Sustainable Settlement Energetics:

EMERGY and Ecovillage

E. Christopher Mare

Antioch University Seattle

Summer 2002

Happy Valley

Contents:

Introduction

This paper is a preliminary theoretical exploration into the energetics of sustainable human settlements.

"Energetics" is defined as "the study of [energy] transformations creating the inanimate universe and sustaining life on Earth" (Smil, 1991). It is understood that at the most fundamental, substrative levels, the vastness that is the Universe is a dynamically pulsating, undulating, vibrating energy matrix-flux and that each and every distinct manifestation in the Universe – whether it be a 'thought-form' or something more tangible – is an embodiment of a particular quality and pattern of energy expression in that matrix-flux. Both the quantum physicist and the serious student of meditation would agree with these perceptions. This makes a study of "energetics" precursory to in-depth understanding in any field of inquiry.

A "sustainable human settlement" is defined as a discrete human habitation system that has the potential to be continued into the indefinite future – for as far along the time horizon as one can imagine. This paper, then, will attempt to discover and describe those qualities and patterns of energy transformation that characterize, constitute, and ultimately produce such a long-term viable human habitation system. Implicit in this statement is the assumption that an *un*sustainable settlement will embody a different or contrary expression of energy transformations. For the sake of clarity, both the terms 'sustainability' and 'settlement' will be elaborated upon in some detail in subsequent sections of this report.

The overall purpose of this investigation is to provide a context within which the crucial, yet all too often vague, discussion of 'sustainability' can have a meaningful scale of application and operation – based on the settlement – and an objective method of evaluation – based on the optimal use of available energy. The final intent is to organize, synthesize, and present the conclusions as a coherent set of proposals that can be used as semantic design criteria for settlement designers and planners interested in creating truly sustainable systems.

The primary analytic tool that will be used throughout this exploration is the "EMERGY" environmental accounting technique devised and formalized by Professor Howard T. Odum at the University of Florida at Gainesville. It must be stated at the outset that a complete EMERGY analysis is a highly technical and sophisticated energetic accounting system using detailed scientific quantitative calculations. The full range of technical details and their application is beyond the scope of this little 3-credit

Independent Study, so I will be concentrating foremost on the *conceptual* basis of EMERGY analyses and specifically how EMERGY concepts can be used to effectively analyze the energetics of human settlements.

Of necessity, the paper will be broadly inter- and trans-disciplinary, and will reference and cross-reference principles and conceptual material from the following disciplines: Ecology, Human Ecology, Landscape Ecology, Economics, Human Geography, History, Psychology, Urban Planning, Energy Theory, and Ekistics,[1] with a philosophical underpinning grounded in Whole Systems Thinking.

In preparation for the discussion that will follow, it will be useful to review fundamental energy principles as defined by the laws of thermodynamics:[2]

First Law: Energy entering a system is neither created nor destroyed. All inflow energy is either stored in one of the tanks inside or flows out through pathways to the outside.

Second Law (The Principle of Universal Depreciation): Everything that is recognizable in our biosphere has a natural tendency to depreciate and be dispersed. The things that depreciate are the real wealth of our lives. They require continued repair and replacement. As energy loses its concentration and ability to do work, it leaves the system in degraded form.

Third Law: As the heat content approaches zero, the temperature on the Kelvin-scale approaches absolute zero (-273C), molecules are in simple crystalline states, and the entropy of the state is defined as zero.

Fourth Law? (Maximum EMPOWER Principle): In the competition among self-organizing processes, network designs that maximize EMPOWER will prevail.[3]

Fifth Law? (Energy Transformation Hierarchy): Energy flows of the universe are organized in an energy transformation hierarchy. The position in the hierarchy is measured with transformities.

---

[1] 'Ekistics' is a term first coined by Greek architect and planner C.A. Doxiadis in the late 1960s to define a *scientific*, *multi-disciplinary* approach to the study of human settlements. In effect, this paper could be considered an ekistic analysis focusing on energetic parameters.

[2] These definitions are taken from Odum, 1996, pp.4, 5, 16.

[3] EMPOWER is defined as the EMERGY flow per unit time. In standard physics, *power* is defined as the flow of energy per unit time, or simply the ability to do work. In a more humanistic sense, power is defined as the ability to influence others, and is often associated with the accumulation of material wealth.

With these principles in mind, let us now proceed to understanding them and applying them within the context of sustainable human settlements. But first, an overview of EMERGY is necessary.

EMERGY

It was discovered in the course of evaluating and formulating coherent energy policy, at any scale, that great confusion arose when attempting to transpose calculations or facts from one discipline to another: Should decisions be based on maximizing monetary return, energy efficiency, economic productivity, or environmental stability? Even among strictly energetic (i.e. thermodynamic) calculations, there was no commensurable denominator by which to translate data between fields. H.T. Odum solved this problem by creating a "science-based evaluation system…to represent both the environmental values and the economic values with a common measure. EMERGY, spelled with an "m," measures both the work of nature and that of humans in generating products and services. By selecting choices that maximize EMERGY production and use, policies and judgments can favor those environmental alternatives that maximize real wealth, the whole economy, and the public benefit" (Odum, 1996, p.1).[4] And, "EMERGY is a measure of the available energy that has already been used up (degraded during transformations) to make [a product or service]. Its unit is the emjoule" (p.2). EMERGY also can be considered "energetic memory" (Scienceman, 1987), the total value of energetic inputs introduced over time, both environmental- and human-derived, to produce a usable economic output.

EMERGY, then, is a comprehensive energetic accounting system that can be used to evaluate objectively the *total* amount of energy consumed in an enterprise or process, judging whether this available energy has been used efficiently for the greatest long-term benefit. "EMERGY is a scientific measure of *real wealth* in terms of energy required to do the work of production" (p.7, added emphasis). With this kind of insight, an EMERGY analysis can transcend the often heated, circular, partisan debate between 'environmentalists' and 'economists' by providing an objective, scientific measure by which the interests of both may be e-valuated and co-ordinated, resulting in sound, illumined energy policy designed to serve the needs of the whole.

EMERGY thinking is an applied form of "Systems Ecology," meaning that an EMERGY analysis will inductively apprehend the system under consideration *as a whole,* and will 'holarchically' perceive the characteristic behavior and parameters of that system-whole as 'emergent properties' arising from the dynamic interaction and

[4] Since the vast majority of references in this paper come from Odum's culminating work *Environmental Accounting: EMERGY and Environmental Decision Making*, further quotes or references from that volume will be listed with a simple page number.

interrelationship of its constituent parts.[5] This is exactly the opposite investigative technique used by the predominant 'reductionist' scientific mainstream, which earnestly dissects and examines the details of constituent parts in isolation in an effort to understand the properties and determine the meaning of the whole.

Before going any further, it is time to elucidate this term 'economy,' as it is being intended here; for true economic understanding is such an essential consequence of an EMERGY analysis, and the common usage of 'economy' surely has become distorted. Etymologically speaking, 'economy' is derived from the Greek roots *eco* – 'home' and *nomos* – 'managing,' such that originally economy connoted the process of managing the home – or, by extension, *managing the immediate local environment*. Another term closely allied with 'economy' is 'ecology' – or the study of the home. It is understood that before one can competently *manage* the home (or immediate local environment) one must first *study* the home and come to understand all its multifarious dimensions, processes, and interrelationships. This makes 'economy' rightly a subset of 'ecology;' in fact, one may even speak of the "Economics of Nature" (Van Kooten and Bulte, 2000). The truth is, all discrete living systems – from organisms to ecosystems to the planetary system Gaia – engage in economic processes of some kind, at some scale. All human economic processes originate from, co-evolve with, and are supported by local ecological processes; this is fundamental. Economic thinking placed outside of, in lieu of, or on top of ecological thinking is only a cerebral abstraction, separated from the source, and this is the cause of much distortion.

In traditional (i.e. pre-industrial) cultures, an economic process was considered as the combination of activities whereby a collectivity of humans interfaced with, used, and transformed or transfigured a particular circumambient environmental system to produce useful products and services to satisfy their needs. The people were immersed in this environmental system, this local ecology, and symbiotically identified with it as their own; thus traditional economics was very much *place-based,* indigenous and vernacular. People tend to take care of that with which they can identify.

This traditional perspective of the economic process differs markedly from the predominant, mainstream, "neoclassical" view, which posits as a maxim an unending hedonistic stream of material *wants* as inherent to human nature. All these wants, these desires, are potentially, theoretically, supposedly satisfied by the so-called economic process. Acquiring the means of procurement is equated with the right to consume –

[5] 'Holarchy' and 'emergent properties' are systems languaging. A horizontal holarchy – as differentiated from a vertical hierarchy – is an aggregate system where constituent parts are perceived as interrelating, semi-autonomous subsystems of their own. Emergent properties are characteristics or behavior of the more-inclusive, whole system that cannot be inferred by studying the subsystems independently, on their own.

and it doesn't matter from where or under what circumstances the resources come as long as they do come. The works, products, and services of pre-existing, primordial environmental systems are viewed as exploitable and conceivably inexhaustible resources existing solely as a utilitarian means for satisfying these egoistic desires.

This neoclassical view, as it has progressed, has further degenerated pure economics by turning it into principally a *financial* accounting system, where the increasingly disconnected-from-reality energetic abstraction called 'money' is the sole indicator of value, and the prolific, life-giving, irreplaceable work and services provided by Nature are listed as freely available "public goods" – their contribution or depreciation not at all accounted for.[6] Odum's EMERGY accounting system addresses this glaring oversight by reintroducing the work, products, and services provided by Nature into the overall economic e-valuation, combining the work of Nature and the work of humans into a common denominator called "emjoules," which can be valued in terms of "emdollars."[7]

A specific EMERGY analysis will first isolate and enclose the particular system under consideration into an "environmental window," the level of organization in which a given economic process interfaces with a given environmental system. By first defining this environmental window, essential inputs, pathways, storages, producers, consumers, and outputs – and most importantly the interconnecting and inter-influencing relationships amongst them all – can then be conceptually displayed and clearly visualized by creating a "systems diagram," which is an art form of its own. The systems diagram is able to take an awkwardly complex situation and make it manageably comprehensible.

Once the systems diagram has been graphically composed and all the essential inclusive elements have been arranged, specific energetic values can then be calculated and applied to each of the symbols and interconnecting pathways, resulting in a thorough, objective, scientific mathematical analysis of the system under consideration. The result is an elegant and informative visual representation of the requisite factors to be included when forming rational, reasonable energetic decisions and judgments; the

[6] Services provided by Nature include fresh air, rainfall, soil fertility and stored mineral content, biodiversity, photosynthesis, genetic predisposition of species, carbon sequestration, the purification and filtering activity of wetlands, erosion control, climate homeostasis, etc., etc.

[7] As an example taken from p.58: the emdollar value of the solar energy stored in a forest hectare that required 200 years to develop is calculated to be $71,428 1993Em$/ha. Standard economic analyses would not include this work provided by Nature at all; total value of the forest hectare would be determined solely by market price, in dollars, at the time of harvest. Doesn't this seem odd? Weren't the inputs of rain, soil fertility, stored mineral content, genetic predisposition, etc., as well as solar input, also determinate in overall productive value?

obvious conclusions and logical courses of action are clearly and indisputably displayed. The systems diagram is such a valuable analytic tool because it can bypass reams of politically or subjectively influenced writing and can get right to the conceptual heart of the issue, in the sense that "a picture is worth a thousand words."

