In Ortega, E. & Ulgiati, S. (editors): Proceedings of IV Biennial International Workshop "Advances in Energy Studies". Unicamp, Campinas, SP, Brazil. June 16-19, 2004. Pages 127-137

ECOLOGICAL ENGINEERING: INTERFACE ECOSYSTEMS AND ADAPTIVE SELF-ORGANIZATION

Mark T. Brown
Associate Professor; Department of Environmental Engineering Sciences
University of Florida; Email: mtb@ufl.edu

ABSTRACT

Restoring humanity's partnership with nature is essential if society is to transition to the coming lower energy age. In this paper, we describe general principles and fundamental concepts of ecological engineering for a lower energy future. *Self-organization* is the process by which the various parts (components) of systems become connected and interact so as to work together. Interactions of components that contribute to better use of available resources succeed because they are reinforced. Self-organization results in emergent properties of systems. Self-organization is rapidly adapting the environmental systems of the biosphere to our fuel-driven, high energy economy. The systems of atmosphere, oceans, and landscapes, including weather and global atmospheric circulation, ocean temperatures and global oceanic circulation, and the ecosystems of the landscape are self-organizing in rapid sequence to the accelerated growth of populations, fossil fuel use, and conversion of wild lands into developed lands. It is now more apparent than ever that our fuel culture cannot last forever. As it shrinks, *environmental fit* is likely to become society's next concern and humanity will need knowledge to refit society to renewable resources. New kinds of ecological systems and human dominated systems will be needed to fit human society to the environment of the future. New innovative combinations of plant and animal species will be needed to interface with the diversity of human technology.

1. ENVIRONMENTAL INTERFACES AND MANAGEMENT

In the past, with less energy at their command, humans controlled a small percentage of the environment. Humans relied directly on natural systems to provide clean air and water, and on relatively simple domestic ecosystems to supply food and fiber. Now, with rich supplies of energy at their command, humans control and manage enormous quantities of the world's emergy, affecting the whole biosphere. The empower[1] of human operations is now greater than the natural processes that maintain the stability of the air and ocean (Brown and Ulgiati, 1999). Concentrations of carbon dioxide are rising, other wastes are increasing, and the productive buffer of our natural systems is being displaced or degraded by developed lands. Everywhere human culture is becoming more and more dominant, displacing ecosystems and ultimately changing the driving energies of the biosphere. As a result, the biosphere's ecosystems must change which requires that human culture must change to fit in a never ending cycle of self-organization. The design and management of nature's self-organization is the field of *ecological engineering*, where the energies of human control are smaller than the environmental part of the interface.

Shown in Figure 1 is a diagram illustrating three ways in which our fuel subsidized society interfaces with the environment: (1) protected wild ecosystems used for watershed control, life support, and tourism; (2) extractive yield systems such as agriculture, forestry, mining, aquaculture, and fisheries that provide products to the economy; and (3) *interface ecosystems* that are self-organizing with society. All three of these are the realm of Ecological Engineering, albeit at very different scales. Taking

[1] Empower is emergy per unit time. Emergy is defined as the energy of one type that is required to make something (Odum, 1996)

each of these separately we will seek a rational and principles for their effective employment as strategies for the future that will foster a better fit between humanity and nature.

