifier effects of different forms of energy. Emtropy becomes the cumulative effect of different forms of entropy. Maybe the best available example is to refer to the energy systems model of the universe proposed by Odum [4, p.576] in which he suggests that we may regard the second law of thermodynamics as an incomplete component pathway of the larger universal system, where the heat sinks, which are the entropy flows from different sources of different qualities of entropy, are combined into a single pathway of low energy radiation.

V. *EMFORMATION*

Information. Closely related to entropy is the entity known as "information". According to Odum [4, p.303]: "Whereas the word "information" refers to many related quantities and ideas, one specialised use of the word can be defined according to information theory. Here information is defined as the logarithm of possibilities. It is the logarithm of complexity... The logarithm of this number is the information content. Thus information is an added function of complexity... Several kinds of information are used, depending on the base number. Where the logarithm is to the base 2, the unit is called a bit. One bit represents the information in a decision between two choices as in the flipping of a coin. There are two possibilities and one choice. Log of 2 to the base 2 is 1... Information measures the complexity of the situation without indicating whether there is realisation of combinations, connections, or knowledge of them".

The Connection. The relation between entropy and information was also summarised by Odum [4, p.311]: "The information content of molecular states is entropy S. It is proportional to the log of molecular possibilities and it can be expressed as bits by using log to the base 2. The Boltzmann equation is S = K log N. However, where the log is to the base e and the constant K is the Boltzmann constant (3.35E-27 kcal per mol. deg), the entropy is in calories per degree kelvin per mole... Although some people use the word "information" for macroscopic items and the word "entropy" for molecular ones, others use the terms interchangeably, since both have the same formula (the logarithm of the possibilities). What is different is an enormous difference in scale". By analogy with entropy therefore, we immediately suspect the existence of the concept "quality of information", analogous to both emergy and emtropy, with a unit the *embit*, and symbol "eb" or "eI".

Information Quality. Supporting quotations were gradually located. Odum [4, p.314] wrote: "Because of the high quality and embodied (accumulated) energy of the high-quality complexity, depreciation there represents more calories of replacement value per bit than does depreciation of the lower-quality materials. Bits alone are not a measure of energy flow or energy quality. The comparison of bits may require multiplication by their energy transformation ratios". He also wrote [4, p.331]: "Providing energy quality factors can be developed for various kinds of information, the embodied energy in information can be handled as with lower-quality flows in estimating potential production, limiting factors, growth trends, and spatial patterns". Empirical

support is quoted by Odum [4, p.320]: "Tribus and Mc.Irvine [19] found that higher-quality communication equipment transmitted more bits of information per calorie of heat... The higher quality flows have less actual energy, but more control actions of an informational nature".

Energy and Information. One must however take great care here. Odum [4, p.310] wrote: "As illustrated, energy needed for organisation may be postulated as proportional to the possible connections. Information content of the possible connections is the logarithm of the possible connections, which is proportional to N^2. Therefore, information is proportional to the log of the energy going into organisation, and energy is an exponential function of the information content in the organisation or potential organisation". Information may therefore be transformed proportional to the logarithm of the transformity, defined earlier as informity. Information and entropy are not forms of energy, and are not measured in form joules. Similarly, Dillon and Ragadé [20, p.103], raise the issue of quality of information, and challenge the Shannon equation relating entropy and information as only specifying information quantity, whereas "argument must be focussed on the quality and meaning of the information if it is to have any validity at all".

Meaning. We therefore confirm the opinion of Bar-Hillel [21, p.284] that the word "information" has been the source of great confusion, in that it only measures quantity of message, not quantity of meaning. Bar-Hillel and Carnap therefore introduced a theory of semantic information, based on a logical, as opposed to statistical notion of probability, both being theories of selection, according to Zwick [22, p.93]. The items in a hierarchy of messages – data, information, knowledge and wisdom of Dillon and Ragade [20, p.104], and molecular messages, stimuli, signal, sign, symbol and sentence of Brent [12, p.107] – can therefore be multiplied by individual informities to produce emformation as a cumulative measure of meaning. For if human bodies have evolved, then presumably so also have their languages and words, the 50% redundancy of the English language mentioned by Zwick suggesting the maximum power principle may also be applied to the evolution of language. Zwick's word "constraint" implies energy hierarchy applies.