As an example of a systems diagram, consider the EMERGY analysis of a typical salt marsh (p.113):

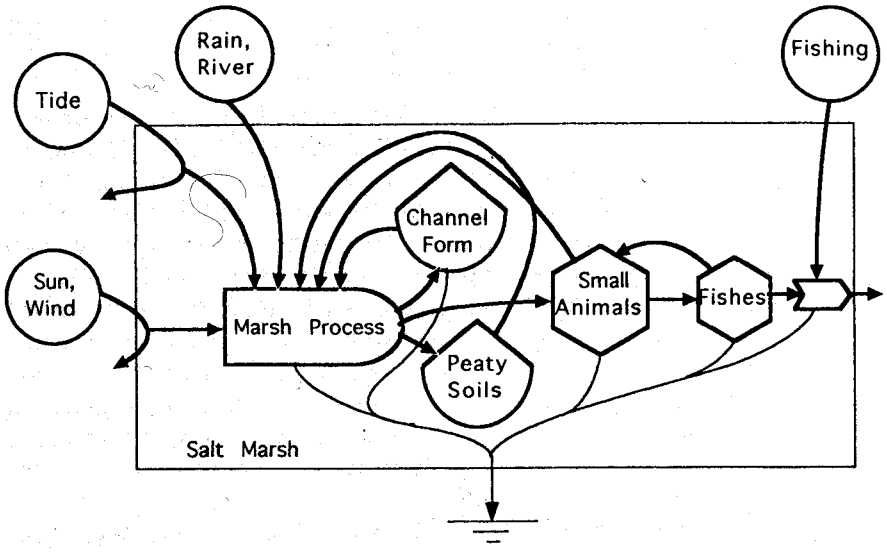


Figure 7.2. Energy systems diagram of a salt marsh aggregated according to the main necessary components and processes as a step in setting up EMERGY evaluation for Table 7.3.

In this particular systems diagram, initial "energetic inputs" external to the environmental window are 'tide,' 'sun,' wind,' and 'rain, river.' These inputs supply energy to the "primary producer" 'marsh processes.' The primary producer stores embodied energy in the "storage tanks" 'channel form' and 'peaty soils.' The primary producer also feeds directly the "consumer" 'small animals' and this consumer in turn feeds 'fishes.' There is an "interaction gate" where 'fishes' interacts with a further source 'fishing' to finally produce an energetic output leaving the window. As per the second law of thermodynamics, all components in the system, in the process of doing work, channel degraded energy to a "heat sink," or ground. This systems overview illustrates clearly the interrelationship between all the parts of the system and between the parts and the whole. It would be possible from here to add specific energetic calculations, in emjoules, to each of the components and processes and to arrive at a total economic value for this salt marsh, in emdollars.

In all these EMERGY systems diagrams, high-quality, renewable environmental sources – sun, rain, wind, tide, geologic heat, etc. – are depicted on the left side of the

window, as primary inputs; their gradual, eventual degradation in the course of doing economic work, both environmental and human, is accounted for in the symbols and pathways that move to the right of the diagram. This energetic degradation, in technical terms, is called "transformity," an all-important essential energy concept. "Transformity, the EMERGY per unit energy, identifies the scale of energy phenomena….The quotient of a product's EMERGY divided by its energy is defined as its *transformity*" (pp. vii and 10). All energetic processes on Earth ultimately originate with the initial pure solar input; this is fundamental. The solar input is used by biogeophysical processes at successive steps along economic pathways until it is eventually consumed; but at each step, the initial solar input (available energy) does work of some kind for the system (or systems) as a whole. Transformity, then, is a measure of the stage of solar degradation, and subsequently, almost paradoxically, *energetic investment*. "Goods and services that have required the most work to make and have the least energy have the highest transformities" (p.10). To the left of the systems diagram is high (potential) energy but low transformity and to the right of the diagram, after successive stages of use, is low (consumed) energy but high transformity. EMERGY is a calculation of the *total energy* used in the process, and does not degrade or diminish, but accumulates.

For conceptual clarity, the whole transformity process can be reiterated in terms of the energetics of the fundamentals of ecology:

"Terrestrial energy in any form ultimately originates from the Sun. Plants, as primary producers, collect this energy and utilize it in their metabolism, photosynthesis, creating sugars and expelling degraded energy. Humans and other heterotrophs then absorb plants for their own metabolism, and in turn expel degraded energy into the environment as waste material that can be utilized by bacteria and other decomposers. The bacteria and decomposers then convert this waste material back into a form that can be utilized by plants. The original, pure solar input is eventually lost, however, and the plants need a continual supply of incoming solar power to keep the whole process alive. This is a simplified version of the primary energy cycle of Life on Earth; it all begins with the Sun. The continual, inevitable degradation of incoming solar energy to less usable forms is termed 'entropy' (heat loss to the environment). A viable economy – which ultimately means the process by which Life sustains *itself* – will be modeled upon this primary energy cycle. Its goal will be to arrest the flow of entropy and enhance the utility of the solar input at each stage. This is the essence of sustainable settlement economics" (Mare, 1997)

As has been demonstrated in this section, EMERGY is a useful conceptual tool (and can be used as a more precise scientific measurement tool) for evaluating a system's

effective use of available energy. What would it look like, then, to frame an environmental window around a *sustainable human settlement?* What would be the source inputs, the primary and secondary producers, the consumers, the storage tanks, the interface with the larger economies of both humans and Nature, and the interconnecting pathways between all these components? Before this can be meaningfully answered and graphically illustrated, it will be necessary to first examine more closely these crucial terms ‘sustainability’ and ‘settlement.’

Sustainability

SUSTAIN: To keep someone or something alive or in existence – *American Heritage*

The elusive concept 'sustainability' has become a sort of collective mantra at the dawning of the 21st century; yet, like all popular but relatively ambiguous terms (including 'love' or 'quality of life') it can mean different things to different people depending on the context of the discussion and one's inherent values and goals. In these days, "Sustainability is used as a rallying point for different ideological positions and interests" (Redclift, 2002, p.189). For example, a forester may speak of a 'sustainable yield,' a planner may speak of 'sustainable growth,' and a food producer may speak of 'sustainable agriculture,' though these applications are not necessarily complementary with one another. Much of the current discussion focuses on 'sustainable development,' but this usage is actually a contradiction in terms considering that the world is already *overly*-developed and environmental systems are already *overly*-taxed so that any new development, in the sense of population or economic expansion, is a further step in an increasingly unsustainable direction. Sustainable development is usually concerned with achieving some sort of economic, gender, or racial equality – especially in reference to the relationship between the so-called *developing* and *developed* hemispheres – yet this goal is more like rearranging the seating on the decks of the *Titanic* instead of duly altering the ship's course.

The oft-cited seminal definition of sustainability provided by the Brundtland Report (1987) goes something to the effect: "consuming resources at a current level that does not diminish future generations' ability to access or use those same resources." While well-meaning in intent, this focus on achieving intergenerational equity by means of a stabilized condition of *resource throughput* will inevitably lead to failure since, 1) population growth is expanding exponentially, and thus 2) the *rate* of resource consumption is likewise expanding exponentially. As Meadows, et al. (1993) so skillfully point out, in an exponentially expanding system the reaction time in which to avoid overshoot is *diminishing* exponentially. Realistically, using resource throughput as a measure of sustainability would mean adapting the economic process to a *geological* time-frame, and I'm sure no one is ready to accept that.

Any attempt at moving toward sustainability within the limited mindset of current economic parameters will be a futile effort; and yet, "As the sustainability debate became more mainstream in the 1980s, much of it was influenced by neoclassical economics, and an attempt was made to translate environmental choices into market preferences, following neo-liberal orthodoxy" (Redclift, 2002, p.190) *This will never work* because in the global capitalist system (i.e. neo-liberal orthodoxy) there must be continuous, linear, unending growth or the system will collapse in upon itself; and the perceived potential for unlimited growth is the very crux of the problem. In a materially-closed system such as the Earth, growth must be cyclical and pulsing as resources are produced, consumed, recycled and then regenerated. Additionally, as has already been pointed out, the 'marketplace' does not account for the depletion of "public goods" – the free and vital services provided by Nature – so how could market preferences in any way contribute to the long-term maintenance of these stocks? The discussion of sustainability, when used in the context of current economic parameters, is more like wishful thinking: It is being used loosely as a sort of conceptual 'negative feedback' with the hoped-for-purpose of bringing the current system back in line so that this system can be "kept alive or in existence," and then everyone can carry on business as usual. But make no mistake: this system is seriously structurally flawed and cannot be remediated; its very goal (however explicitly unstated) is to exploit the life out of living systems. How could it possibly sustain itself under these conditions?

Robert Gilman (1991), as an ecological futurist, puts forth a more visionary while at the same time pragmatic definition of sustainability: A sustainable situation is simply one "that can be continued into the indefinite future." If a given socio-economic process or presence is to have the chance to be continued into the indefinite future, then more fundamental, elemental parameters besides resource throughput and market preferences must be considered. For example, attention must be given to the supporting socio-cultural fabric that is producing and using those resources: the socio-cultural fabric must be attended to, nurtured, and conserved. And the socio-cultural fabric does not occur in a vacuum but is structurally coupled to a specific ecosystem and locally occurring set of environmental conditions – a living, place-based ecology. The local ecology then also needs to be attended to, nurtured, and conserved. This dynamic, productive interface between the socio-cultural fabric and the local ecology finds its utilitarian expression through economic processes. Thus, in order to be sustainable and continued into the indefinite future, human economic processes must necessarily strike a symbiotic, synergistic balance between the long-term needs of the local ecology and the long-term needs of the inhabiting humans. By attending to and nurturing the health of the whole, the health of each component within the whole is thus attended to and nurtured.

All this seems so elementary. What is implied is that in order to be sustainable, economic processes are best organized at an *ecosystem scale,*[8] the level of interactive environmental perception in which the human being lives and operates on a daily basis. The ecosystem scale is that level where the energetic feedback loops generated from economic functions can be most immediately and significantly evaluated and fine-tuned, and where available energy can be most usefully and conservatively managed. This is the scale where economics is a natural outgrowth of a unique, vernacular, place-based culture – as in the original intention of *eco-nomos*: 'managing the home' – and where human beings can intimately identify with the natural systems and processes with which they interface, and from which they draw their sustenance; thus it is significantly *human-scale*. Extrapolating the economic process beyond this scale becomes a vapid abstraction, lacking a land base and thus a real contextual basis.

And so, what is ultimately required to achieve lasting sustainability is a complete dismantling of the so-called global economic system and a decentralized reorganization along bioregional-ecosystemic lines, readapting and realigning the human economy with the economy of Nature. This transformation-conversion will be greatly facilitated and assisted by the substitution of resource and financial indicators with EMERGY indicators so that *EMERGY* is maximized, for the benefit of all. EMERGY is a measure of *real wealth*.

Even if this was understood and accepted, how would it be possible to manage an EMERGY conversion at a global scale? Where would be the points of intervention? The inputs and outputs could conceivably be measured, but the entire process in between is unwieldy and ill-defined. While it is conceivable to create a window around large system levels – such as 'states' or 'nations' or the entire 'global system' – much ambiguity will result because of the necessary generalizations and abstractions. That is why it is important to repeatedly emphasize that a sustainable economic process – and its eventual EMERGY conversion – will be most efficiently organized at a human scale – a *settlement* scale. Once the economic processes are being effectively implemented and practiced at that scale, they can be systemically fractalized upwards from there. A top-down approach is profusely wasteful of available energy.