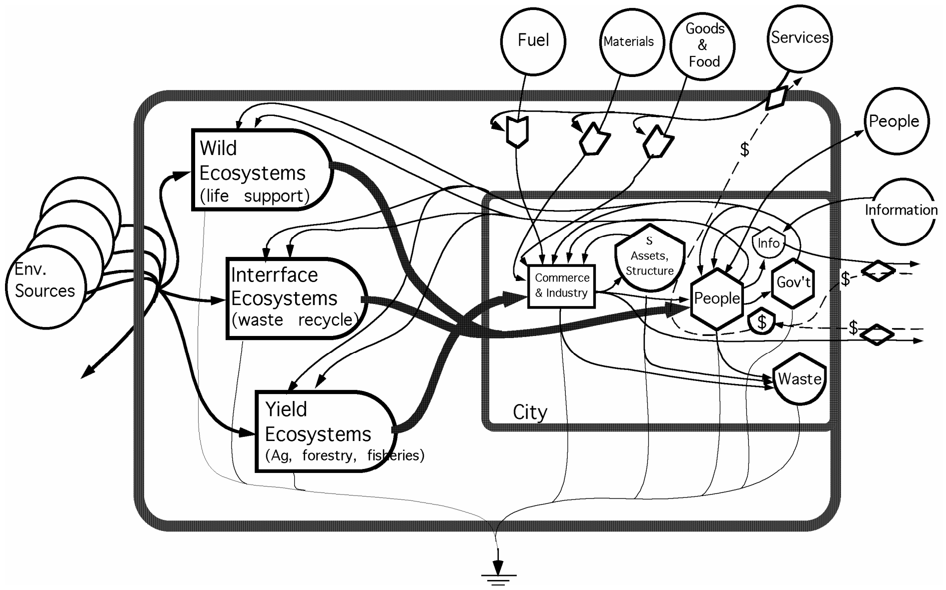

Figure 1. Diagram illustrating three realms of ecological engineering: a) wildlands and watershed protection, b) interface ecosystems for waste recycle, and c) extractive yield. Urban systems use directly the natural capital and environmental services from each realm. Often the feedbacks from the city to the environment are missing

2. PROTECTED WILD ECOSYSTEMS

As a result of the changing face of the biosphere, human society, now, more than ever needs wildlands protection (Brown and Vivas, 2004). There are several reasons for and ways to protect wild ecosystems…

2.1. Wildlands protection through watershed protection

Water will probably become limiting to human society before fossil fuels do. Already in many parts of the globe, there is grave concern over availability of freshwater. Inspired ecologically engineered development is necessary to minimize losses of recharge capacity and destructive runoff. Holistic approaches to planning and ecologically engineering landscapes to set aside wildlands for the protection of watersheds against incompatible uses is critical if dwindling water supplies are to be maintained and water quality is to be protected.

2.2. Wildlands protection through bio-reserves

It may be necessary and prudent to protect large areas of the biosphere as reserves, limiting human use and contact. These reserves are ecological refugia for genetic information that may be important in the future. Much needed is an understanding of the required size and spacing of bioreserves to insure viable gene pools for self-organizing landscape restoration. Landscape restoration can be greatly facilitated if seed sources are readily available. Our simulation models (Figure 2) of regions that incorporate bio-reserves as an integral part of the cycle of lands suggest that about 25% of land area need by protected to maximize economic yields (Odum and Brown, 1987).