VI. *EMPRICE*

Odum Economics. Odum has introduced economics with differing perspectives. Odum [4, p.476] wrote: "Where humans are part of systems, there are economic transactions and flows of money. Economic behavior

of human beings causes money, a symbolic form of information, to flow in countercurrents to the flow of commodities bearing energy. Because of commonalities among systems, there are many similarities between systems of economics and those of ecology". But Odum [4, p.12] also wrote: "Money is an exchange medium that flows as a countercurrent to energy... and can be symbolized separately in the energy circuit language. Thus money flows as a countercurrent to materials, information and all other quantities used. Money is given out for goods purchased according to a ratio called price... Money is really a type of energy flow since it is a quantity that controls or releases other energy flows and thus has high energy value in its interactions".

Energy to Money Ratio. Central to this thinking therefore is the energy to money relationship. According to Odum [4, p.480]: "The flow of money is an indication of the evaluation of the effect of the energy flow by the unit receiving the energy. Whereas embodied energy measures energy required, money spent tends to measure energy effect to the extent that the money flows are free to adjust as in the free market... The dollar/embodied energy ratio is useful in practice to calculate embodied energy in feedbacks... The ratio of actual energy to dollar flow decreases as one passes from source to consumer services along the pathways of the energy web. There is little wonder that the public has trouble understanding the energy basis for economics when the actual energy decreases as the accompanying dollar value increases". We have however already eliminated the phrase "actual energy", which was not intended to be a technical phrase, and "embodied energy" is now "source emergy".

Emprice. Once again we must note the confusion when, for example, the ratio of money to embodied energy is described as a ratio of dollars to embodied energy. The new phrase should be either money to solar emergy ratio, or dollars to solar emjoules ratio. This emergy phraseology then avoids confusion with the inverse ratio, energy intensity used by economists [23, p.148] to describe the quantity of energy contained in a unit of currency of goods and services, either in terms of primary or useful energy. However, the word price, used in economics and generally to mean money per unit purchase, or dollars per unit quantity, has also been used by Odum [4, p.477] meaning the dollars to solar emjoules ratio for the entire economy. To avoid confusion, this entity is better known as *emprice*, with a unit called an *emdollar*, (3.8E12 solar emjoules in 1980 for example), a world currency unit which can be quoted on stock exchanges around the world, and used as a means of equilibrating balance of payments in emergy terms [24]. An International Emergy Investment Company would be an appropriate practical beginning.

Sun Symbol. The entity an "emdollar" has however a wider significance as a scientific substitute for the gold standard, formerly the world attempt at providing a stable inflation free world currency. For Brown [25, p.209], when reviewing the psychoanalytic theory of money, wrote: "It has long been known that the first markets were sacred markets, the first banks were temples, the first to issue money were priest kings... As far as gold and silver are concerned it is obvious to the eye of common sense that their salient characteristic is their absolute worthlessness for all practical purposes... Keynes also recognises that the special attraction of gold and silver is due not to any of the rationalistic considerations generally offered in explanation, but to their symbolic identification with Sun and Moon, and to the sacred significance of Sun and Moon in the new astrological theology invented by the earliest civilizations". The solar emdollar thus becomes a deeply significant monetary unit for environmental economists to develop.

Technocracy. Before proceeding further, however, it is important to mention that our policy for a Scientific Party, which forecast two main international political parties, an International Scientific Party and an International Peoples' Party, must not be confused, as is sometimes asked, with that of the Technocrats [4, p.265]. According to Gunderson [26, p.356], "Technocracy was a radical social movement and philosophy that exploded into prominence in the United States in the early 1930's. It was an indictment of both capitalism and the money system of exchange. It emphasized and even glorified the machine process and technical skills and knowledge. A new unit - productive energy - was to replace monetary standards... It faded rapidly because of its extremism and disdain for political action and because of the rapid reforms made by the New Deal". By contrast, an International Scientific Party, would aim to be a leader of the world in political matters, but possibly only within the framework of a World Parliament, and would see no point in eliminating the valuable social functions of money.