[8] "Most landscape ecologists use the "ecotope" as the smallest landscape subunit and not the vaguely defined "ecosystem." This is actually the tangible site of its ecosystem. Its boundaries are pragmatically defined according to the requirements of the study…aggregated into ecotope-types…landscapes should be conceived as integrated, ordered wholes and interacting systems. To their physical, geographical space, *Homo sapiens* have added throughout their cultural evolution also conceptual-noospheric space and new emerging structural and functional qualities. Our present landscapes are therefore complex natural and cultural gestalt systems…They represent thereby a higher order of complexity in the ecological hierarchy than the natural bioecosystem" (Naveh, in Kim and Weaver, 1994, pp.188-89). This is what I'm trying to get at here. It is true: I have seen used both the terms "global ecosystem" and "pond ecosystem." Since I am not yet functionally literate with the term "ecotope," I will continue to use the fuzzy "ecosystem," meaning a well-defined, encompassing, circumambient local ecology.

In summary, achieving long-lasting sustainability is a matter of structurally coupling human habitation systems to particular ecosystems, and from there evaluating their mutually-productive interface, as enacted and realized through environmentally conscious economic processes, with EMERGY analyses and measurements. In this way, ecologically integrated, place-based socio-cultural systems will have the chance to be continued into the indefinite future.

Now that all that's been said, and a workable solution has been forwarded, how about approaching this over-used term 'sustainability' from a more philosophical angle. As noted at the opening of this section, the dictionary defines "sustainable" as: "*to keep someone or something alive or in existence?*" Is that such a worthwhile goal? It conjures up images of a terminally ill patient hooked up to life-support equipment. Might it not be best to just pull the plug? Or maybe it would be best to not try to save the 'patient' at all; that is, let this global economic system have its last oil-infused hedonistic binge, its final gluttonous heyday. We might insist: "Go ahead, ravage the planet; devour the life-force and the last remaining resources; go into overshoot and collapse – and be quick about it! We'll pick up the pieces from there." Those who are most environmentally conscious will prosper most in a post-collapse world. The greater Life will surely live on in some form.

If sustainability is merely the concerted effort to achieve some sort of lasting steady-state – homeostasis and homeorhesis[9] – then perhaps it is time to begin thinking *beyond sustainability,* beyond mere stable survival. What would it take for the human presence on Earth to really *thrive,* to *flourish,* to actualize its true latent potential, to become a co-operative partner in co-evolution with the greater Life of which it is a part? What sort of socio-economic and socio-cultural systems could be designed to serve these ends? *Homo sapiens sapiens* is surely not the endpoint of Creation, the final evolutionary statement in the long and glorious history of Earthlife. Either *Homo sapiens sapiens* will further evolve into a new, ecologically and cosmically aware, energetically resourceful species, or it will be the terminus of the anthropoid experiment.

[9] Edward Goldsmith (1998, p.472) defines homeostasis: "From the Greek *homeo*, same, and *stasis*, stoppage. A term coined by Walter Cannon in the 1920s. A homeostatic machine is a machine with feedback that is able to return to a ground position after a disturbance. In the living world, behavior is largely irreversible and living things after a disturbance do not return to a ground position but to a slightly new position that is as close as possible to the previous one. Thus it is best to see a natural system as displaying homeostasis when it is able to reduce discontinuities to a minimum in the face of internal or external challenges. It is essential to the thesis of this book that a system can only maintain its homeostasis by maintaining that of the hierarchy or larger living systems of which it is a part;" and then homeorhesis: "A term coined by Waddington, from the Greek *homeo*, same, and *rhesis*, flow. Homeostasis applied to a developing system…"

These, I believe, are the full philosophical implications inherent in the sustainability discussion, and for these reasons it is necessary to place the context of the discussion *beyond sustainability,* beyond mere steady-state material maintenance. What if 'sustainable development' meant actually *enhancing* the profusion and abundance of the living biota of the Earth, for the benefit of the greater Whole? What if sustainable development meant developing those intangible human qualities that make life really wonderful: love, compassion, joy, equanimity, a spiritual connection with the Source, healthy bodies, strong family ties, keen senses and intuition, superlative mental faculties, etc.? These qualities are potentially limitless! Let us invest our energies there.

In order to facilitate and assist this kind of sustainable development, it is time to begin conceiving, designing, and implementing those vibrant, effulgent living contexts within which human beings will have the opportunity to actualize their as-yet-unmanifest, full latent potential. This is the unspoken promise of the emerging 'ecovillage' vision, for the ecovillage could serve as just such a context.

Settlements

All 'higher animals' define a limited area of activity within which to conduct their most intimate business of maintaining life – reproduction and the nurturing of the young, sleep or regeneration, the procurement and storage of food, etc.[10] This limited area of activity is a *territory,* and the more industrious animals will concentrate this activity in the construction of a built environment: a den, a burrow, a nest, a web, a shell…or in the most socially complex animals such as ants, bees, termites, and the various species of *Homo,* an elaborate aggregation called a *settlement*.

Human settlements, when viewed as discrete habitation systems, come in a wide variety of shapes and sizes, forms and functions. In an attempt at outlining a preliminary categorical taxonomy, there are, in hierarchical order of complexity: camps, homesteads, hamlets, villages, towns, cities, metropolises, megalopolises, and ecumenopolises.[11] Theoretically, these could be considered to comprise, in totality, the basic systemic structural aggregations of human settlement, leaving room of course for specific cultural adaptations. There are also many culturally specific settlement types – villas, estates, manors, plantations, pueblos, cohousing developments, subdivisions, temple complexes, necropolises, etc. – but for the purposes of systemic analysis, as is being conducted here, the aforementioned could be considered the systemic archetypes. These habitation systems are defined more by function than by actual resident population (Hudson, 1970), though relative size is an important defining characteristic.

The relationship between 'form' and 'function' becomes particularly cogent when discriminating among these various arrangements. For example, a 'city' is not just an overgrown 'town' but actually poses a distinctly different purpose for its existence than does a town. Likewise, a 'metropolis' is more than just a collection of 'cities;' specific systemic emergent properties arise as a settlement reaches this scale,

[10] 'Higher animals' is used to describe a level of sentience and self-determination distinguishable from more simple creatures. In truth, however, all organisms adapt themselves to limited zones or niches from which to conduct the business of maintaining life, however rudimentary that business may be. There is a defining characteristic about this 'home' environment, such that the environment shapes the organism as much as the organism shapes the environment; they are intimately *co-evolving.*

[11] "Ecumenopolis" is a termed coined by Doxiadis to describe a *continent-wide* urban agglomeration, if you can imagine that. Doxiaidis, born and raised in a congested European milieu, devoid of wilderness, believes this is the logical destination of human beings. Interestingly, Paulo Soleri, another European and the visionary ego-force behind Arcosanti, concurs: "the city is the necessary instrument for the evolution of humankind" (www.arcosanti.org/arcology). This sentiment deserves a closer look.

properties that cannot be inferred by examining the cities in and of themselves. Most importantly, each of these scales will embody a distinguishably different socio-economic character or mood or feeling, and each scale creates a unique set of relationships externally, within its encompassing ecosystem(s), and internally, among its constituent parts, including the resident population.

The intention here is to propose *that* particular scale within which the long-term viable goals of sustainability[12] may be most readily actualized; or, stated more emphatically, there *is* a particular scale of human settlement within which the socio-economic process may be most effectively organized so as to achieve the goals of sustainability. It is at this scale around which the placement of an 'environmental window' in an EMERGY systems analysis will produce the most meaningful and serviceable results. This is the scale where detailed bio-geophysical energetic inputs can be accurately calculated and then – synergized with the feedback loops of a well-defined, circumscribed, specific human economic process – comprehensively evaluated in terms of effectively maximizing EMERGY output. The degree to which a particular settlement scale can effectively maximize EMERGY output – or more precisely, maximize EMERGY output through unit time: *EMPOWER* – is the degree to which that settlement scale can be considered sustainable. This settlement scale can then be proposed as the functional, operational 'unit' of sustainable settlement in a theoretical ekistics for the 21st century.

It has already been determined that in order to be sustainable – continued into the indefinite future – a human socio-economic process must be organized so as to conserve both a) its supporting ecological base, including the work provided by healthy, diverse, productive environmental systems – its *natural capital*, and b) its supporting socio-cultural base, including the work provided by healthy, diverse, productive human systems – its *social capital*. If any given socio-economic process, operating at whatever associated systemic scale, is using and exploiting either of these to the point of depletion or exhaustion, so that they can no longer function as self-maintaining, self-regenerating, integral wholes, then that socio-economic process absolutely will not be viable in the long-term; *it will not be sustainable,* no matter how the yields are calculated or the figures rearranged, no matter what technological substitutes may be invented or applied. By deduction, we can conclude that *the most* sustainable scale of human settlement, that which has the greatest potential for continuing into the indefinite future, is that scale within which the correlating socio-economic process most efficiently and productively utilizes – and conserves in that utilization – both its natural

[12] Please remember that I am thinking in terms of 'beyond sustainability;' however, I found that it is too cumbersome to insert 'beyond' each time 'sustainability' appears in the text.

and social capital. This would be maximizing EMPOWER and thus maximizing real wealth and prosperity.

Perhaps it is already apparent that organizing a socio-economic process at the scale of the 'global economy' is not in the least bit sustainable. This 'form' has the 'function' of maximizing the throughput of *financial capital* – especially money – so as to give the impression of vigorous wealth-production. There are surely a number of big players at the top skimming off quite a lot of financial wealth, but the system as a whole is a complete energetic abstraction, and thus an illusion; there is no accommodation built into the system for measuring the value of the input of healthy, functioning environmental systems nor the value of the input of healthy, functioning socio-cultural systems. In effect, the global system, organized around the avaricious goals of global corporate capitalism, is oblivious to its impoverishment of both natural and social capital. It can be said of this system that its covert and unarticulated purpose is to exploit the life out of living systems in order to convert that life into financial capital, for the benefit of a few. Even more poignantly indicative of its eventual demise, there is absolutely no inherent informational feedback mechanism for measuring the value *lost* by the depletion and eventual exhaustion of these supporting living systems. Since these supporting living systems self-organize, organically, at an ecosystem scale – an identifiable, delimited, biogeographical boundary – even a qualified EMERGY analysis done at the scale of the 'global economy' will be an abstraction, and so of little service.

To put things in perspective, this so-called global economic system is not a recent invention, a 'good idea' dreamed up by some devious, greedy macroeconomists cloistered in a boardroom; no, it is the inevitable culmination of the 5200 year march of *civilization.* And what exactly is civilization? Derived from the Latin root *civitas,* or 'city,' civilization is essentially the culture of cities – city life. In order to understand the reasoning behind the choice of an optimal sustainable settlement scale, it will be useful to backtrack a bit and conceptually trace the history and effects of civilization – the culture of cities; for, once 'city' became the predominant operational settlement unit, the eventual appearance of the global system was virtually assured.

The first civilizations, the first human societies to be organized in densely populated, urban city centers, arose in ancient Sumer, circa 3000 B.C. Within a relatively very short time these societies laid their surrounding, supporting ecological base to waste, completely exhausting the organic productivity of the land to the point that it still has not recovered (Carter and Dale, 1976). Co-incidentally, traditional long-standing socio-cultural processes, based on the egalitarian networks of extended clans, were also seriously disrupted, and displaced by a strict stratified class hierarchy.

