

THE NEED FOR A NEW, BIOPHYSICAL-BASED PARADIGM IN ECONOMICS FOR THE SECOND HALF OF THE AGE OF OIL

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1. Introduction

The realization that the conceptual base for much of conventional economics is quite flimsy is no longer news to either those who follow events within the field or to many interested outsiders in the natural sciences. For an easy example, since 1998 a surprisingly large number of Nobel Laureates in economics (Joseph Stiglitz, George Akerlof, Daniel Kahneman, Robert Aumann, Thomas Schelling, and Amartya Sen) were people whose work challenged, in various very fundamental ways, the basic existing paradigm of conventional neoclassical economics. (Neoclassical economics, which we abbreviate here as NCE, is sometimes called neoliberal, or welfare or “Washington Consensus” economics).

More fundamentally, some twenty years ago in the journal *Science*, Nobel prize winner in economics Wassily Leontief found the basic models of economics “unable to advance in any perceptible way a systematic understanding of the operation of a real economic system.” Instead they were based on “sets of more or less plausible but entirely arbitrary assumptions” leading to “precisely stated but irrelevant theoretical conclusions” (Leontief, 1982). He asked others in “demography, sociology, political science ... ecology, biology, health sciences and engineering” to assist in removing economics from the “splendid isolation in which it is found”. More than a few investigators have responded (knowingly or not) to Leontief’s call to action, and there has been some marvelous new research addressing the issues he raised. Today it is not hard to find economists, natural and social scientists, and incisive journalists with similarly pungent criticisms of the present state of economics (Hanson-Kuhn, 1993; Gintis, 2000; Hall et al., 2001; Henrick et al., 2001; Easterly, 2001; Stiglitz, 2002; Cassidy, 2002; Gowdy, 2004; Perkins, 2005). While most of the criticisms address the often extremely adverse or self serving social consequences of the use of the neoclassical model, our focus here (and especially in Gowdy et al., in preparation) is on the internal logical and empirical inconsistencies of that model. Most importantly these

models, like any believable model, must be based upon, or at least consistent with, known laws of behavioral, biological and physical science, and not simply ideology. Although the ideology that pervades economics today is sometimes associated with political ideology it is more often related to its own self-contained but rarely tested ideology, such as “free markets lead to efficiency” or “economic analysis is value-neutral” or “externalities can be internalized, resolving the original problem”. Many economic models used routinely are so inaccurate that they almost invariably make poor predictions of the behavior of real economies, for example in the behavior of Latin American economies subject to structural adjustment (Hanson-Kuhn, 1993; Hall, 2000). Still these models continue to be used routinely, even while top theorists criticize their validity using the scientific method. Why are they still used? There are many reasons. Probably the most important are that the theory has a certain logical basis, it is well and elegantly developed, it uses mathematical “rigor” that is impenetrable to most, because we have not had an acceptable alternative since the era of classical economics, and because they are not entirely incorrect in their formulations and predictions. Yet they are also enormously and deeply flawed, in a way and to a degree that is almost inconceivable and even an embarrassment to someone who has a background in natural sciences or who believes in generating truth from the use of the scientific method.

For starters, one question rarely asked in economics is the relation between energy and any economic activity. In most of the world’s economies, be they capitalist, communist or anything else, there are no increases in economic activity without a more or less commensurate increase in the use of energy (e.g. Ko et al., 1998; Tharakan et al., 2001; Hall and Ko, 2004 – the U.S., which has outsourced much of its economic production, may be an exception). What is less likely to be asked by economists is the degree to which ANY economic “law” or policy can be made to “work” simply because additional cheap, high quality energy could be pumped out of the ground readily to make it work. Since the ready availability of cheap energy is unlikely to continue it is critical that we develop a new, more realistic paradigm for economics for the second half of the age of oil, that is for the inevitable downward trend of post-peak oil and gas that is likely to be upon us soon.