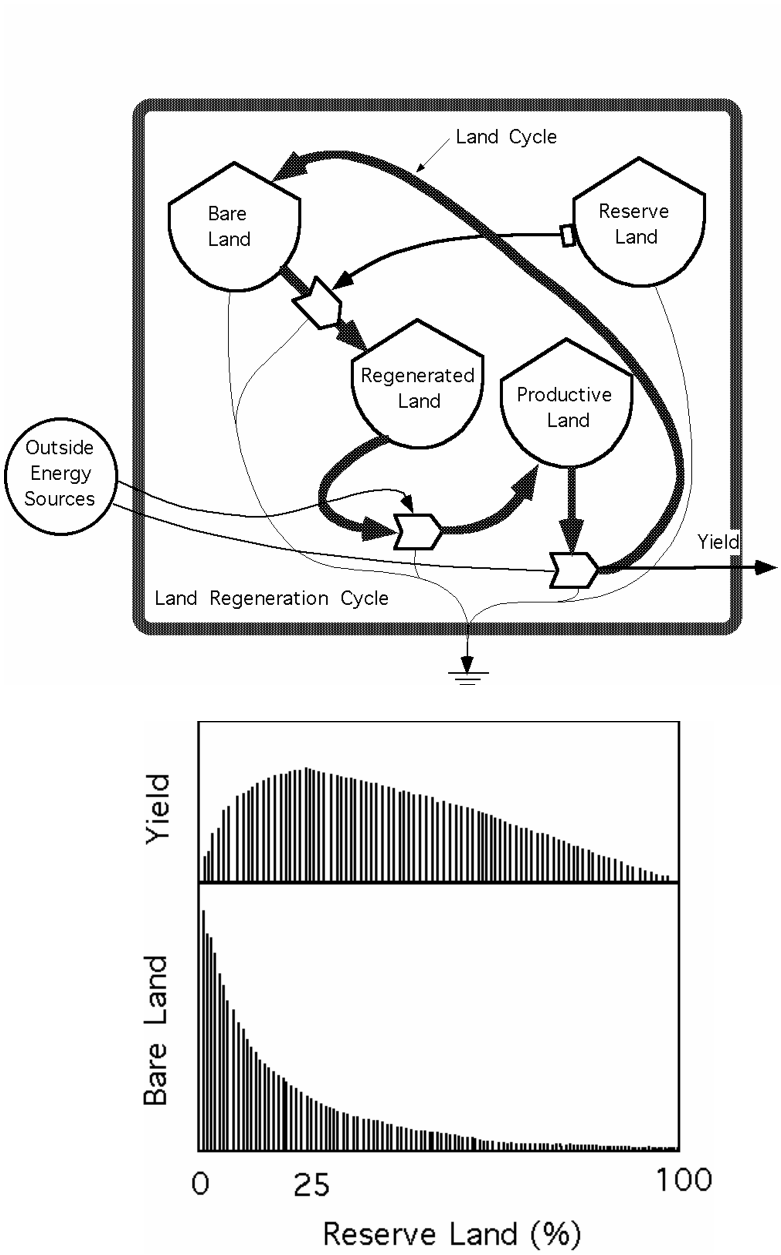

Figure 2. Model of landscapes that cycle land between economic uses to bare ground, to seeded and regenerated land to productive land indicates that approximately 25% of lands need be preserved as "bio-refugia" and seed sources for the regenerative cycle to maximize yield. Each vertical line in the graphs represents a simulation run of the model. The graphs show the yield that results from successive amounts of reserve land (top) and the amount of bare land remaining during each simulation run. Model was first published in Odum and Brown, 1986

2.3. Wildlands protection through Recreation and Ecotourism

Wild ecosystems are protected in parks, where impacts are minimized and often human management is greater than natural inputs of ordering energies. Figure 3 is a diagram of a tourist system that shows the relationship between people and environment during tourist activities. Park systems are driven by contributions of nature (through ecosystems), money contributed by tourists (dashed lines), and purchased inputs of fuels, electric power, goods, and services. Preservation of ecosystems for their tourism values may not be all that it is cracked up to be, however. As more and more tourists use the environment, a larger energy budget is required to maintain ecosystems in good health… rarely are there arrangements to reinforce the environment in exchange for the load placed on it. In addition, ecotourism can be a mixed blessing to local economies. The tourists represent a demand on local resources that cannot be used by local populations, essentially draining these resources from the local economy. Much of the money tourists spend is used to buy other inputs from outside the region and very little money makes its way into the hands of the local populations. Probably more important is the fact that tourists have negative impacts on the local economy. Their demand raises the local price of food, land, and other environmental products, which reduces local living standards.

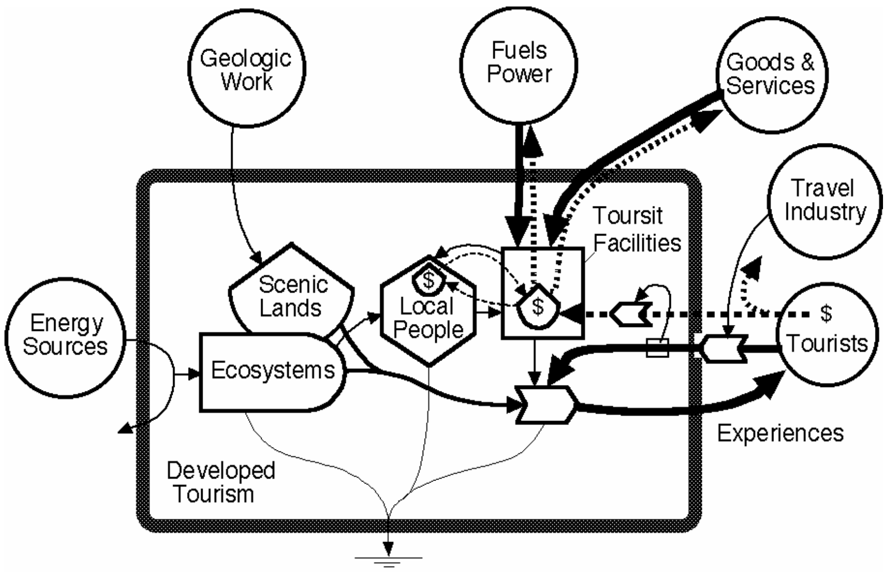

Figure 3. Diagram of a tourist system that shows the relationship between people and environment during tourist activities. Park systems are driven by contributions of nature (through ecosystems), money contributed by tourists (dashed lines), and purchased inputs of fuels, electric power, goods, and services

2.4. Wildlands protection for human life support

Our global metabolism is now out of balance caused by the increased use of fossil fuels and the increased destruction of earth's vegetative cover. With consumption of oxygen and organic matter greater than production the imbalance has caused a steady rise in carbon-dioxide in the atmosphere. More carbon-dioxide and related gases are increasing the atmosphere's greenhouse effect in storing atmospheric heat, increasing the temperature of the oceans, adding more vapor to the air, and causing stronger storms.