Before this civilization phase, the people of this extended region organically self-organized themselves into agrarian, village-scale settlements in the surrounding foothills, but excessive population pressure forced them down into the lowland plains to construct their first cities (Whitehouse, 1977). These lowlands were bounded by the Tigris and Euphrates river systems (in modern day Iraq!) at the confluence of numerous trade and invasion routes. The excessive populations were thus under the constant threat of pillage and plunder and so were forced to concentrate themselves into densely packed defensive centers. These were the first cities!

This defensive pattern created a precedent: A large percentage of any surplus energy resources were diverted and channeled into the necessities of maintaining a state of military readiness and tactical advantage. Schmookler (1984) calls this the advent of "inter-societal anarchy," where the city-society that was able to consolidate and wield the most raw power – in all its forms – would win out and eventually force any competing city-societies to match its level of military and technological sophistication, or else be vanquished or assimilated. He also calls this "will to power" the one over-riding, predominant characteristic of civilized societies.

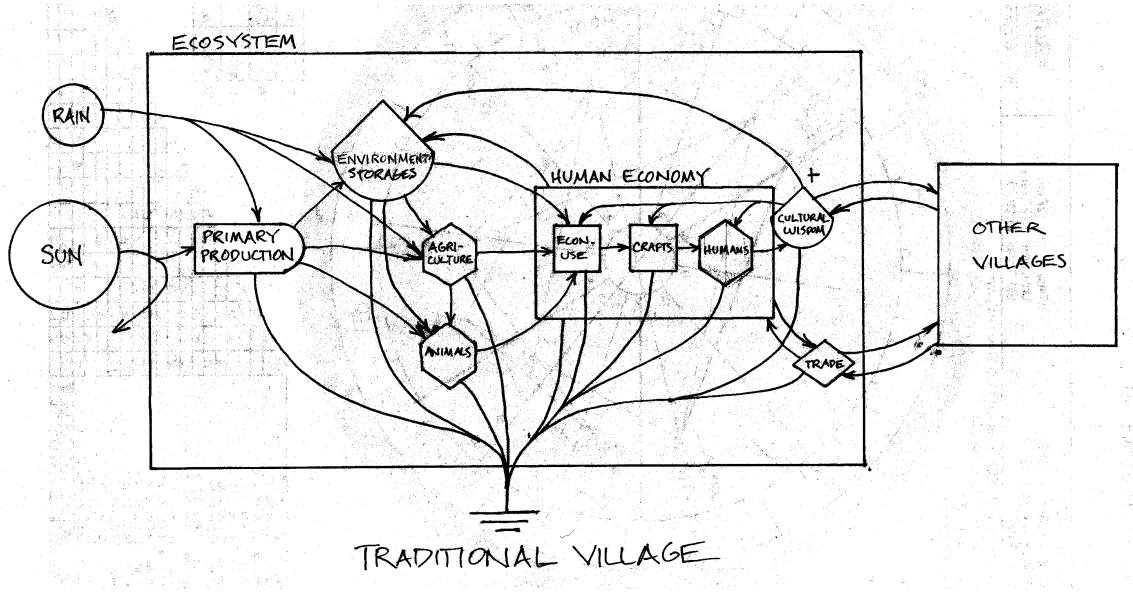
These overpopulated city centers, exceeding the carrying capacities of their local ecologies, inevitably needed to project themselves way out into the hinterland to draw energetic resources back into themselves to maintain their existence. This was the very source of the conflict, because other overpopulated city centers were doing the very same thing. An intense struggle arose (and continues until this day) over access to and control of limited, concentrated, high quality energy resources; for, (even without exposure to EMERGY principles) it was understood that the society that could maximize power – energy flow per unit time – would win the inter-societal anarchy.

Preceding this phase of intense, energy resource acquisition clashing, the traditional, agrarian, village-scale settlements up in the foothills – the products of millennia of co-evolution with circumambient ecosystems – were almost entirely *solar-powered.* As a consequence of being solar-powered, since the same amount of solar energy is available to all and cannot be hoarded, there was no need for aggressive military policy and standing armies. Likewise, with fixed solar insolation as the limiting factor to growth, human population levels could be held in a relatively balanced steady-state.

The agri-cultural and socio-cultural systems these village-scale societies constructed for sustenance were organized in such a way as to optimize incoming solar insolation so as to maximize solar gain and productive output – *at the settlement scale*. Output was enhanced through positive energetic feedback loops tied back to and amplifying the initial solar input. These energetic feedback loops were in the form of: recycled animal manures and compostable vegetative materials; animal muscle-power;

human ingenuity and resourcefulness; acquired and stored cultural knowledge about indigenous plant properties and cultivation techniques; the 'artificial selection' of promising genetic material (essentially genetic modification); tools and tool-making technologies; etc. Further inputs into the society-as-a-whole came from energetic transformities of the initial solar input in the form of stored biomass for materials, fuels, and food.

Here is an example of an EMERGY systems diagram for such a traditional village:



This diagram is intended to illustrate the feedback loops and the essential fact that the human economy is integrated into the larger ecosystem, as represented by a window within a window. Sun is the primary energy source powering the whole system, supported by rain. Environmental storages, agriculture and animals are used directly for economic use. There is some trade of goods and culture with neighboring villages.

These ubiquitous village-scale habitation systems, wherever they manifested around the globe, were self-contained, self-reliant, self-regenerating, *self-organizing organic living systems,* existing as what could be called anthropomorphological outgrowths or subsystems of the natural ecosystems to which they were coupled. Originally, and for a long while, a steady-state of dynamic equilibrium could be attained through the *negative feedback* (growth inhibition) of traditional cultural wisdom, taboo, and inherited custom designed to ensure that the socio-cultural systems could and would perpetuate themselves. But at some point, and for whatever reasons, at several locations around the globe populations began exceeding carrying capacities and were forced to move down into the lowlands of river valleys to construct cities. Once

initiated, this civilized solution soon gained momentum, for human population continued to relentlessly expand – driven by the positive feedback demands of the need for power maximization – and more societies were forced to organize at city-scale. This whole perspective contrasts markedly with the prevailing cultural evolution view, which looks upon the evolution to the city as a technical advancement and obvious improvement over traditional situations. It wasn't; it was an adaptive technical response to overpopulation.

Back to the abbreviated history of civilization:

By 600 B.C. the seat of civilization had been transferred to Classical Greece. Before their civilized phase, the Greeks too lived for millennia in arcadian, village-scale settlements, buffered from each other by the omnipresent mountain valleys in diverse and relatively peaceful, co-existing subcultures. Within a few hundred years of attaining civilization, the Greeks completely denuded their once forested peninsular landscape, leaving behind bare rock and silting up their harbors in the process; and then they too collapsed (Carter and Dale, 1976). As compensation for the extra 'fuel' needed to drive their civilization, the Greeks introduced institutionalized slavery as an established socio-economic norm. Onto Rome.

The Romans got much better at the imperialistic aspect of civilization; they were able to effectively subjugate distant populations throughout Western Europe and the Mediterranean in order to bring back energetic resources to the central cities of the Empire. These energetic resources were minerals, biomass, fuels, agricultural and human productivity, the accumulated cultural inheritances of millennia, etc. Even with all this extra resource consumption, Rome too collapsed after just several hundred years, as a result of internal social decadence and, once again, environmental depletion. This recurring theme of overshoot followed by collapse is certainly one of the defining characteristics of civilization. After a period of some confusion called the Dark Ages – apparently named for its conspicuous absence of a centralized, civilized power structure, even though the people close to the land continued to carry on their lives as usual – the seat of civilization eventually passed to Northern Europe, finally resting in Great Britain.

This passage marked an entirely new phase in the ascent of civilization. Europe is a fairly small and compact place; it could not have supported its continuous growth without an aggressive policy of *colonialism*. By forcefully laying claim to the energetic resources of distant peoples around the globe, enforced by a dominating military and technological presence, Europe was able to reinstitute and extend its civilized expansion. As resources were confiscated and drawn back to the center, excess population pressure was dumped onto the colonies, especially the 'New World.'

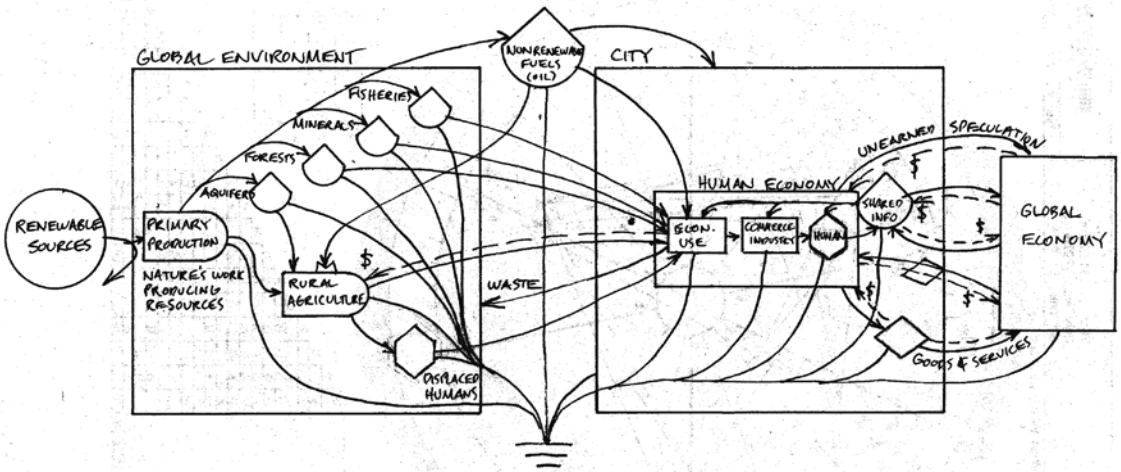
Great Britain, as the champion of empire building and the new seat of civilization, had the esteemed distinction of inaugurating the Industrial Revolution. This Revolution was only able to be initiated in the first place because of the influx of high-quality resources coming in from around the globe in excess of local resources. The Revolution was sustained by the exploitation of displaced peasants coming into the burgeoning cities as a cheap labor pool. It was ultimately fueled by the advent of technology for harnessing and exploiting fossil-fuels, beginning with the native coal deposits (see Schumacher, 1973).

This was such an extremely important energetic transformation in the rise of civilization; so much so that it continues to dominate world economics and politics today.[13] Fossil-fuels were (and are) a relatively cheap, easily transportable, highly concentrated source of energy far surpassing the utility and productivity of biomass fuels. Energetic ratios in socio-economic processes became highly distorted as this non-renewable (actually slowly renewable) source allowed previously unrealized concentrations of wealth, privilege, and power. Power here can be used in both its thermodynamic sense and also in its social sense; the flow of energy per unit time is *power*.

The ubiquitous use of fossil-fuel energy came into its own as the 20th century progressed, and the rate of use is still increasing. Such high concentrations of high-quality fuels led directly to an exponential surge in human population. The vast majority of this new population was channeled into the burgeoning urban centers. It must be stated forthrightly, especially in a paper entitled "Sustainable Settlement Energetics," that such undreamed-of-before population densities could never have been maintained without these concentrations of fossil fuels. On the flip side, such teeming, unhealthy population densities will not be able to be sustained once the fossil fuels are finally depleted. The use of fossil fuels will be understood as a brief and rapid surge, a dazzling blink of the planet's eye, a one time, get rich quick, reshape-the-face-of-the-globe energy bonanza.