2. Is ecological economics the answer?

This is not the first call for or approach to a different type of economics. The society and the Journal “Ecological Economics” is “a new field formed at the intersection of...ecology and economics” (Costanza, 1989). Its guiding force and first President and Editor in Chief Robert Costanza -- in the first editorial -- welcomed to the journal a broad range of new ideas at that intersection (Costanza, 1989). In the decade and a half that has followed there has been an enormous increase in the intellectual dialogue and number of publications at this interface, reflecting and causing very different approaches to (and results from) cost-benefit analyses and other policy-related economic applications. As a result, natural ecosystems probably have been evaluated and protected more effectively than would otherwise be the case. Nevertheless, the relatively rare collaboration between ecologists and economists often had the ecologists doing their “nature-based thing” while the evaluative procedures were turned over to economists. The economists then attempted to put a dollar-based “shadow” price on the ecological structure or function that the ecologist had estimated using for the most part conventional economic tools. (This perspective is of course somewhat of a

caricature as there was a diversity of other types of papers in the journal). One important result of this shadow price type of analysis has been an assessment of the “value of the world’s ecosystem services” which was estimated as some 33 trillion dollars, roughly twice the Gross World Product (Costanza et al., 1997).

In the minds of many environmental scientists, however, even after all externalities have been internalized and a price put on all of nature this type of relatively conventional economics remains incomplete or inappropriate for evaluating natural ecosystems because they feel that it mis- or under-values nature and its essential contributions to human welfare. Specific concerns included: (1) the use of market-derived entities (e.g. dollars) as an evaluation metric for essential “birthright” goods and services (e.g. the planet’s climate-control system, biodiversity, or the basic resources critical for the survival of modern humans) that have no relation to the often trivial or manipulated human tastes or routine purchases that assign value to dollars (Daly, 1977); (2) the use of a relatively high “discount rate,” that trivializes the value of the essential contributions from nature over long time periods and devalues the importance of our children’s needs; and (3) a general mistrust of conventional (e.g. neoclassical) economics (NCE) as a scientifically-defensible entity (e.g. Hall et al., 2001; Gowdy and Erickson, 2005; Gowdy, 2005). Many feel that some other approach to economics and to the evaluation of natural ecosystems are needed, but it has not been clear where to turn. The only real alternative to the presently dominant neoclassical economic system of analysis is (or some would say was) Marxism, although, that too had insufficient mechanisms to evaluate nature properly and was also, like NCE, growth oriented. Other approaches exist, such as the Georgist movement, but they seem to have little impact beyond their immediate advocates. Thus, the field has been left to the neoclassicists and their ilk by sheer default. Is there some other approach that is not based on the human willingness to pay criteria? Can we make an approach to economics that is not based on the neoclassical assumption that humans are self interested and “rational” i.e. completely materialistic and value goods and services only as they contribute to their immediate and often trivial personal gratification? Or perhaps most fundamentally why should we base our analyses of economics solely on markets in the first place, when economics is about so many other things as well. While it is true that ecological economics can and sometimes does take these issues into account we believe that we need a more explicit approach that is based as much on natural as social science for its evaluative base. We feel that biophysical economics offers a reasonable and scientifically defensible approach that may fill this void.

3. What, then, are economies and how should we study them?

Economies exist independently of how we perceive or choose to study them. For more or less accidental reasons we have chosen over the past 100 years the social sciences and an inappropriate and overly-simplified analytical model borrowed from physics as the essential conceptual base for undertaking our definitions and analyses of economies and economic systems, even though actual economies are as much about biophysical as social activities. Real economies *must* be based on many things, including the physical materials and energy required to provide goods and services as well as the NCE-sanctified market interactions that transfer these goods and services from firm to household or household to firm. Curiously, in

the 1870s or so, economics somehow became ONLY a social science, and it has remained that way.

The present social science focus was not particularly the case with earlier economists, who were more likely to ask “where does wealth come from?” than are most mainstream economists today. In general, these earlier economists started their economic analysis with the natural biophysical world, probably simply because they had common sense but also because they deemed inadequate the perspective of earlier mercantilists who had emphasized sources of wealth as “treasure” (e.g. precious metals) derived from mining or trade. In the first formal school of economics, the French *Physiocrats* (e.g. Quesnay, 1758; see Christensen, 1989 and 2003) focused on land as the basis for generating wealth. The biophysical perspective continued with Thomas Malthus’ famous *Essays on Population*, (there were six of them) which assumed that human populations would grow exponentially-- because it seemed unlikely that anyone would control the “passion between the sexes”-- unless somehow “checked” by factors that either reduced the birth rate or increased the death rate. Since Malthus had little faith in the “moral restraint” of the working classes, and believed that birth control was “vice,” he recommended a rather Draconian social policy to increase the death rates among the poor. In Malthus’ view the agricultural production needed to feed this exponentially increasing human population could grow only linearly, i.e. less rapidly than the number of humans. He also opposed the importation of cheaper continental grains, as a limited food supply assured increasing rents for his patrons, the landed aristocracy, and squeezed the profits of the rival capitalists. It was this view -- that the human prospect was limited by inadequate food supplies, and that class conflict was inevitable, that led the Victorian philosopher Thomas Carlyle to give economics the label of “the dismal science”. Adam Smith and other *classical* economists focused on both land and labor as means of transforming the resources generated by the natural world into materials that we perceive as having wealth. Later, David Ricardo made important observations about the general need to use land of increasingly poor quality as populations (and hence total agricultural production) expanded. Even Marx, while focused firmly on labor, was keenly interested in the long-term adverse effects of large-scale agriculture on soil quality. He firmly believed that capitalism exploits the land in the same way it does labor.