VII. *EMONOMICS*

Economic Value. As briefly mentioned earlier, Odum [4, p.252] has proposed a solar emergy theory of value, but in his chapter *Economic Systems and the Nation* only briefly mentions value explicitly. We therefore note the opinions on economic value of economist Heilbronner [27]: "The problem of value is not held in much esteem in contemporary

economic thought... Indeed, I would venture that most economists today do not even see the need for a "theory of value", as distinct from a theory of price, and would in fact be hard pressed to explain the difference between the two"[p.1]. But Heilbronner has become convinced of the importance of economic value, which he sees as "the effort to tie the surface phenomena of economic life to some inner structure or order[p.2]... What is surprising is that after so many decades of discussion and debate, the nature of that order-bestowing substance or process remains unresolved"[p.4].

Labor Power. Heilbronner then reviewed the five distinct approaches to the value problem: the normative (morality), the human labor theory of classical economics, the Marxist distinction between concrete labor (labor-in-general) and abstract labor (labor power), and the post classical utility theory. He concluded with great hesitation: "Here I believe that only one candidate for such a definitive principle has not been ruled out, namely the quanta of abstract labor, suitably weighted by some as yet inadequately explained calculus which would serve as a starting point from which the real world configuration of prices could be explained"[p.24]. Immediately we are alerted to the possibility that the unknown calculus to which Heilbronner refers is energy analysis and emergy synthesis, and that concrete and abstract labor refer merely to the difference between human power and embodied human power, measured in power (watts) and empower (emwatts) respectively. Maybe we can speak of emvalue in a value added hierarchy diagram, as in Odum [4, p.495]. Quanta of energy are photons however; quanta of emergy suggest emtrons, the equivalent of one transformation step in quantum particle hierarchy.

Unscientific Economics. As the significance of the emergy and economics relation emerges, we note there is a very formidable case for rejecting economics as a science. For economist Eichner *et al.* [28, p.427] wrote: "An examination of economics as a discipline reveals that it is based upon an epistemology, or method of establishing the validity of knowledge claims, that runs counter to the norms of science. The prevalent view among economists is that formal (mathematical) proofs are not just helpful or indeed even necessary but also sufficient - and thus that empirical proofs can be dispensed with altogether". In particular it is claimed that neither of the two cornerstones of economics, the utility function and the production function are satisfactory empirical concepts; the first because it cannot be given explicitly, and the second because one of its variables, quantity of capital, has been shown "impossible to define consistently": neither are functions in the mathematical meaning of the word.

Sanctions Against Economics. Eichner *et al.* argue that an empirical economics is, however, quite feasible, "a complete and comprehensive alternative based on industrial input-output statistics and the observed behaviour of firms and households"... Nevertheless, most economists continue to use models of market behaviour "which differ in their fundamental characteristics from any market economy known to have ever existed". He concluded that "sanctions will be needed from outside the discipline, because "the same mechanisms which, in other fields, lead to the reinforcement of scientific norms – the system of graduate training, the appointment and tenure of faculty, the refereeing of journal articles and the peer review of research proposals – instead act to preserve the core body of non-scientific theory in economics". Eichner suggests "that what is needed is a protest by the scientific community, such as would undoubtedly occur if creationists and such others were given grants by the National Science Foundation or Nobel prizes.

Emonomics. Such a protest would not be easy to organise. What is quite possible however is for science faculties in the universities of the world to lauch their own courses in money matters, which is now taught in liberal-arts oriented faculties by staff to students who do not have the basic education in physics and chemistry even to attempt energy and emergy calculations. It is therefore suggested that the money science, now known as economics, be renamed monomics; and that, in those science faculties where energy and money matters can be studied and researched together, should be taught emonomics, a subscience of the sciences of energetics and emergetics (or emology). The word economics (derived from the Greek oikos = a house and nomos = a law), can then be abandonned, but the environmental word ecology (derived from the Greek oikos = house and logos = a discourse), which now has such a confusing and meaningless relation to the word economics, can be retained because it is an undisputed empirical science.