Simulation of global CO_2 models (Odum and Odum, 2001) suggests that if part of the earth's bare lands are revegetated and the consumption of fuels decreases 1% per year, we could reverse the current trend of increasing atmospheric carbon dioxide in about 30 years. Figure 4 shows a simplified macroscopic mini-model of the global CO_2 cycle and simulation results.

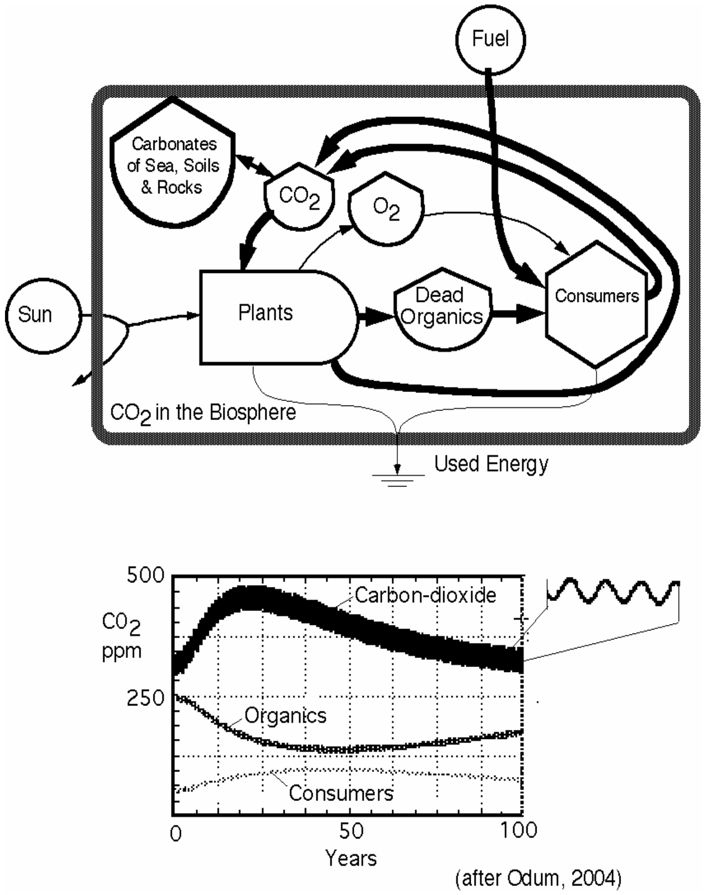

Figure 4. Macroscopic mini-model of global CO_2 showing the production of CO_2 by human society and the cycle where some CO_2 is sequestered in the bicarbonate cycle of the oceans and some in terrestrial forests. The model was simulated with increasing forested land and decreasing fossil fuel consumption by 1% per year. The current trend in increasing CO_2 concentrations is reversed in about 30 years. Model is after Odum and Odum ,2001

3. MANAGEMENT OF YIELD SYSTEMS

Humans plant simple *yield systems* (agriculture, forestry, aquaculture, etc.) and then apply enough control energy to prevent nature from reorganizing. In order to maintain a high net production humans subsidize yield systems and control natural tendencies toward increased diversity. The large yields require large subsidies…. more ecologically inspired agriculture relies less on fuel subsidies and more on diversity (multicropping and permaculture) and human labor. Yield systems that do not incorporate direct feedbacks to the environment will not be competitive in the future. Recycle of nutrient rich waters, solid waste recycle to lands, and more human services are examples of needed feedbacks.

4. MANAGING INTERFACE ECOSYSTEMS

Shown in Figure 5 is a much-simplified diagram of the interaction of the human economy with interface ecosystems. The work of ecological engineers is shown as the feedback of services and actions controlling the flows of genetic information. Through out millennia, genetic information to seed new situations has been supplied from the earth's pool of species… moved around the world primarily by earth processes… and in recent history, by people. Hand in hand, evolution controls species, the available species determine the nature of the ecosystems, and the ecosystems then control the next evolution of species. The present changing conditions associated with the pervasive activities of humans is causing adaptation of the earth's ecosystems to fit them. Ecological engineers can help in this transition by facilitating the movement of species to fill new situations.