In the 1870s, these early economic perspectives, all explicitly biophysically-based, were displaced by the “marginalist revolution” of William Stanley Jevons, Karl Menger and Leon Walras that was based on abstractions such as “subjective utility” and that ignored measurable physical inputs and outputs of material or energy. This novel approach to economics was called *neoclassical*, and the ideas of the marginal revolutionists still dominate today. In the words of the early marginalist Frederick Bastiat: “exchange is political economy.” Hence production became a less important issue to economists compared to market-based human preferences, and the common sense biophysical basis for economic analysis was snuffed out intellectually, although of course not in real economies. By the early 20th Century land, representing all of nature, was simply omitted, along with energy, from neoclassical production functions. Generations of economists subsequently have been trained from a perspective that is divorced from biophysical reality except as it effects prices, within a world view that is often extremely mathematical, theoretical and even doctrinaire. On the other hand one might say that neoclassical economics does a good job of reflecting the

essential human characteristic of a desire for more of whatever and the reality that much of what happens within economics does indeed occur within what we may call markets.

Three factors played a large part in seeming to put the dismal Malthusian fears to rest and hence removing biophysical issues from the immediate attention of economists: the opening of the Americas to immigration by the surplus Europeans, their virtual extinction of the Native American potential competitors there, and the industrialization of agriculture, which generated an enormous increase in food production. A fourth factor might be considered technology by itself, although most technologies were associated with industrialization so that we might consider them as a force working together. With this increasing creation of surplus wealth economics, starting with Keynes, focused increasingly on *consumption* and became more and more intertwined with the social sciences. Today economic theory starts with “rational” and self-interested individuals who choose to satisfy their own personal needs and preferences by freely substituting one good for another to maintain their well-being, and allocating their limited resources (i.e. incomes) to purchases that they believe will lead to their largest personal satisfaction. Simultaneously, concepts of economic *production* have focused increasingly on capital as an abstract but critical notion, while labor has been reconstituted as “human capital” and land has simply been omitted. Recently, in an attempt to give value to nature, ecological economists have christened biophysical stocks as “natural capital” that subsequently produce flows known as natural resources.

Although conceptual economics divorced itself from biophysical reality this was not the case, at least in theory, in one respect, which is with respect to the development of the underlying mathematical theory. At the turn of the last century, economists chose physics (and, more explicitly, the analytic mathematical format of classical mechanics) as a model for capturing the essence of their discipline. This is reflected in the familiar graphs and equations of commodity value and cost vs. quantity, with price determined as the intersection of downward trending demand curves (derived from utility curves) and upward trending cost of supply curves. Although physics served as the model and its intellectual popularity as the motivation, the resulting economic model was physically unrealistic because it represented a dynamic, irreversible process with a static and reversible set of equations as the conservation principles that constrained the equations of physics were incompatible with capital accumulation and, indeed, growth or even production in the economists’ model (e.g. Mirowski, 1984).