VIII. *EMTELLIGENCE*

Energy in Psychology. Although this article has been written for a book on environmental economics, it is instructive, bearing in mind the common concept-fields of modern science, to indicate how the concepts of emergy, empower and emformation also apply to other sciences, in particular to psychology and political science, which might better be called politology. In psychology, for example, there has been mention for many years of the concept of mental energy, even implying

an embodied energy concept, as mentioned briefly by Odum [4, p.265], which has otherwise been known as will-power, psychic energy or psychological energy, a very questionable collection. For example, Cattell [29, p.55] wrote: "Dynamic models of learning psychology inevitably involve one in using the concept of energy - which countless psychologists like Freud and McDougall hve found necessary, but which personality psychometrists and classical learning theorists have avoided like the plague because they can see no scientifically defensible, operational way of handling it".

Power. Brent [12, p.91] has however recently summarised the literature concerning the use of the concept of energy in psychological and social theory, the "two types" of energy - physical and psychical, and the physical environment and psychical field: "The prepsychological levels are then seen as "providing" the energy for the psychological levels to function; the psychological levels, as constituting the form of that function". He also summarises how general systems theorists such as von Bertalanffy and von Neuman "believe that once matter is organised at or beyond the biological level there is in fact no practical use for so microscopic a concept as energy. They argue that from this point in evolution onward information rather than energy is the primary determinant of phenomena". Brent concluded therefore that "most important in psychological and social systems was the relation among information, organisation, and physical power - power being the rate at which energy is expended".

Different Transformities. The point of view which emerges from the work of Odum however is very different. First, Odum [4, p.310] made explicit the energy basis of information, which is proportional to the logarithm of the energy flow supporting it, and so the two concepts are not independent. Second, Odum [4, p.265] quoted Boltzmann as implying a psychological embodied energy concept when he wrote, "Only if it had been proved that when mental energy is developed an equivalent amount of physical energy always actually disappears, that is if mental energy can be measured in such units that the amount developed was always exactly equal to the physical energy lost, should we be entitled to speak of mental energetics". The conclusion is that physical energy and psychical energy are basically the same entity, but that psychical energy is very highly transformed physical source energy capable of producing great mental complexity in humans.

Emtelligence. One is therefore tempted to suggest that psychological concepts and understanding would be dramatically improved if the entire vocabulary of critical concepts and theories were reviewed and translated into Odum energy language and diagrams. The personality

theory and VIDAS model of Cattell [29, p.55], for example, is distinguished by "incorporating empirically derived structural concepts, reservoirs related in the energy field to actual human ergs factors of innate, constitutional origin, and response plan storage reservoirs of sems of environmentally learned origin". It awaits energy systems modelling, in which the relative effects of genetics and environment on personality can be displayed. One wonders at the underlying energy basis also of the words emotion and empathy. Similarly, in the field of intelligence testing, the very conflicting interpretations of genetic and environmental effects may disappear if intelligence quotients are simply adjusted for the emergy signature of the socioeconomic system of the person being measured, producing the entity emtelligence instead.

Human Memory. Specifically, one can ask the relation between the concepts of energy memory and human memory. Humans have evolved, so one must expect to find evidence of memory evolution also, not likely however in prehistoric human fossil remains. However, very recent human memory research summarised by Alper [30, pp.44-51] mentions that "one of the biggest theoretical breakthroughs was the demonstration that there are at least two types of memory, perhaps stored by distinct biochemical mechanisms in different parts of the brain". One type is called declarative memory, associated with facts, the hippocampus and the amygdala, calpain-fodrin reaction and fast time; the other is called procedural memory, associated with skills, the cerebellum, new protein synthesis and slow time. One is immediately tempted, from this description, to see a hierarchy of memory functions and storages, associated with increasing complexity of the message, or emformation, the human memory of its energy sources.