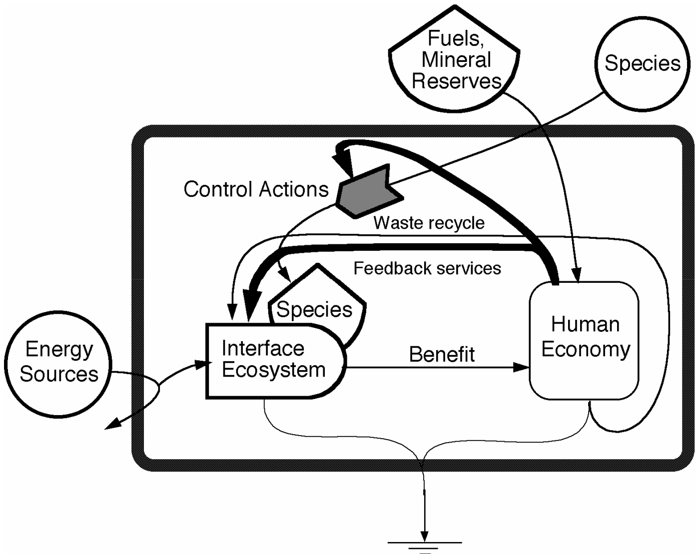

Figure 5. Diagram illustrating the place of ecological engineering in the overall system of humanity and nature. The human economy driven primarily by non-renewable inputs of fuels and mineral resources can influence interface ecosystems through controlled introductions of genetic information to foster adaptive self-organization, and through management services (dark flow lines). Interface ecosystems receive and recycle wastes to the biosphere providing a benefit to the human economy

Everywhere at the interface between our rich, fuel culture and the natural environment stand emerging eco-systems. These interface systems often look terrible, disrupted, patchy, stunted, and low in productivity. Left alone, nature, using available energy sources and whatever species are at hand, will eventually develop ecosystems adapted to the new conditions, a consequence of the maximum empower principle. On the other hand, ecological engineers can assist adaptive self-organization through their management inputs and facilitate the spread of genetic information that these new emerging environments require. Since humans have disturbed and displaced large areas of the environment in which conditions are much different, new species may be required to form new ecosystems associated with human society. Large scale multiple transplantation is needed now to develop new designs and new ecosystems. This kind of self-design will take place anyway, but over very long time scales… Ecological engineers can help by providing multiple-seeding tests in selected situations.

Interface ecosystems associated with the waste streams of our fuel culture are badly needed. Technological treatment solutions only create more pollution and are costly to build, operate and maintain. Ecological systems built as waste interface systems cost little or nothing to operate and are self-maintaining. The millions of species of plants, animals, and microorganisms are the raw materials of self-design and the palette of the ecological engineer for building waste treatment ecosystems. The use of species from different systems generates new combinations of organisms that may organize new relationships around wastes and cultural by-products. Multiple seeding and the ensuing self-organization, as an ecological engineering technique, may provide new ecosystems for these new conditions. Human society depends on this same adaptive process of transmitting and selecting information. National meetings of scientists such as annual AEES[2] meetings are where newly generated information is, selected, extracted, shared, reinforced and eventually used. The diagram in Figure 6 shows the annual information cycle of academic science where scientists and engineers spend the bigger part of the year generating new information, then select and extract some small portion for sharing. If, in some way, it "catches on", it finds a reinforcement loop, becomes a part of our information base and gets used, ultimately feeding back to generate new information within the research groups. New ideas are the "seeds" of our human cultural ecosystem.

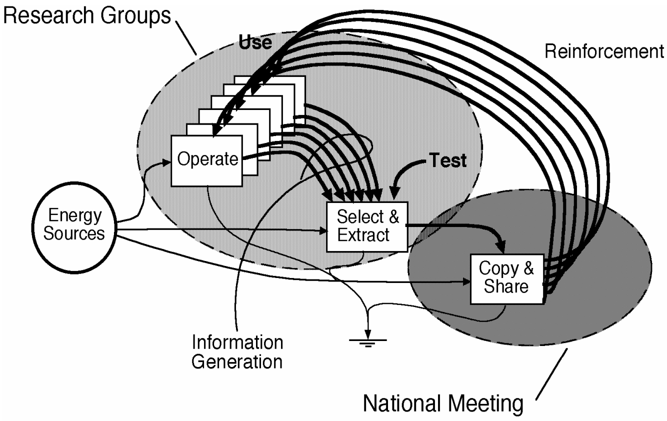

Figure 6. Diagram of the information cycle. The diagram shows the annual information cycle of academic science where scientists and engineers spend the bigger part of the year generating new information, then select and extract some small portion for sharing. If, in some way it "catches on" then it finds a reinforcement loop, and becomes a part of our information base and gets used, ultimately feeding back to generate new information. New ideas are the "seeds" of our human cultural ecosystem. In ecological systems the information cycle can be thought of as short term generation of new genetic information and the longer term evolution of different species characteristics adapted to differing conditions. The information cycle can be enhanced in natural systems by the introduction of new information (ie species)