Why should the current discipline of economics be a social science *at the expense of a* biophysical science? There are many who, like us, believe that this choice is worse than arbitrary because it is *only* cheap energy that has allowed us to essentially ignore over the last century the biophysical world that was the focus of early economists. It is *only* through energy that is cheap in the market, but not at all otherwise, that we have been able to generate such enormous wealth at so little cost to our individual salaries or time. Many economists argue that since energy costs are equivalent to only some 3 percent of GDP then they are trivial in importance compared to the rest of the economy and also that we need not be too concerned about future possible energy shortages. But what if this cheap energy declines in abundance, as seems inevitable to many of us? Energy and minerals increased to 12 percent

of GDP in the oil-constrained and economically-devastated decade of the 1970s, as is likely to occur again, perhaps soon. One can argue that if the present 3 percent of GDP energy cost is subtracted from the current economy, most of the other 97 percent of GDP will cease to exist. In other words, we are extremely lucky that we have to pay only the *extraction costs*, rather than the full-value *production, value-to-society* or *replacement* costs that Mother Nature might charge if there were mechanisms to do so. The full price would have to include the costs of natural capital depreciation, including both the fuel itself and the nature destroyed by its extraction, shipping and use, as well as the military costs of assuring resource availability. These we are hardly paying at present. If and when we run out of luck, and these costs come due, as will likely be the case, economics will become a whole new ball game in which the focus will return again to production and which will result in a new way of thinking about monetary and energy investments. Thus there are good reasons to examine economies from a biophysical and energy perspective as well as from a social- and market-based perspective. This may be a difficult leap initially, but the shift in perspective should become obvious and desirable once the idea is broached.

4. The economy of nature

At one extreme we can consider ecosystems such as natural streams, forests, or grasslands as economic systems (Odum, 1972; Ricklefs, 1976). These systems have “economic” structures for production (photosynthesis), consumption (respiration) and for transfer of “goods” through exchange processes (e.g. food chain material and energy transfers, nutrient cycling), although they are different in that only humans are thought to possess “utility”. A critically important insight that has been gained from the study of these natural ecosystems is the importance of a thermodynamic perspective. In the absence of a continual input of energy, the highly ordered molecules within an ecosystem will, over time, degrade into completely random assemblages. It is only the continual input of energy from the sun, the capture of this energy by green plants, and the effective transfer of energy to other components of the system that allows ecosystems and their components to fight the general tendency of all things towards randomness (often called a tendency for disorder, or entropy). Ecosystems have been described as “self-designed” entities; organisms within the ecosystem, and perhaps ecosystems themselves, interact to build a biological structure that best captures and utilizes available energy (e.g. Odum, 1988; 1994; 1995; Brown and Hall, 2005). The blueprints laid down in an organism’s DNA are fine-tuned through natural selection so that energy may be used to capture, reorder, and maintain both additional energy and the molecules in that organism in the otherwise extremely unlikely patterns that we call life. Energy is captured and used to generate biological structure, which in turn maintains, replicates and sometimes changes itself through natural selection. It does not take much imagination to transfer this concept to human economies as both are equally biophysically based.

Most of us, however, would not consider such systems of nature as “real” economies because that term tends to be reserved for systems that include humans, human processes, market transactions, money and/or other human-directed activities. Nevertheless, “real” economies (including those of the city of Syracuse, NY or of the country of Costa Rica) are, in fact, subject to the same forces and laws of thermodynamics as natural ecosystems and have much in common with them. Since the structure of many human-constructed systems

(e.g. cities) contains so much more mass, both abiotic and animal, than that of natural systems, the energy requirement to construct and maintain them is much larger. This requires not only the usual input of solar energy, but also the concentration of massive quantities of fossil fuels and energy-intensive materials, which in turn generate enormous “ecological footprints” on the rest of the world (Wackernagel and Rees, 1996). Hence these “real” economies are as much about the movement of materials and the use and dissipation of energy as they are about the social or human-involved transactions.

Hence we see many reasons for needing an explicit approach to economics that is biophysically based: it was the basic way that early economists, unconstrained by existing dogma and blessed with considerable common sense, viewed economics, it gives a united view of nature and human activities and of the various science and economic courses our students take, it reflects much better the real value of energy and resources to our economy and it helps prepare us for possible near future large changes in our economy emanating from a sharp loss in premium fossil fuels. The name for such an approach is simply *biophysical economics*, although we might have chosen the word bioeconomics as was used earlier by the pioneer biophysical economist Nicholas Georgescu-Roegan (e.g. 1975).