Here is an example of an EMERGY systems diagram for a generic 20th century city run on fossil fuels:

[13] As of this writing, the so-called Bush administration is searching for an excuse to invade Iraq (ironically, the provenance of civilization). Iraq is said to be holding ten-percent of the world's oil reserves, amounting to trillions of dollars. Concurrently, there is a perpetual "war on terrorism" being waged in Afghanistan. It turns out that there are untold natural gas reserves waiting to be mined in the area surrounding the Caspian Sea, many more trillions of dollars. The most logical (i.e., economic) place to run a pipeline to get this gas to a seaport and then to the world's markets is right through Afghanistan and out of Pakistan. It seems that the U.S. military is being used as a proxy force to ensure the safe passage of this oil, and that the "war on terrorism" has either been fabricated or provoked as justification for this perpetual military presence.



This schematic is intended to illustrate the city's almost total reliance on non-renewable fuels; as a result, gone are the reinforcing feedback loops to natural processes and natural storages that a solar economy must employ. Nature's work is simply consumed here and returned as waste. The city exists as a 'technosphere' on its own, without any integration into a local ecology. The city extracts its resources globally, and money swirls round and round in the 'global casino.'

Finally enter the USA phase of civilization. The United States was originally organized as an agrarian society, under republican principles of democracy, but by the middle of the 19th century industrialism had been integrated in full force, and by the middle of the 20th century the nation had become the most powerful in the world. The USA was able to leap into a position of civilized prominence by a rapid and systematic exploitation and consumption of previously stored stocks of high-quality energy transformities: forests, fisheries, soils, minerals, aquifers, wildlife, etc. The establishment of the USA phase of civilization was the foundation for the eventual transition into the global system. It is no longer accurate to speak of the USA as the new 'seat' of civilized power, however, in the sovereign sense that it has been used up till now. That may have been true for a short while but now the seat of the new global system lacks a land base and the levers of the global economic process are manipulated by elitist financiers scattered about the globe.

Notwithstanding, the USA has achieved the pinnacle of those less desirable characteristics attributable to civilization: an economy intricately strapped to the production for war, including a domineering military presence deployed around the globe to ensure resource input tribute; a highly stratified society that is ever-increasing the gap between rich and poor; a majority of the population segregated in cities (or suburbs) with this percentage still growing; technology increasingly employed as a

substitute for natural processes; a hedonistic socio-cultural foundation that rewards decadence and ostentatious extravagance; and, most saliently, the extreme concentration of arbitrary power in the hands of a few.

The USA-global phase of civilization is, paradoxically, its culmination and the foreshadowing of its eventual demise. The USA was ordained to be the "light of the world;" instead it has turned into a rogue nation, with its current leadership and the herd it leads antagonistic or blind to the needs and health of the greater world. Such high concentrations of valuable energy had the potential to catapult the human condition into new levels of consciousness and well-being; and perhaps they still will. Perhaps, after the collapse of the "New World Order," the people of the USA will demonstrate for the world sustainably prosperous strategies for post-collapse regeneration, where human systems are once again modeled after natural systems, and in this special case aligned with the spirit of the indigenous peoples that were the first to inhabit this continent; yet remember: everybody in North America is an immigrant. Maybe in the post-collapse world it would be better for the new ecologically aware species of humanity to vacate this continent and turn it back over to natural processes exclusively, as a garden for evolution, so the planetary system Gaia can replenish and restore high quality stocks of high transformity genetic diversity.

This rough overview of the history of civilization was necessary to illuminate the essential point that *civilization does not work*: it is inimical to natural living systems. To organize any society or socio-economic process at city-scale is just not sustainable. Wherever civilization – city-based culture – is instituted the inevitable accompanying results are the exploitation of supporting environmental resources to the point of depletion and eventual exhaustion. Why does this repeatedly happen? It all comes down to the dynamics of population pressure. A city, by definition, is a settlement that has expanded to the point of debilitatingly exceeding its local supporting ecological base.[14] As compensation, the city, as a systemic unity, must project its power into outlying areas to procure and draw resources back to its center to keep itself in existence. This projection of power will inevitably come into conflict with other overpopulated civilized centers employing the same strategy, and an ongoing perpetual state of war (economic or military) results. This cannot be avoided once settlements are impelled to organize at city-scale. In the search, then, for defining a sustainable 'unit' of settlement in a theoretical ekistics for the 21st century, all those settlements organized

[14] In an important work by Wakernagel and Rees (1984), *Our Ecological Footprint*, the authors calculate that the city of Vancouver, B.C., for example, consumes a resource base equivalent to *twenty-one times* its actual size!

at city-scale and beyond can be effectively eliminated. *Civilization is not sustainable*. Does this come as a surprise?

What about 'town' scale, the next level down? Could 'town' be the sustainable unit in a theoretical ekistics scientifically, objectively based on the maximization of EMPOWER? To answer this question, it will be useful to focus on socio-economic dynamics. A town is a precursor to civilization, in that at town scale local ecological carrying capacity already begins to be exceeded. A town is usually considered as providing some sort of economic function for the regional economic center – the city. More importantly, a town is a settlement that has grown to the size of being unable to embody a cohesive social unity. A town is so large that inevitable factions develop over the use and distribution of ever-scarcer resources. These factions develop because the endemic population (5000 – 50,000) has grown so large that individuals who have real economic interests and relationship do not necessarily maintain face-to-face contact anymore. The personal human interaction is increasingly replaced by abstract laws, codified to enforce the status quo – which is the consolidation of arbitrary power in the hands of a few. Once codified laws are used as the basis of human interaction, bypassing natural laws and the judgment of traditional extended family networks, it is only a matter of time before that society enters the anarchic power play of civilization. Ergo, the town is not the scale around which to begin organizing for sustainability; it is a transitional stage.

The next scale down is the 'village'… what is it about the village? I see the word 'village' being used all around for various assorted constructions of the built environment – shopping centers, apartment complexes, subdivisions, cohousing developments, even singular businesses – yet none of these is even a remote semblance of an actual village. I sense there is a nostalgic sentimentality associated with this word, a sort of familiar remembered feeling of connection and belonging. Each of us, no matter our heritage, has ancestors who grew up and lived out their days in real villages. Think back to those early villages in the foothills surrounding the Mesopotamian plain, before the people were forced to enter the mad, violent, inter-societal anarchy called 'civilization.' I speculate it was there that the truly endearing qualities of human nature – love, tenderness, generosity, reciprocity, compassion, strong family and tribal bonds, a spiritual connection and identification with the Source, etc. – were most easily, naturally nurtured and cultivated. Without seeming overly romantic, I have seen these same qualities thriving, almost defiantly, in the remnants of traditional villages I have had the opportunity to visit in my time. There is something special – downright perennial – at this scale of socio-cultural and socio-economic organization.

A village can be defined as having three essential characteristics: 1) It is small enough so that everyone within can be known or at least recognized; there are no

strangers; 2) It is large enough so that all the basic needs of a high quality life can be satisfied entirely within the settlement, if need be; thus, it is self-contained and self-reliant – though I would not go so far as to say 'self-sufficient;' and 3) It is organically, symbiotically coupled to a particular ecosystem, a specific biogeographical reality, and has self-organizingly grown through time as an anthropomorphological outgrowth co-evolving with that particular ecosystem.

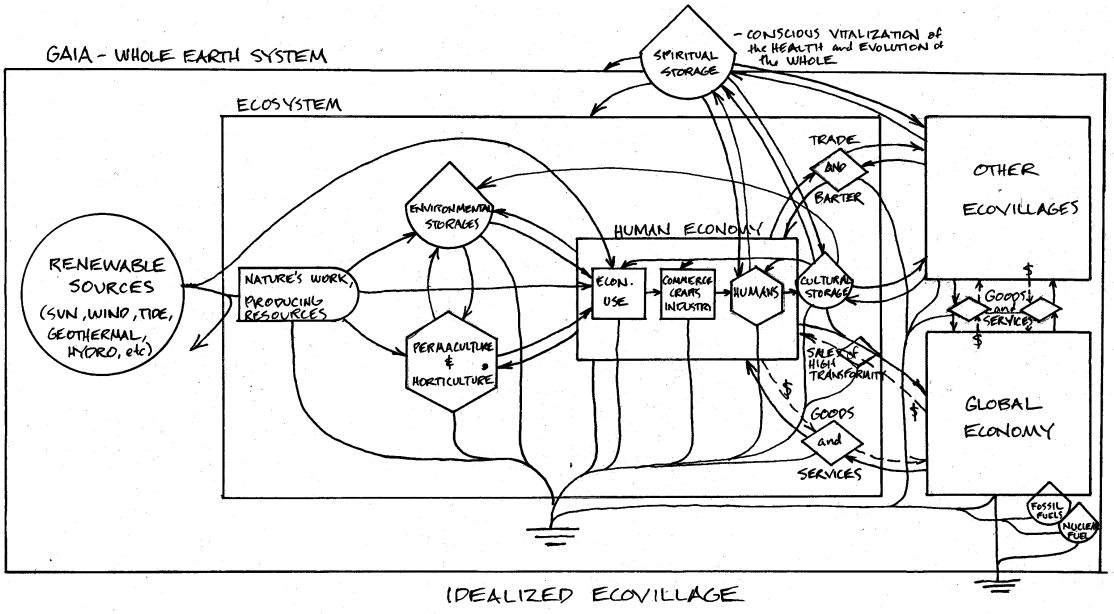
These three characteristics give the village its demonstrated durability; in fact, they could be considered initial design criteria for a sustainable human settlement. Thus, as a maxim, it is proposed here that *village*-scale is the optimum scale around which to begin organizing for long-term sustainability. Hamlets and homesteads are too small to accommodate a specialized internal economy, so there is a diminution of real socio-economic potential. Cities and beyond are monstrous, mechanical behemoths mindlessly devouring their resource base. Towns are somewhere in between but they begin to abstract personal human relationships. 'Village,' then, is that magic size where the best of all worlds can be realized: it is human-scale, flexible, adaptable, large enough to contain a specialized economy and advanced cultural refinement but not so large as to alienate or abstract itself from life-giving natural processes.

This is not to say that all sustainable settlements in the 21st century need to be Arcadian, agrarian outposts; no, what is being proposed here is the optimum, systemic *scale* around which to begin conceiving and designing for sustainability. Eventually, coinciding with the exhaustion of fossil fuel reserves, over-sized population centers will need to be scaled down significantly as human population realigns itself with global carrying capacity at the local level. Actual population may need to be reduced by half or more. In the interim, large population aggregates can begin now preparing for this downsizing by radically decentralizing and consciously retrofitting into distinct, self-contained, village-scale subunits – urban villages – with well-defined centers and well-defined boundaries, organically, like cells in a tissue or organs in a body. In this way, they can begin "preparing for a prosperous way down."

This is where the emerging concept of the 'ecovillage' becomes so valuable and conceptually useful. The ecovillage is being conceived as a synthesization of all the redeemable qualities and characteristics of 20th century civilization with the organic social cohesion and organization of traditional tribal cultures. The ecovillage accepts widely yet discriminately employed appropriate technologies but couples them to human-scale socio-cultural and ecological systems. The ecovillage is becoming the testing ground for new models of full-featured, ecologically-integrated, life-enhancing sustainable living in community. For these reasons, the ecovillage will prove to be the quintessential model for sustainable human settlement in a theoretical ekistics for the 21st century – and beyond!