IX. *EMPOWER*

Political Power. Closely related to the question of psychological energy is the entity known as "political power". According to Riker [31, p.341]: "The notion of power is often said to be central to politics. But while that analysis is a very ancient activity, the conceptual clarification of the nature of power has been undertaken only in the past generation. The reason for this discrepancy I leave to the historian of political ideas. In this introduction I merely observe that the clarification has not proceeded as far as is needed, so that we are still not sure of what we are talking about when we use the term". Riker then described and analysed five formal definitions of

political power, which concluded there were at least four distinct meanings, each of which appears quite reasonable by itself". The unit, the joule of energy, was not mentioned. Dahl [32, p.407] wrote: "How to compare and measure different magnitudes of power poses a major unsolved problem... given the absence of any standard unit of measurement".

Odum on Political Power. By contrast, Odum [2, p.206] wrote: "The true power of individuals, groups, and political bodies lie in the useful potential energies that flow under their control. Power does work, gains and manipulates storages of energy, and directs forces... The energetic laws are as much first principles of political science as they are first principles of any other process on earth. Many of the political, military, and international problems of our times as well as the role of democracies can be clarified by phrasing them in power units. Energy diagrams for political institutions show energy controls and the constraints energetic principles place on their design. Some of these diagrams bear a close resemblance to networks of ecological systems". A footnote mentioned "usual means for representing social and political power may not show clearly the connection of true energetic energy flow (power) and the manifestations of this at the level of human interactions".

Empower. The footnote concludes, "The essence of these theories do, however, seem measured by physical power. For example, deference value and influence are proportional to physical power gained". Someone must therefore reinterpret all five concepts of political power just mentioned in energy systems diagrams just as Odum has started already [2, pp.210-11]. But as we have seen already, form energy must be multiplied by transformity to provide a measure of capacity to control through feedback operations, which is solar emergy, the rate of change of which is solar empower. Careful study of the aggregated model of the economy of the United States [4, p.488] shows how government and control operations by humans are related to the operation of the ecosystem. We often talk of empowering the government or the people, by which we mean placing political power under their control [33, p.36], thus connecting physical and political empower concepts.

Maximum Power Principle. Measurement of political power is however a more difficult matter. But Riker [34, p.120] commenced research as to whether politicians maximise political power, just as economists and people generally are supposed to maximise utility and ecosystems their energy transformation, known now as the maximum empower principle, thereby unifying the underlying energy basis of the physical, biological and social sciences, as suggested by Odum [2, p.209] when introducing social structure and power. An introductory paper has

already been prepared showing an elementary model relating left and right political attitudes with the maximum empower principle [35]. This however does not yet include the effect of personality on political attitudes, which produced an inverted parabola connecting political parties into a power maximising hypothesis [1, p.36]. Liberal arts political science has developed in energy ignorance: science faculties could offer "politology" courses and research in politics instead.

Religion. These concepts would however not be complete unless they could also be applied to that elusive phenomena known as "religion". For as Odum [2, p.236] wrote: "Well known in anthropological studies is the nearly universal presence of religion in human networks. Strong morality apparently has a survival role in programming power budgets". The central entity around which most religious discussion takes place, however, is the soul. According to Odum [2, p.247]: "If the soul is identified with a level of special complexity of the unit system, it emerges during network formation and its unique aspects become incorporated into the total system's information storages and inheritance as a form of immortality". If a soul is identified as say the most fundamental .01 per cent of the information stored in the human brain, which is proportional to the logarithm of supporting energy flow, it can at least be theoretically measured in soals, the logarithm of transformity unit, thus introducing the science of "humology".

X. *REFERENCES & ACKNOWLEDGEMENTS*

1. D.M. SCIENCEMAN and F. CALDWELL. A Policy for a Scientific Party. *General Systems Bull.* 15, 31-39, 1984.
2. H.T. ODUM. *Environment, Power and Society.* Wiley-Interscience, New York. 1971.
3. H.T. ODUM and E.C. ODUM. *Energy Basis for Man and Nature.* Mc. Graw-Hill, New York. 2nd ed. 1981.
4. H.T. ODUM. *Systems Ecology – An Introduction.* Wiley-Interscience, New York. 1983.
5. A.J. LOTKA. Contribution to the Energetics of Evolution. *Proc. Natl. Acad. Sci.* 8, 147-155, 1922.
6. R.D. MATTUCK. Feynman Diagrams. Pp. 441-445, *The Encyclopaedia of Physics* (3rd ed.). Van Nostrand Reinhold Publishing, New York, 1985.
7. M. SLESSER (ed). *Energy Analysis Workshop on Methodology and Conventions.* IFIAS. Workshop Report. Report Number 6. 1974.