4.1. Evaluating the Costs and Benefits of Ecological Engineering

The real wealth coming from environmental systems is a combination of their services and natural capital. Environmental services and natural capital (otherwise known as the storages and components of ecosystems) cannot be evaluated properly using traditional economics. The notion that one can determine environmental values by creating pseudo markets is a false one. Determining how much people are willing to pay does nothing more than create a false impression of value. Systems of value based on utility assume that humans are the ultimate consumers of all things and that their willingness to pay is the meter stick by which we should measure all values. Willingness to pay is a false god of value. What is required is a system of value that is free of human biases. A value system based on inputs rather than consumption. Figure 7 shows an emergy based system of value that assumes real wealth of environmental systems results from what is embodied into products and services and not what can be extracted. The concept of basing value on what goes into making something rather on what utility one gets out of

[2] American Ecological Engineering Society

it is somewhat foreign to our thinking, and runs counter to traditional economic valuation. However, humans are used to thinking of a "donor based value system" for many things…the more we put into something (art, information, craft, service, etc) the more "valuable" it is.

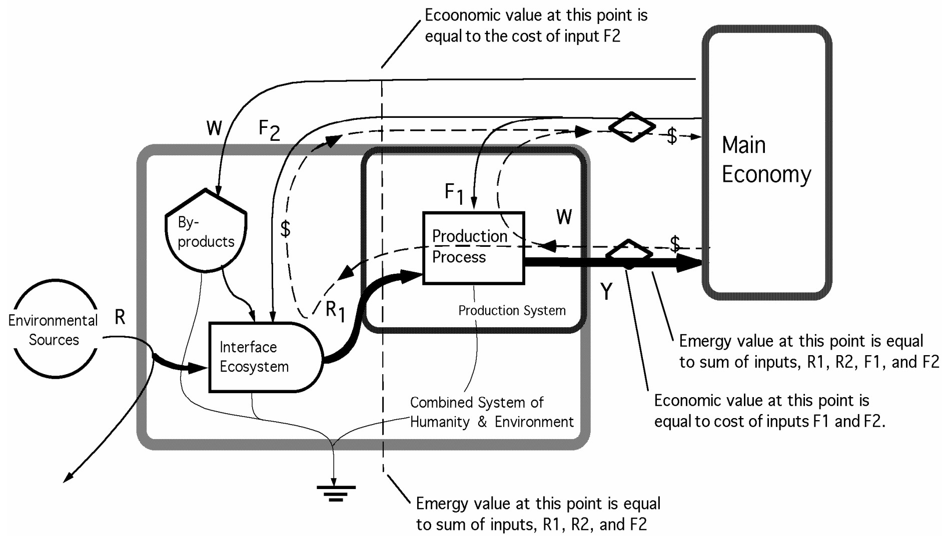

Figure 7. Inputs of emergy, when summed, provide the basis for determining the value of environmental services (R1). The Yield (Y) from this system may be some harvested product or service. Its economic value is the monetary cost of inputs F1 and F2. The Emergy value of the product is the sum of R1, F1, and F2. W is waste by-products from the main economy, F1 and F2 are economic feedbacks (goods and services) from the main economy

4.2. Three Realms of Ecological Engineering

Ecological engineering uses small energy to have large effects by going with, rather than against, the self-organizing tendencies of nature (Odum, 2003). As energy becomes less available for the present massive, high intensity agriculture, forestry, aquaculture, and biotechnology, productivity may be sustained by using techniques of ecological engineering which let the ecosystems do most of the work. Figure 8 shows three main areas and scales of Ecological Engineering in the future: 1. the smallest scale is design and management of interface ecosystems (ie waste processing), 2. an intermediate scale of restoration and "refitting" of ecosystems in an increasingly human dominated landscape, and 3. a regional scale the ecological engineering of the LANDSCAPE itself the design of landscapes that include humans and nature and that incorporate elements of self-organization. At all scales some general initiatives are appropriate for the future of ecological engineering. The following is a list of initiatives that span these three scales:

Manage whole systems and whole cycles: At all scales of the economy, from government, to industry to commerce instill responsibility for management of the whole cycle of materials. For instance, industry should be responsible for managing materials used in products from mining through use and back through reuse, reprocessing, and environmental recycle. Wastes generated by residential developments should be managed as close to point of generation as possible.

Encourage industrial ecology: Industrial ecology deals with the relationship of industry to environment. At present industrial ecology is thought of as a method to improve the "greenness" of industry by reducing environmental impacts, Ecological engineering can help industry and society with better environmental interfaces at all scales…at the scale of individual processes to development of management schemes for whole life cycles of materials and products.

