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Short communication

Reflections on Howard T. Odum's paper: *Energy, Ecology and Economics*, Ambio, 1973☆

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Thirty years have passed since Howard T. Odum wrote his paper, *Energy, Ecology and Economics* for Ambio (Odum, 1973). The energy, environmental and economic situation was in many ways very different during the decade of the 1970s than it is today. Broad environmental concerns and legislation were relatively new, and climate change was not an everyday topic. The world oil embargo and "energy crisis" of 1973–1974 resulted in shortages and sharp price increases of oil, gasoline, and other products worldwide, and had a severe impact on the economy and inflation, people's hopes and perceptions for the future, and the ability to conduct business. Uncertainty about future energy supplies led to significant new initiatives in energy technology development, from photocells, to biomass, to fusion power. Odum's attention to the interaction of energy, the economy, and the environment presented in a systems context in his 1971 book, *Environment, Power and Society*, seemed almost prescient (Odum, 1971). It was an exciting and heady time for those of us who believed in Odums's ideas and the central importance of energy to human economies and the natural ecosystems of the world.

Based on his wide breadth of understanding of natural ecosystems, Odum had extended his theories and methodologies to the economic systems of humans, which he viewed as another type of ecosystem. Upon recently rereading the Ambio paper, it still remains daring in its scope and breadth. But are the ideas expressed therein correct? Has history bypassed this paper? Are its generalizations too sweeping, or does it still push the envelope and cause the reader to seek deeper energy and system-oriented meanings behind world events? I would have to answer that the paper still remains relevant, although we have learned a great deal in the interim. Some of Odum's conclusions have probably been framed in more concrete terms by others, others led to detailed investigations during the past few decades, others probably would not be considered in the policy making arena because they are too abstract, or perhaps too long range in their view. In addition, technology innovation has occurred, which has changed the costs, economics, and conclusions about what might be viable. Nevertheless, as we move into the millennium, many of the questions H.T. focused on and struggled with, although sometimes expressed in dense language, remain relevant, as I note in the remainder of this paper.

Odum addressed a number of really basic issues in one, hard-hitting, thought-provoking eight-paged paper, including:

- *The net energy concept:* The true value of energy to society is the net energy, which is that energy left after the energy costs of getting and concentrating the energy are subtracted. Hundreds (if not

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thousands) of analyses have been conducted on various energy technologies during the past three decades, and analysts continue to disagree on the net energy contribution of various technologies. For example, different estimates of the net energy of corn-to-ethanol conversion have been made, with much of the controversy sparked by corn-state politics rather than reality, as essentially all credible analyses show that the energy return on investment (EROI) of corn-based alcohol fuels is barely better than one, at best. Evaluations of the increasing energy cost of petroleum production in the United States, and the movement of major petroleum exploration offshore, provide a stark view of how dependent our fossil-fuel-based economy is on easily obtainable oil (see, e.g. Odum et al., 1976; Hall et al., 1986; Gever et al., 1991; Hanson, 1999; Shapouri et al., 2002; Pimentel et al., 2002; Eliasson and Bossel, 2002). One can derive EROIs for the U.S. petroleum industry in national statistics that show oil production has declined from the 50:1 or so that was characteristic of the early part of the 20th century to something on the order of 12:1 today. This has to be a very important issue for the U.S. economy. Is there a minimum EROI below which a modern industrial economy will not be very viable?