As a self-contained, self-reliant, self-regenerating, self-referencing, self-organizing organic *living system*, the ideal ecovillage contains exciting possibilities for analyzing and evaluating its energy transformations. This ideal ecovillage may very well be the most constructive and instructive human habitation system around which to enclose an environmental window and conduct a meaningful, serviceable EMERGY analysis. Using EMERGY concepts and principles in its design, and drawing up detailed and ongoing EMERGY systems diagrams to measure its success, the ideal ecovillage may take charge of its available energetic realities and efficiently fine-tune its energy transformations with the goal of consciously maximizing EMPOWER, and thus real wealth and prosperity, for the benefit of all.

Here is an example of an EMERGY systems diagram for an idealized ecovillage:



Once again, the settlement is integrated into an ecosystem, but the context now has been expanded to include the whole Gaian system. Wherever there are energy storages, mutually-supportive feedback loops are in place to maintain and enhance stocks. Diverse renewable sources are used directly in the human economy, and, though functionally self-contained, this economy encourages a variety of exchanges with other economic entities. A new stock called “spiritual storage” has been added, and it can be seen that the global economy, with its continued reliance on non-renewable fuel sources, is actually producing entropy where this realm is delineated. Perhaps humanity will one day reach a level where even the whole Gaian system will be energetically perceived as being contained within a still larger, whole *solar* system?

Design Criteria

We have finally arrived at the proposed purpose of this paper: outlining the design criteria for sustainable human settlements based on energetic considerations. These criteria are intended to serve as a guide for settlement designers and planners interested in creating truly sustainable systems. It is important to state explicitly at the outset the design criteria in any design scenario, so that the outcome of the finished product can be gauged against the intended results. The following criteria, then, describe those energetic dimensions that must be designed into human habitation systems if they may have the chance to be continued into the indefinite future. The discussions in the previous sections were designed to lead the reader into regarding the following criteria as acceptable, unequivocal, even matter-of-fact. If optimal use of available energy is the defining essential quality of any sustainable settlement, then the following design criteria outline the required parameters – the patterns, processes, and structures – that must be considered in order to achieve the desired results.

As the paper unfolded, first came an overview of EMERGY concepts and principles. It was demonstrated that the EMERGY environmental accounting technique is the most effective way to evaluate whether a given human-managed system is making the most optimal use of available energy. This is because an EMERGY analysis takes into account both the energetic inputs of environmental systems and those of human systems and synthesizes them into a common denominator – the "emjoule." Real value can then be determined by converting these quantities into "emdollars." A sustainable human settlement will place great emphasis on maximizing EMERGY – real wealth – and this wealth can be objectively measured and calculated – and compared. In the competition among sustainable and unsustainable settlements, those that maximize EMPOWER will prevail.[15]

Then came an overview of 'sustainability.' It was proposed that a sustainable human settlement is one that is biogeographically, structurally coupled to a particular ecosystem – a specific, living, place-based ecology. This is necessary so that the socio-economic process of the settlement – the dynamic interface between its socio-cultural systems and the co-evolving local ecology – is able to efficiently utilize and conserve

[15] This will become increasingly apparent as fossil-fuel stocks dwindle. The powers-that-be will attempt to translate and convert energetic necessities into other highly centralized and controllable energy sources – nuclear fission or fusion – but this will amount to an overt act of geocide (See Lovins, 1977). It is far more sustainable to rely on the EMERGY sources freely provided by Nature, especially the already-existing fusion reactor, our Sun.

both its natural and social capital. Settlements that exploit either of these to the point of exhaustion will not be able to be continued into the indefinite future.

Finally, it was important to look more closely at the term 'settlement.' It was demonstrated that the most optimal scale around which to begin organizing for sustainability – the scale that is most organically integrated into its associated ecosystem; the scale that can most readily preserve a salubrious, intact, human-scale socio-cultural system; the scale that can most efficiently utilize and manage available environmental energetic inputs and the feedback loops generated from human energetic inputs – is the *village scale.* It was further proposed that the emerging concept of the 'ecovillage' is the ideal context in which to begin envisioning and designing sustainable human settlements in the days to come. In this way, the ecovillage may become the operational 'unit' of sustainable human settlement in an ekistic analysis for the 21st century.

With these initial considerations thus stated, what then are the more specific energetic design criteria for the proposed ideal ecovillage and how can an EMERGY evaluation facilitate conceptualizing the required parameters?

To begin this level of understanding, let us refer back to Professor Odum, the source in these matters, and examine an important fundamental principle of long-term viable, self-organizing systems: Autocatalytic Storage and Maximum Empower (pp.19-20). This is essential: "Energy systems networks contain energy storages autocatalytically coupled to energy transformation processes…The term *autocatalytic* refers to the differential equation for the storage where the term for production is a product of the input source and the feedback from storage…As suggested by Lotka…as the fourth law of thermodynamics, autocatalytic feedback designs develop because they maximize power. Designs that process more useful energy will prevail in competition with alternate designs because more available energy provides contingency needs and better adaptation to surrounding conditions."

That's it in a nutshell; that's the place to start. A sustainable self-organizing ecovillage will manage and promote its energetic resources according to this fundamental autocatalytic principle, the suggested fourth law of thermodynamics. This principle is illustrated graphically in the following systems diagram (p.20):

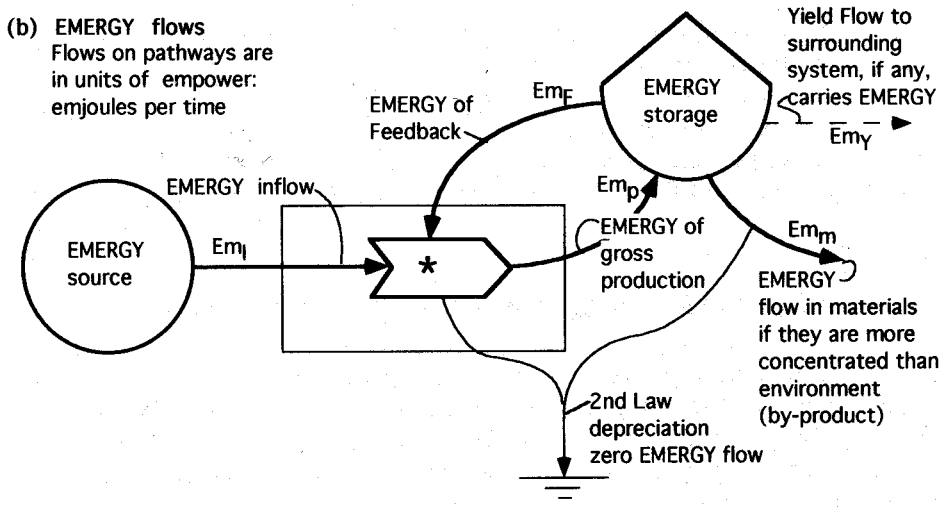


Figure 2.3. Systems diagram of the autocatalytic coupling of storage to energy transformation processes.

This fundamental principle can be reiterated more succinctly with the following maxims (pp. 20-21):

1) Self-organizing systems develop autocatalytic storages to maximize useful power transformities. (Maximizing power use also maximizes the rate of dissipation of available energy and the rate of entropy production.)
2) Self-organizing systems disperse energy faster, maximizing the rate of entropy production by developing autocatalytic dissipative structures. (Maximizing dissipation also maximizes useful power transformations.)[16]

`

These maxims make it clear that a sustainable human settlement – ideally a self-organizing living system – will not impose undue artificial restrictions on energy use and consumption. As Odum describes it, "Whereas energy conservation in the sense of increasing efficiency of use has a net benefit, an economy that conserves, in the sense of restricting fuel use, tends to reduce its net EMERGY and thus its ability to compete economically" (p.16). It could be said that maximizing EMERGY throughput correlates directly with a high quality life full of diverse and multifarious opportunities. A

[16] Note: "dissipative structure" is a defining characteristic of all living systems (as first articulated by Prigogine and Stengers, 1984). Dissipative structures ingest and metabolize high-quality energy from the environment and expel degraded entropic byproducts. In the process, they are able to sustain themselves in highly energetic, dynamic conditions far from equilibrium, a necessary quality for life. Of course, these dissipative structures require a continual supply of high-quality energy from the environment to maintain their dynamic, far from equilibrium conditions, and in biological systems this energy *originates* exclusively from the Sun.

sustainable strategy, then, is not to unnecessarily, penuriously limit EMERGY production, as if by some moralistic imperative, for this could lead to cultural degeneration and stagnation; but rather to vigorously promote maximum EMERGY flow for maximum wealth production, so prosperity can be enjoyed by everyone. Maximum EMERGY flow means greater and more diverse energy transformations, richer storages, multi-various feedback loops, and a higher quality of life with increased abundance for all living systems. In a post-fossil-fuel world, maximizing EMERGY production will be largely an *ecological design challenge*, employing the resources of creativity, understanding, ingenuity and resourcefulness. Applied ecological engineering certainly will become a burgeoning field of activity.

If we insert 'ecovillage' into the environmental window displayed in the autocatalytic diagram above, we can begin articulating more specific energetic design criteria for a sustainable human settlement:

1) Diversify and maximize EMERGY *sources.* Since these inescapably originate with locally occurring environmental sources, this means a thorough evaluation and inventory of endemic environmental energetic inputs, depending in character on the qualities of the particular ecosystem to which the ecovillage is coupled, and including in various proportions: sun, wind, rain, tides, geothermal, hydro, etc. In whatever capacity these sources are available, each needs to be exploited and maximized to its fullest extent, in all design considerations. These are 'free' and renewable sources and so amount to a virtually inexhaustible supply of potential energy. This design criterion for maximizing the productive use of diversified environmental sources can be applied at any scale within the ecovillage, in both active and passive design: from the whole settlement to clusters within the settlement to individual buildings and rooms within buildings, as well as within each energetic transformation level of the economic process.
2) Diversify and maximize EMERGY *storages.* Applying the concept of transformities, these storages can take on a multitude of forms. For a partial listing: Net Primary Production (the amount of carbon sequestered in an ecosystem from atmospheric carbon dioxide); biomass and biomass fuels (methane and alcohol); species and thus genetic diversity; productive soils; water storages of all kinds such as wetlands, dams, and ponds; tools and tool-making technologies; stored and recycled heat; electric potential stored in batteries; useful information, knowledge, and memory in all their forms; long-standing vernacular cultural traditions specific to that place; goodwill and good deeds; etc. – in sum, *diversify and maximize the storages of natural, social, cultural, and spiritual capital.* These storages need to be conserved and

enhanced wherever possible entirely within the circumscribed boundaries of the ecovillage; they are the real wealth of the community. Unsustainable settlements have the characteristic of unwisely exploiting and exhausting their EMERGY storages for short-term financial gain; thus they fritter away their capacity for maximizing EMPOWER and true prosperity.

3) Given a flow of maximized, diversified EMERGY sources and given a supply of maximized, diversified EMERGY storages, maximum creativity can then be employed *to productively channel and direct the storages into positive, reinforcing feedback loops to qualitatively amplify and enhance the productivity of the initial EMERGY inputs,* at each stage of energy transformation. This takes settlement design to a whole new level and this is the magic of autocatalytic design: the applications are virtually inexhaustible. A simple example is the use of compost, where crop residues are fed back into the soil from whence they came to enhance agricultural productivity. Another common example is when profits from a business are fed back into its infrastructure to make the business more profitable. Recycling in all its forms is an application of this principle.