Since so much of economic discourse these days is politically charged before what we say what biophysical economics *is* it is important to say a few things about what it *is not*. Biophysical economics is in no way opposed to the use of markets and market theories for distributing routine economic goods and services, nor is it in any way opposed to price incentives for doing many things. By itself it has no value judgments about the distribution of wealth, although since an important part of the “bio” in biophysical is the number of humans it does believe that per capita resource use and distribution issues are important to put on the table. It takes no position on, for example of, whether expanded international trade is good or bad, except to say that it should not be accepted simply on faith. Rather the issue requires empirical analysis, including the use of biophysical methods. While it is obviously based on the biophysical world it acknowledges that there are many critically important issues that are not well addressed by biophysical means but that lie within the social realm, many of which are thoughtfully addressed today by various economists including some neoclassical economists. It has no intrinsic “leftward” or “rightward” political leaning although it believes that sometimes issues usually argued from that perspective can be addressed empirically using the scientific method. For example the question of whether “free markets” and “technology” lead to more efficient economies over time has been addressed empirically by Hall and Ko (2004). Perhaps most importantly biophysical economics is *not* about putting prices on the processes and functions of nature within a system of conventional economics, but rather in evaluating them on their own terms—although sometimes monetary prices are useful as a secondary metric. With these things said we can go on to what biophysical economics *is*.

5. What is biophysical economics?

Biophysical economics is a system of economic analysis that is based on the biological and physical (as opposed to social) properties, structures and processes of real economic systems as its conceptual base and fundamental model. It acknowledges that the basis for nearly all

wealth is nature, and views most human economic activity as a means to increase (directly or indirectly) the exploitation of nature to generate more wealth. As such, it focuses on the structure and function of real economies from an energy and material perspective, although it often considers the relation of this structure and function to human welfare and to the money (i.e. dollar) flows that tend to go in the opposite direction to energy (Odum, 1972). From a biophysical perspective, one's job is viewed as trading one's time at work (the monetary value of which is related to the energy flows of society controlled by the individual) for access through wages and salaries to the energy flows of the general economy. This "general economy" contains goods and services created from the extraction of energy from the earth in anticipation of some demand for them. At present, each dollar we spend requires roughly 12,000 Kjoules (about an 8-oz. coffee cup's worth of oil or equivalent energy) to generate the good or service purchased. With economic inflation, the energy per dollar decreases over time so that in 1970, one could receive about ten times more energy (as used to generate goods and services) per dollar than he or she can today. The ice cream that fueled Hall's paper route in 1954 cost only 5 cents, but required for its production roughly the same amount of energy as today. A biophysical economist might ask "how many minutes of labor did you have to put in to earn that nickel? At your current salary do you put in more or fewer minutes for that ice cream cone? If your salary is high is it commensurate with the energy flow in society that you control?" Or perhaps "When you spend your salary how much of the world's nonrenewable resources are depleted, and how much did you contribute to changes in the atmosphere?"

Figure 1 is our perception of the simplest diagram that one could use to represent a real economy, although it is far more complex and infinitely more accurate than the "firms and households" diagram said to represent the economy in most introductory economics textbooks. This diagram, and real economies, includes (from left to right): (1) energy sources (principally, the sun) that are essential for any economy; (2) the material that circulates upon the earth's surface through natural and semi-natural ecosystems; and (3) the human-dominated steps of exploitation, processing, manufacturing and consumption. Black and white arrows show the transfer of materials and energy through the economy. Raw materials are refined by human activities until the heat is dissipated and the materials are either released as wastes to the environment or recycled back into the system. From this diagram, one could argue that the most important activity of the economic process is the proper functioning of the hydrological cycle, since virtually all economic production and manufacturing are extremely water-intensive. From the standpoint of a traditional economist, the hydrological cycle is not important because we pay very little for it. A biophysical economist, on the other hand, would argue that it is critical for many reasons and that it is only because we can extract its services from nature at little direct monetary cost that we can have the high generation of wealth within today's economy.