8. M. SLESSER, H.T. ODUM and D.A. HUETTNER. Energy Analysis. *Science* 196, 259-262, 1977.
9. M.W. GILLILAND. Energy Analysis and Public Policy. *Science* 189, 1051-1056, 1978.
10. A.-M. JANSSON (ed). *Integration of Economy and Ecology.* Askö Laboratory, University of Stockolm, Sweden. 1984.
11. W.J. MITSCH *et al.* (eds). *Energy and Ecological Modelling.* Else vier Scientific Publishing, Amsterdam, Netherlands. 1981.
12. S.B. BRENT. *Psychological and Social Structures.* Lawrence Erlbaum Associates, London. 1984.
13. J. SOMA. The New Energy Hyperequation and its Implications. *Energy Eng.* 82 (2), 62-70, 1985.
14. R.G.D. STEEL and J.H. TORRIE. *Principles and Procedures of Statistics - A Biometrical Approach.* Mc.Graw-Hill, New York. 1980.
15. J. SOMA. Nomenclature for Exergy. *Energy Eng.* 80 (5), 17-20, 1983.
16. *The International System of Units.* U.S. Department of Commerce, National Bureau of Standards. 1981.
17. R. COSTANZA. Embodied Energy and Economic Evaluation. *Science* 210, 1219-1224, 1980.
18. J. CAMPBELL. *Grammatical Man.* Penguin, Middlesex, England. 1982.
19. M. TRIBUS and E.C. Mc.IRVINE. Energy and Information. *Sc. Am.* 225, 179-188, 1971.
20. J.A. DILLON and R.K. RAGADE. Quantity and Quality in Information Flows. *Proc. Soc. Gen. Sys. Res. Conf.*, pp. 101-105, 1984.
21. Y. BAR-HILLEL. *Language and Information.* Addison-Wesley, Reading, Mass. 1964.
22. M. ZWICK. Information, Constraint and Meaning. *Proc. Soc. Gen. Sys. Res. Conf.*, pp. 93-99, 1984.
23. J. PERCEBOIS. Is the Concept of Energy Intensity Meaningful? *Energy Economics* 1, 148-155, 1979.
24. J. MORRELL. *The Future of the Dollar and the World Reserve System.* Butterworth, London. 1981.
25. N.O. BROWN. *Life Against Death - The Psychoanalytical Meaning of History.* Sphere Books, London. 1970.
26. S.E. GUNDERSON. Technocracy. P. 356, *Encyclopaedia Americana.* Vol.26. University of Chicago Press, Chicago. 1978.
27. R. HEILBRONNER. The Problem of Value in the Constitution of Economic Thought. *Paper presented to the American Economic Association.* 1983.
28. A.S. EICHNER. The Lack of Progress in Economics. *Nature* 313, 427-428, 1985.

29. R.B. CATTELL. *Structured Personality - Learning Theory.* Praeger, New York. 1983.
30. J. ALPER. Our Dual Memory. *Science* 86, 44-49, 1986.
31. W.H. RIKER. Some Ambiguities in the Notion of Power. *Am. Pol. Sci. Rev.* 58, 341-349, 1964.
32. R.A. DAHL. Power.Pp. 405-415, *International Encyclopaedia of the Social Sciences, Vol. 12. Macmillan, New York. 1968.*
33. R.N. ADAMS. *Energy and Structure - A Theory of Social Power.* University of Texas Press, Austin, Texas. 1975.
34. W.H. RIKER. A Test of the Adequacy of the Power Index. *Behavioral Science* 4, 120-131, 1959.
35. H.T. ODUM and D.M. SCIENCEMAN. Commonalities between Hierarchies of Ecosystems and Political Institutions. *Paper presented to the American Association for the Advancement of Science,* Society for General Systems Research, New York, 1984.
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