- *Lotka's maximum power principle*: Systems win and dominate that maximize their useful total power from all sources and flexibly distribute this power toward needs affecting survival. Odum struggled with applying this generalized notion of a thermodynamically based, Darwinian-like principle to see whether it could be applied to explain how our economies seek and capture energy, diversify their energy sources, and continually reinvest in structure and technology to maintain and increase those energy flows. During times when there are opportunities to expand one's power inflows, the survival premium is on rapid growth; during times when there are no new sources, systems should invest all available energies in long-staying, high diversity, steady-state activities. Odum was trying to understand what forces were behind rapid economic growth versus steady-state economies. The boom years of the 1990s following rapid oil price decreases in the mid-1980s seemed to illustrate this principle. Odum often asked the question: "How much longer will cheap and plentiful energy sustain the rapid frenzied growth of the world economy?" Analysts continue to investigate the conventional oil resource base and opinions continue to differ on when peak world production might occur (see, e.g. Campbell and Laherrere, 1998; Bentley, 2002; USGS, 2002; Hall et al., 2003).
- *Maximize the use of natural energy flows*: Odum analyzed the energy flows and work output of the environment and their contributions to the human economy, e.g. what is referred to now as "environmental services" (e.g. providing clean water and air, soil filtration, maintenance of diversity, development of soil, harvestable products, etc.). He developed and applied his energy and ecological theories and techniques to proposing optimal mixes of urban and natural areas for the long-term survival of both (see, e.g. Odum and Odum, 1972; Zucchetto, 1975; Zucchetto et al., 1980; Zucchetto and Jansson, 1985).
- *The ability to do work for humans depends on energy quality and quantity*: Odum subsequently developed an accounting system for how to compare the ability of different forms of energy to do work, in order to grapple with the problem of energy quality. It was observed that it was much more difficult to provide useful work to the economy with dilute sunlight than with concentrated sources of coal or oil. Since it takes energy invested in structure and storage to concentrate solar energy, much as plant and trees already do, Odum believed "The reason major solar technology has not and will not be a major substitute for fossil fuels is that it will not compete without energy subsidy from the fossil fuel economy." Was he right? Aside from hydroelectric power and woody biomass, we are still waiting for solar-based energy technologies to become more than just a tiny fraction of our energy supply. Although there have been major improvements and cost reductions in such technologies (e.g. wind), fossil fuels continue to dominate the world economy.
- *Nuclear energy is now mainly subsidized with fossil fuels and barely yields net energy*: His calculations of the net energy of fission plants was positive, but not as yielding as other investigators concluded, such as Chapman and Mortimer (1974). His analyses were lower yielding in part because he considered the energy costs of a potential major accident and the social and institutional controls of protect-

ing society from such accidents. He was asking hard questions about the net energy yield of breeder reactors and fusion devices that still have not been fully answered. Although fission reactors now supply about 20% of U.S. electricity generation with high capacity factors, the 1970s optimism about nuclear power has waned, no new reactors have been ordered since 1978, the breeder program was shut down, and fusion research has yet to demonstrate a net energy yield. Commercially attractive fusion reactors still seem very far off. However, the increased concern about emissions of greenhouse gases from the energy sector may lead to a resurgent interest in nuclear power if a significant shift away from coal and natural gas is required. Hall et al. (1986) had reviewed the EROI for nuclear power as undertaken by various assessments (including H.T. Odum's) and found them not as different if similar quality assumptions were made, roughly 5:1 on heat values of energy or 15:1 if electricity is given a factor of three in terms of quality relative to heat energy. Toward the end of his life, Odum, told Charlie Hall that he thought that now that nuclear technologies had settled down it seemed capable of supplying society with energy with a modest EROI, and he thought that it might be a viable option. It is not known how the new terrorist-impacted world might change such assessments.

- *Systems in nature are known to shift from fast growth to steady state gradually, but other instances are known in which the shift is marked by total crash and destruction of the growth system before the emergence of a succeeding steady state regime*: Odum was concerned that the current high-energy-use industrialized society would boom and bust as the natural bounty of concentrated energy stored in fossil fuels waned. When exactly that might occur was uncertain, but concepts of steady-state economies fly in the face of the prevailing growth paradigm and people's expectations of continued growth for succeeding generations (Daly, 1997). Odum was concerned that if we did not prepare for the downturn and begin a gradual transition, then the way down would have serious disruptions on people (see contributions by Campbell and Ulgiati in this volume). Thought-provoking remarks in the conclusion of his paper include: "Disease reduction of man and his plant production systems could be planetary and sudden if the ratio of population to food and medical systems is pushed to the maximum at a time of falling net energy." "... the cultures that say only what is good for man is good for nature may pass and be forgotten like the rest." "Has the human system frozen its direction into an orthogenetic path toward cultural crash, ... or will our youth be ready for the gradual transition to a fine steady steady state that carries the best of our recent cultural evolution into new, more miniaturized, more dilute, and more delicate ways of man-nature?" From the viewpoint of the U.S. economic boom of the 1990s, Odum seems off the mark, although a little less so by 2003, but if one considers the collapse of the Soviet Union, economic stagnation and/or decline of a number of countries in the African and S. American continents, a decade of economic stagnation in Japan, one wonders if the world system as a whole will remain on a rapid growth path. What new energy technologies will succeed the fossil fuel era? How will the earth support systems remain viable and continue to provide environmental services with a world population reaching 10 billion? It seems to me that even if H.T. did not get all the details right, he was asking truly important questions that are likely to be with us for at least decades and probably centuries to come. The unintended consequences of rapid scientific and technical innovations, especially on the environment and society, perhaps are more important to address in a precautionary framework than ever before as the global economy becomes more interdependent. Odum and his wife delineated what they saw as an approach to a coming global transition in *The Prosperous Way Down* not long before he died (Odum and Odum, 2001).

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