Provide incentives for environmental reinforcement: For too long feedback to the environment has been thought of as planting trees, restocking fisheries, or managing wildlife populations. It now time to rethink environmental feedback from a whole systems perspective. Emergy equal to that drawn from the environment must be returned to maintain symbiotic interfaces. Those who extract from the environment should provide feedback services and resources equivalent to the amount harvested.

Manage systems at all scales with high diversity: Low diversity interface ecosystems provide one type of yield or service, high diversity provides multiple services and values. Sustaining high diversity forests protects watersheds and their discharges and provides multiple other services. Manage landscapes for high diversity of land uses and land cover instead of monocultures of agricultural crops. Except where concentration of wastes dictate simple systems, development of "plantation-like" interface ecosystems are likely to fail because of the mechanisms that keep ecosystems diverse. The maintenance of single species monocultures goes against the successional tide and requires large energy subsidies.

Organize systems based on nutrient status: Whether at the scale of landscapes or individual interface ecosystems, organize systems to maximize use of nutrients close to their source. High nutrient runoff from developed lands should be channeled through high nutrient early successional ecosystems first followed by increasingly mature and diverse systems as nutrients decline. In interface ecosystems zone systems so that concentrated wastes are first released to many small highly managed systems and then passed to larger systems of decreasing management requirements.

Connect organic waste to decomposition: Relegating organic wastes to land fills wastes this valuable resource and squanders much land and energy in operation and maintenance of solid waste facilities. Organic wastes should be combined with nutrient flows to speed decomposition and develop useful products like compost, fungus, worms or fishes.

Use Microcosms to test properties of interface ecosystems: Often environmental conditions associated with high energy human systems produce new situations that offer new opportunities for ecosystem development. To test alternative designs set up microcosms or mesocosms that exhibit the new conditions and then seed them with available species. The systems that emerge and their self-organizing properties provide insight into the larger scale opportunities.

Control systems by controlling energy sources: Pulsing systems often have higher yields as ecosystems respond to pulsing energy sources in conditions may be introduced to which ecosystems respond with pulses of net production for repair. The fluctuations in wastewaters and stormwaters from urban centers can be turned into benefits. Small amounts of limiting materials can be used to control ecosystem self-organization. For example, adding fertilizer nutrients to some organic wastes can speed decomposition.

Increase adaptation with controlled introductions: Species transplanted from one location where they were part of a stable system to another may result in higher yields. The new situations created by human dominated systems may require ecosystems composed of new species introduced from other locations for rapid adaptation and self-organization.

Evaluate systems using emergy: The costs and benefits of ecological engineering projects cannot be evaluated with money alone, because it does not include the real wealth coming from the environment. Evaluating with emergy includes both the work of environmental systems and that by humans in the economy.