"Permaculture" is an ecological design strategy full of practical examples of autocatalytic design. Take a dwelling in a temperate climate that is to be heated by passive solar. The amount of solar insolation falling on the dwelling is fairly constant but through good design this steady rate can be amplified and multiplied. First, situate the dwelling with the long axis running east-west so there is more surface area facing the Sun. Then place a glasshouse on the sun-side to serve as a storage of warm air. Further, place dark-colored barrels full of water in the glasshouse to serve as more heat storage. Place a pond in front of the glasshouse to increase solar gain with its reflection. Inside the dwelling, use dark-colored building materials with dense mass as walls in locations where the Sun can shine directly on them. Then, plant a semi-circle or U-shape of tall evergreen trees around the dwelling, open end facing the Sun, to create a favorable microclimate for further trapping and storing heat, and deflecting cold, polar winds. Each of these design applications uses storages as positive feedback to amplify and multiply the source – the heating effect of the initial solar insolation. Combined, they can produce a comfortable dwelling in cold weather without the need for heating fuels.

These are just a few examples to demonstrate the autocatalytic principle in action. In an actual village design scenario, there will be a multitude of site and situation specifics that can be given the same kind of thoughtful scrutiny. Many of these considerations can be applied at actual settlement scale.

4) Within the autocatalytic designs, actively promote complex network configurations with maximum interconnecting, mutually-productive inter-relationships. These relationships can support one another in their amplification functions and can serve as: a) a string of multipliers when arranged in series; or b) as a multi-pronged power-block when constructed in parallel. This principle can be paraphrased with the permaculture design aphorism, "Each function is supported by many elements, and each element has many functions." An example of this principle applied in an ecovillage design setting, with the intended result of supplying high quality food energy, would be the cultivation of a wide diversity of crop types instead of a simple monoculture. Another example would be the rotation of tasks and responsibilities within the ecovillage so that many people can become familiar with them, instead of having individuals toiling at the same task their whole lives. Still another would be the powering of the community-center building: In Summer it could be powered by solar; in Winter it could be powered by hydro; at the Equinoxes it could be powered by wind. These same sources could be strung together in series to power a high-energy need such as light industry. This principle can further include (perhaps can even be restated as) the deliberate establishment of open, multi-purpose, mutually-productive, interconnecting communication networks, of all kinds.

These four principles of autocatalytic design serve as strong foundations for sustainable energetic design criteria. Everything that follows is derived as extensions of these fundamental design principles.

Once again quoting the source, "Prevailing systems are those whose designs maximize EMPOWER by reinforcing resource intake at the *optimum* efficiency [added emphasis]…This statement includes the maximizing of the resource intake *and* the operation at the optimum efficiency for maximum power…In other words, both *intake* and its best *use* are maximized" (p.26). This principle highlights the blatant absurdity of using a nuclear reactor to run a toaster, for example. As a general rule, whenever there are two grades of energy available, the higher-quality source "is only useful if it interacts with and amplifies a lower-quality, high-quantity energy source" (p.26). Amory Lovins and the Rocky Mountain Institute have done some incredible work along these 'optimum efficiency' lines; as such, I highly recommend the book *Natural Capitalism* (Lovins, Lovins, and Hawken, 1999), which gives detailed accounts of the application of this principle in real-life settings and demonstrates the enormous savings that are possible, in both energy use and monetary expenses, when designing with this principle in mind.

There is a palpable distinction between 'optimum efficiency' and 'maximum efficiency:' "[Living] systems perform at an optimum efficiency for maximum power output, which is always less than maximum efficiency. In fact, it will be found that in order to operate at maximum power, the efficiency may never exceed 50% of the ideal 'reversible' efficiency" (Odum in Wiegert, 1976). In these calculations, Power Output/ Power Input = Efficiency.

This concept made a big impression on me. Originally, I believed that a design criterion for an ecovillage would be to maximize biomass, in effect to vigorously accelerate to a mature state of ecosystem succession, so as to maximize stores of carbon, oxygen and photosynthetic production entirely within the ecovillage. A mature state of succession would seem to correlate with a condition of maximum efficiency. Now, however, I believe that the most desirable situation, at least within the ecovillage boundaries *per se,* is to keep biomass storage somewhere around 50% of maximum. This is the optimum range that produces maximum power. Maximum power – energy flow per unit time – is achieved here by having optimally available nutrients, water, and minerals for dynamic spurt-of-growth potential and by having optimum open canopy for productively usable solar insolation. A professor I know and respect likes to point out that the opposite of efficiency is *spontaneity* – maximum efficiency leaves no room for spontaneity or adaptability. In an old growth forest there are no new species being spontaneously generated. And so, as a design criterion for *self-organizing systems*, we design for *optimum efficiency,* 50%, and leave room for plenty of spontaneity and adaptability. Machines (such as cities) are usually designed for maximum efficiency.

Another energetic dimension that will need real close attention in a sustainable village situation is that of the already-mentioned, all important concept of 'transformity.' Transformity, as you may recall, is the quotient of a product's EMERGY divided by its energy. "The more energy transformations there are contributing to a product, the higher is the transformity. This is because at each transformation, available energy is used up to produce a smaller amount of energy of another form. Thus, the EMERGY increases but the energy decreases…" (p.10) – and maximizing EMERGY is what it's all about! The higher the transformity, the higher the energetic investment and level of refinement. Higher emdollar values go with higher transformities. Thus, "High transformity energy should not be used for low-quality purposes, because it wastes energy" (p.148). A vivid example of this would be using pages from the *Iliad* to light a campfire. With this principle in mind, it makes energetic sense to concentrate and conserve high transformities within the ecovillage.

Odum (p.45) makes some calculations at the global scale that reveal just how immense is the value of the preservation of high transformities. World infrastructure is calculated to have a stored EMERGY content of 9.44 x E26 sej with an emdollar value of

$6.3 x E14 Em$ and a replacement time of 100 years. Genetic information, in contrast, has a stored EMERGY content of 2.8 x *E34* sej with an emdollar value of $1.86 x *E22* Em$ and a replacement time of 3 x *E9* years. Genetic information, then, has a real net value some *eight orders of magnitude greater* than infrastructure. These figures expose the total ineptitude of using market-based choices to quantify value. With a market-based value-system, macroeconomists can actually seriously justify the ongoing trade-off of Amazonian biodiversity for cheap hamburger prices, even though replacing that lost genetic information will take some *300 million years!* Transformity considerations also make clear another unsustainable energy exchange: the value lost by trading raw timber for dollars when there is so much more stored EMERGY value in the healthy, living forest than in the momentary cash received for its liquidation. Back at settlement scale, the ecovillage should never trade its raw, unrefined natural resources for cash, but should only trade with the higher transformity of value-added products, as calculated in emdollars.

Since I've been in the mode of pondering sustainable settlement design within the context of energetic parameters for some time now, I think I could go on and on citing specific design criteria – this is an inquiry fecund with possibilities! However, giving some quick evaluation of the EMERGY value *of this essay,* and this Independent Study, leads me to some thoughtful restraint. The stored EMERGY potential of 3-credits in my degree-account is theoretically translated into so many hours of energetic input flow – reading, researching, writing, etc. Since the EMERGY value of the time I have invested in these activities, in comparison with possible alternate activities, now greatly exceeds the stored EMERGY potential of 3-credits, I must make an educated EMERGY value-judgment and begin bringing this paper to a close. I hope the essential points have been conveyed. It may be fruitful to revisit this line of reasoning at some future time, when EMPOWER can once again be maximized;[17] but before wrapping up, let me briefly cite a few more unexpressed energetic design criteria for this ideal ecovillage:

1) Maximize 'edge,' or the actual physical length and surface area of productive interface between the ecovillage and its encompassing ecosystem, featuring polytudinal crenellated patterns instead of more regular polygonal shapes.

[17] This may have indeed occurred. During the late Spring of 2011, I revisited this paper to edit and reformat for posting on my website. Concurrently, I was attending a series of classes exploring Holmgren's *Principles and Pathways beyond Sustainability*, a book that references H.T. Odum as an influential source. The editing and reformatting is being finished in time to share this paper with the class, thus introducing another application of the basic ideas. Since many in the class are associated with the new Transition Town initiative, adapting EMERGY principles to sustainable settlements seems especially pertinent. In that sense, EMPOWER – EMERGY flow per unit time – is once again being maximized at this time juncture.

Increased edge is equated with increased information; increased information is equated with increased energy potential. Resources gather at the edge. The ecotone is the point of maximum species diversity. Infrastructure within the ecovillage should also maximize topographical edge and spatial differentiation, including a hierarchical order of clustering (clusters within clusters within clusters…).

2) Emphasize non-equilibrium, which is the same as saying *design for evolution*. 'Physics-ally' speaking, equilibrium can be equated with death. Sustainable systems are *not* stable systems, in the sense of conservatively resisting change and persevering in established forms, but are rather highly energized systems operating at dynamic conditions far from equilibrium. At first, this may appear paradoxical, but look at the biological record: stable systems are unable to adapt to fluctuations in the environment, and so perish. Non-equilibrium is a pre-condition for maximizing EMPOWER, and for providing a fertile context for the appearance of novel emergent properties – including the expansion of consciousness. While emphasizing non-equilibrium, *orderliness* should by all means be practiced and maintained, for it is out of conditions of order that new life spontaneously generates itself.
3) Design *four-dimensionally*. A sustainable village is not a static 'thing' but rather a living, evolving *process,* continually shape-shifting through time in adaptive response to feedback signals from the environment. Change is the one unchanging expectancy! Generic cities of the 20th century are utterly unsustainable, among other reasons, because they were built as static, rigid, mostly concrete and steel structures, as if they were to exist in their pre-planned constructed forms in perpetuity. A sustainable village in the 21st century will be in a continual process of *becoming*, forever co-evolving with the greater Life of which it is a part, existing as a self-organizing, self-maintaining, self-regulating, self-regenerating, self-referencing, *organic living system* – with all that implies.

Epilogue

Energy. This word sure gets used a lot: “I like your *energy.*” “The *energy* in the room sure felt weird.” “I’m feeling low *energy* today.” Yet, No one ever told me they like my *EMERGY!*

There is a friend of mine, a student younger than myself who asked me to be an advisor in his degree process. He actively practices Qi Gong and wanted to integrate this practice with sustainable agriculture as the basis of his degree. In his writings he would say things like, “I learned to perceive energy at an early age.” Commenting on his writing, I would urge him to describe more clearly just what he meant by *energy,* but despite some physics background, he was never forthcoming in articulating his meaning.

I have been attending some Vipassana meditation courses. At a certain stage in the work, the instructor (on video) expresses, “You may start to feel a free flow of subtle vibrations.” I have yet to experience these subtle vibrations but what I think he is alluding to is the sensation of feeling one’s body *as a flow of energy.*

As the quantum physicists searched ever deeper for the one fundamental particle that they could call the basic ‘building block’ of the Universe, what they discovered instead was that there are no particles at all! At the quantum level, matter itself is made entirely of pulsing ‘probabilities’ of dynamic energy potential.

Energy is fundamental, primordial, basic, elementary. The entire Universe is a manifestation of various levels of energy transformation. That’s why I stated in the introduction to this paper that, “a study of “energetics” is precursory to in-depth understanding in any field of inquiry.” If one’s chosen field of inquiry is an exploration of sustainable human settlements, then a thorough study of energetic principles applied to settlements is absolutely indispensable.

In this paper, I have only begun to explore the possibilities. The implications are enormous, and in these strange, wild days – when control and domination over dwindling fossil-fuel energy reserves has become tantamount to unimaginable, overt violence – I would say concomitant with self-preservation.

This, I believe, is where the sincere study of fundamental energy principles can have their most rewarding and practical return – not at the global scale or even at the settlement scale – but at the individual human scale. Since undertaking this study, I have begun to perceive my life from a whole new perspective – an *energetic* perspective

(what else?). Up till now, I have lived my life in a rather happy-go-lucky way, just believing on faith that the resources I need will be there when I need them. This has worked fairly well in my own self-contained reality, but if an ecovillage managed their affairs in this way, some people might go hungry.

Now I look at my life in a fresh new context: throughout my given span of years, I will have available to me only a certain limited amount of energetic resources to work with; that's an energetic reality: a star has a real physical limit as to how much hydrogen it can fuse into helium. To realize my dreams, my goals, my hidden latent potential as an inquiring child of the Universe, it is up to me to optimize my efficiency so as to maximize my power – my energy flow per unit time – with the purpose of realizing maximum wealth and prosperity in those things that matter most, for the benefit of all. Anything less than that would be a missed opportunity.

From this perspective, it would be revealingly useful for me to conduct an EMERGY analysis of my own lifestyle. Am I diversifying and maximizing my EMERGY sources? Am I diversifying and maximizing my EMERGY storages? Do I have autocatalytic design mechanisms in place to amplify and enhance the initial inputs? Have I incorporated sufficient networking arrangements to qualitatively multiply the connections and communications among the autocatalytic feedbacks? Where in my lifestyle are any energetic leakages, wastefully shunting available energy potential into ground? And most importantly, what steps can I take to maximize EMERGY flow in my life so as to maximize personal EMPOWER, my ability to actualize *real* wealth and abundance, true "sustainable prosperity?"[18]

A resolute, sober study of energy principles – as inflow to a storage of previous knowledge – can have transforming, life-changing results.

To close, I would like to re-express the sentiments of Howard T. Odum as he closed his perspicacious work, the culmination of a lifetime of high-energy thinking, *Environmental Accounting: EMERGY and Environmental Decision Making*:

Prosperous Way Down

"The world's rate of fuel consumption has apparently reached its maximum, and the renewable resources available are decreasing each year due to population increase and environmental encroachment. On an EMERGY basis the world's standard of living is already coming down. Already there are erratic contractions, arbitrary downsizings, and population-resource disasters. Much uncertainty and malaise can be avoided if EMERGY

[18] This evocative phrase is taken from Dr. Linda Leigh's creation: "The Center for Sustainable Prosperity." Dr. Leigh studied with Professor Odum, was awarded her Ph.D. through him, and later went on to become one of the scientists to enter the Biosphere II project. Dr. Leigh was also the assessor for this original paper.

evaluations can be substituted for economic evaluation. If people can regain their commonsense view of real wealth, which EMERGY evaluation gives them, policies can be implemented for selective, slow, and deliberate, and prosperous descent. However that is for another book" (p.287).

Bibliography

1) Abrams, Elliot M. (1994) *How the Maya Built Their World: Energetics and Ancient Architecture,* University of Texas Press; Austin
2) Carter, Vernon Gill and Tom Dale (1977) *Topsoil and Civilization,* University of Oklahoma Press; Norman
3) Choguill, Charles L., John Kissin and Richard H. Seyfarth (1972) *Ecological-Economic Analysis for Regional Development,* The Free University Press; New York
4) Common, Michael (1996) *Environmental and Resource Economics: An Introduction,* Addison Wesley Longman Limited; Harlow, Essex, England
5) Contractor, Noshir S. (1994) Self-Organizing Systems Perspective in the Study of Organizational Communication, Ch. 2 in *New Approaches to Organizational Communication,* edited by Branislav Kovacic, State University of New York Press; Albany
6) Daily, Gretchen C. (1997) *Nature's Services: Societal Dependence on Natural Ecosystems,* Island Press; Washington, D.C.
7) Doxiadis, C.A. (1968) *Ekistics: An Introduction to the Science of Human Settlements,* Oxford University Press; New York
8) Doxiadis, C.A. (1977) *Ecology and Ekistics,* Westview Press; Boulder, Colorado
9) Earle, Carville, Kent Mathewson and Martin S. Kenzer (1996) *Concepts in Human Geography,* Rowman & Littlefield Publishers, Inc.; Lanham, Maryland
10) Fluck, Richard C. and C. Direlle Baird (1980) *Agricultural Energetics,* AVI Publishing Company, Inc.; Westport, Connecticut
11) Forman Richard T. and Michael Godron (1986) *Landscape Ecology,* John Wiley & Sons; New York
12) Goldsmith, Edward (1992/1998) *The Way: An Ecological World-View.* The University of Georgia Press; Athens
13) Glaser, Roland (2001) *Biophysics,* Springer-Verlag; Berlin

14) Goodwin, Richard M. (1990) *Chaotic Economic Dynamics,* Clarendon Press; Oxford, U.K.
15) Gregory, Derek and Rex Walford, editors (1989) *Horizons in Human Geography,* Barnes and Noble Books; Totowa, New Jersey
16) Hawken, Paul and Amory and L. Hunter Lovins, (1999) *Natural Capitalism: Creating the Next Industrial Revolution,* Little, Brown and Company; Boston
17) Herbert, David T. and Colin J. Thomas (1990) *Cities in Space, City as Place,* Barnes & Noble; Savage, Maryland
18) Hudson, F.S. (1970) *A Geography of Settlements,* MacDonald & Evans, Ltd.; London
19) Jantsch, Erich and Conrad H. Waddington (1976) *Evolution and Consciousness: Human Systems in Transition,* Addison-Wesley Publishing Company; Reading, Massachusetts
20) Jantsch, Erich (1980) *The Self-Organizing Universe: Scientific and Human Implications of the Emerging Paradigm of Evolution,* Pergamon Press; Oxford, England
21) Jeffers. John N.R. (1978) *An Introduction to System's Analysis: With Ecological Applications,* University Park Press; London
22) Kim, Ke Chung and Robert D, Weaver (1994) *Biodiversity and Landscapes: A Paradox of Humanity,* Cambridge University Press; U.K.
23) Kitching, R.L. (1983) *Systems Ecology: An Introduction to Ecological Modeling,* University of Queensland Press; St. Lucia, Queensland, Australia
24) Kooijman, S.A.L.M. (1993) *Dynamic Energy Budgets in Biological Systems,* Cambridge University Press; U.K.
25) Krishnan, Rajaram, Jonathan M. Harris and Neva R. Goodwin (1995) *A Survey of Ecological Economics,* Island Press; Washington, D.C.
26) Lovins, Amory (1977) *Soft Energy Paths: Toward a Durable Peace,* Harper Colophon Books; New York
27) Mare, E.C. (1997) *A Pattern Language for Ecovillages,* unpublished
28) Meadows, Donella H., Dennis L. Meadows and Jorgen Randers (1992) *Beyond the Limits: Confronting Global Collapse: Envisioning a Sustainable Future,* Chelsea Green Publishing Company; White River Junction, Vermont
29) Millen, D.J. (1969) *Chemical Energetics and the Curriculum,* American Elsevier Publishing Company, Inc.; New York
30) Miller, David H. (1981) *Energy at the Surface of the Earth: An Introduction to the Energetics of Ecosystems,* Academic Press; New York
31) Ni, Maoshing (1995) *The Yellow Emperor's Classic of Medicine,* Shambhala; Boston, Massachusetts
32) Odum, Eugene (1959) *Fundamentals of Ecology,* W.B. Saunders Company; Philadelphia
33) Odum, Eugene (1997) *Ecology: A Bridge Between Science and Society,* Sinauer Associates, Inc.; Sunderland, Massachusetts
34) Odum, Howard T. (1971) *Environment, Power, and Society,* John Wiley & Sons, Inc.; New York
35) Odum, Howard T. and Elisabeth Odum (1976) *Energy Basis for Man and Nature,* McGraw-Hill Book Company; New York

36) Odum, Howard T. (1983) *Systems Ecology: An Introduction,* John Wiley & Sons, Inc.; New York
37) Odum, Howard T. (1992) *Simulating Ecological Economic Parameters,* International Society for the Systems Sciences, Proceedings of the 36th Annual Meeting; Denver, Colorado, July 12-17
38) Odum, Howard T. (1996) *Environmental Accounting: EMergy and Environmental Decision Making,* John Wiley & Sons, Inc.; New York
39) Prigogine, Ilya and Isabelle Stengers (1984) *Order Out of Chaos: Man's New Dialogue With Nature,* Bantam Books; New York
40) Redclift, Michael (2002) Pathways to Sustainability? *Geography,* Volume 87(3), pp.189-196
41) Roughgarden, Jonathan (1998) *Primer of Ecological Theory,* Prentice Hall; Upper Saddle River, New Jersey
42) Sale, Kirkpatrick (1980) *Human Scale,* Coward, McCann & Geoghegen; New York
43) Sargent II, Frederick, editor (1974) *Human Ecology,* North-Holland Publishing Company; Amsterdam
44) Saxena, Surendra K. and Somdev Bhattacharji (1977) *Energetics of Geological Processes,* Springer-Verlag; New York
45) Schmookler, Andrew Bard (1984) *The Parable of the Tribes: The Problem of Power in Social Evolution,* University of California Press; Berkeley
46) Schumacher, E.F. (1973) *Small is Beautiful.* Perennial Library; New York
47) Scienceman, D.M. (1987) Energy and EMERGY, pp.257-276 in *Environmental Economics,* editd by G. Pillet and T. Murota, Roland Leimgruber; Geneva
48) Short, Professor John Rennie (1992) *Human Settlement,* Oxford University Press; New York
49) Smil, Vaclav (1991) *General Energetics: Energy in the Biosphere and Civilization,* John Wiley & Sons; New York
50) Tuan, Yi-Fu (1974) *Topophilia: A Study of Environmental Perception, Attitudes, and Values,* Prentice-Hall, Inc.; Englewood Cliffs, New Jersey
51) Van der Ryn, Sim and Stuart Cowan (1996) *Ecological Design,* Island Press; Washington, D.C.
52) Van Kooten, G. Cornelius and Erwin H. Bulte (2000) *The Economics of Nature: Managing Biological Assets,* Blackwell Publishers; Malden, Massachusetts
53) Van Mieghem, Jacques (1973) *Atmospheric Energetics,* Clarendon Press; Oxford, U.K.
54) Wackernagel, M. and B. Rees (1996) *Our Ecological Footprint,* New Society Publishers; Gabriola Island, B.C.
55) Waddington, C.H. (1978) *The Man-Made Future,* St. Martin's Press; New York
56) Watt, Kenneth E.F. (1966) *Systems Analysis in Ecology,* Academic Press; New York
57) Whitehouse, Ruth (1977) *The First Cities,* Phaidon Press; E.P. Dutton; New York
58) Wiegert, Richard G. (1976) *Ecological Energetics,* Benchmark Papers in Ecology, Dowden, Hutchinson, & Ross, Inc.; Stroudsberg, Pennsylvania

59) Yates, F. Eugene (1993) Self-Organizing Systems, Ch. 9 in *The Logic of Life: The Challenge of Integrative Physiology*, edited by C.A.R. Boyd and D. Noble, Oxford University Press; United Kingdom

60) Zeleny, Milan (1980) *Autopoiesis, Dissipative Structures, and Spontaneous Social Orders,* AAAS Selected Symposium 55, Westview Press, Inc.; Boulder, Colorado