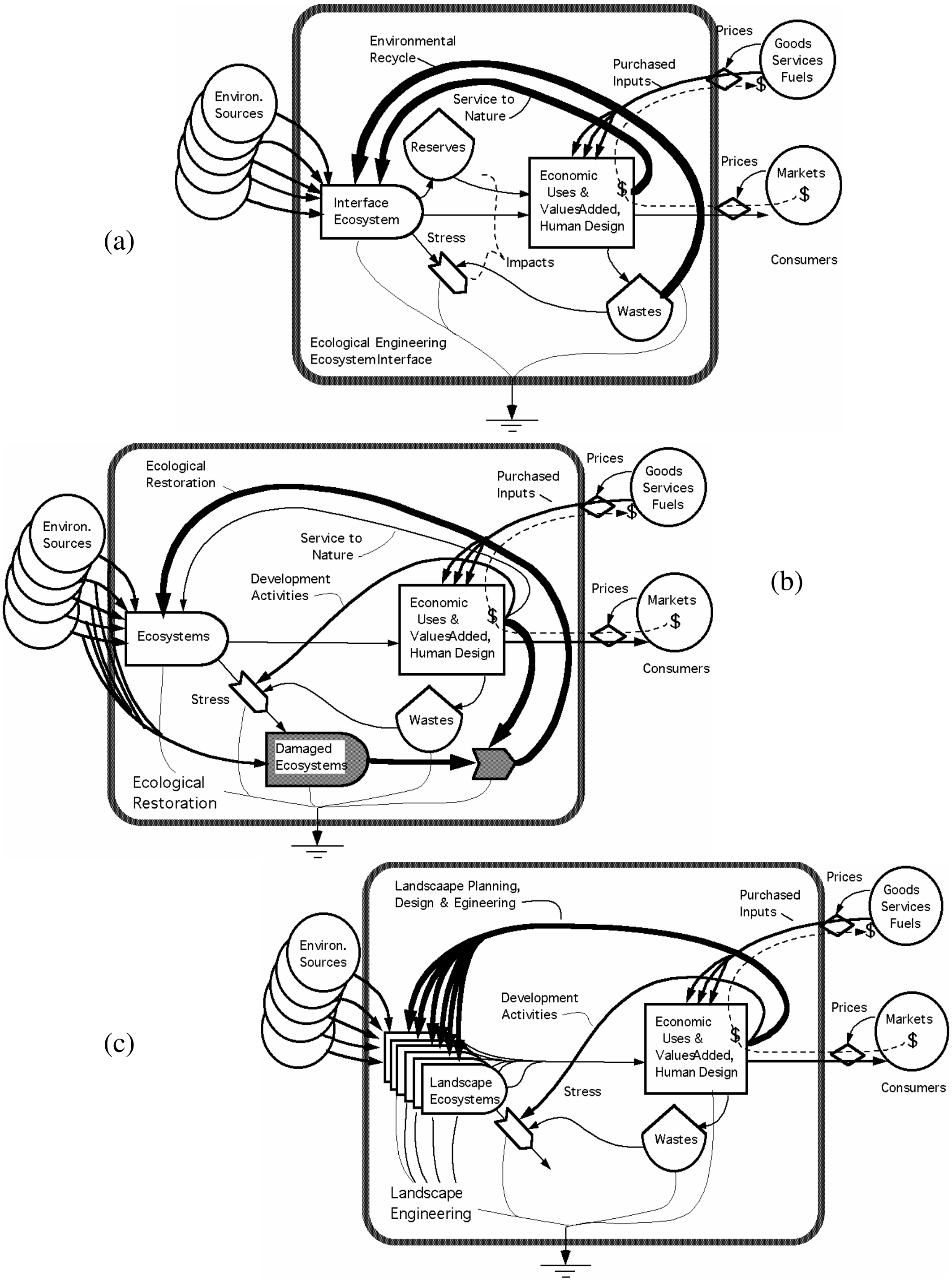

Figure 8. The main areas and scales of Ecological Engineering in the future: a). the design and management of interface ecosystems (ie waste processing), b). restoration and "refitting" of ecosystems in an increasingly human dominated landscape, and c) the design of landscapes that include humans and nature and that incorporate elements of self-organization

5. SUMMARY

Examples of adaptive self-organization are all around us as new kinds of ecosystems are developing at the interface between society and environment in response to the new conditions that have been created. In other words, the landscape of humans and nature is self-organizing. What is needed is mindful design, planning and engineering at the landscape scale to capitalize on and direct self-organization and adaptation.

Field experiments and the use of microcosms have generated much information and formed the basis for principles of adapting ecosystems as interface systems and proven that self-organized ecosystems are capable of "treating" many types of wastes.

Soon the restoration of lands and ecosystems will be a main concern of society as our fuel culture enters a lower energy future based on good use of environmental resources. Restoration should be a main focus of ecological engineers.

Contributions of environment and economy should be evaluated quantitatively on a common basis using emergy. Economic evaluations cannot capture the true value of environmental services or natural capital.

As we approach the peak of our fuel culture we are faced with the possibility of two alternative paths to deal with the reality… the "might makes right" approach our current administration seems bent on pursuing, or one that accepts the reality of a lower energy future and uses the talents, energy and creativity of engineers and scientists to redefine our culture and its fit within its life supporting environment. I believe that defining, designing and managing that fit is the realm of ecological engineering and our challenge in the coming years will be to not only convince society of the coming low energy future, but then to lead the way toward an integrated system of humanity and nature.

References

[1] Brown, M.T. and S. Ulgiati.1999. Emergy evaluation of natural capital and biosphere services. *AMBIO*. Vol.28 No.6, Sept. 1999.

[2] Brown, M.T. and M.B. Vivas. 2004. A Landscape Development Intensity Index. *Ecological Monitoring and Assessment.*

[3] Odum, H. T., 1996. Environmental Accounting. John Wiley. New York.

[4] Odum, H.T. and B Odum 2003. Concepts and methods of ecological engineering. Ecological Engineering 20:339-361

[5] Odum and Odum, 2001. Modeling for all Scales. Academic Press, New York

[6] Odum, H.T. and M.T. Brown, 1987. *Emergy Analysis and Policy Perspectives for the Amazon Basin.* Final report to The Cousteau Society. Center for Wetlands, University of Florida, Gainesville, Florida.