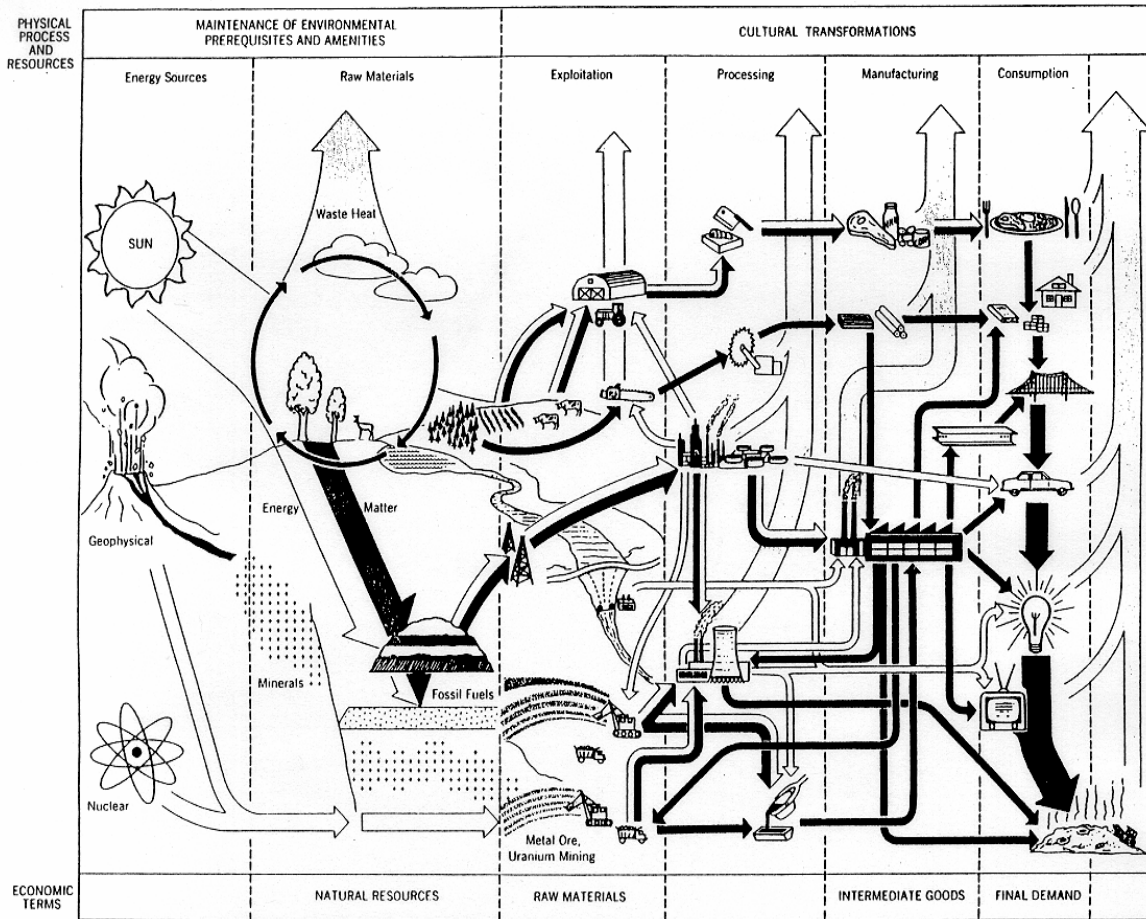


Figure 1. Biophysical model of an economy, with a comprehensive representation of the main steps necessary for economic production, exchange and consumption. Natural energies drive geological, biological and chemical cycles that maintain ecosystems and by so doing produce natural resources. They also maintain a livable environment for humans and their economic and other activities. Extractive industries use economic energies to exploit natural resources and convert them to raw materials. Raw materials are used by manufacturing and other intermediate sectors to produce final goods and services. These final goods and services are distributed by the commercial sector to final demand. Eventually, the goods and energy return to the environment as waste materials and waste heat. Filled arrows are materials, open arrows energy, which is eventually lost as heat.

6. Production functions from a biophysical perspective

Classical political economists had the belief that one could account for wealth by adding up the contributions of each of society's major classes. Landlords received rents, workers wages, and capitalists earned profits and interest. The emergence of neoclassical economics shifted this focus to utility as the basis of wealth. Now workers and capitalists received their rewards according to their incremental contribution to output. Rent is no longer a return to land, but a pejorative term for unearned income.

From the perspective of biophysical economics, the economist's approach -- that considers only the "holy trinity" of land, labor and capital -- misses the boat entirely. While each of these factors is of course important in and of itself, in fact each contributes to economic production by using energy to upgrade raw materials or intermediate goods to more economically useful or desirable forms, or by doing the physical activities we call services. For example, hunter-gatherer societies obtained food using the energy of each individual's muscular activities and the force-concentrating technologies of spear points and knife blades. The labor of artisans generated items exchangeable for food and other commodities. The concentrated energy of fire led to a large expansion in the food that people could eat, a reduction in the pathogens in that food, and the ability to create tools and implements from metal. Farmers redirected the solar energy of ecosystems to human mouths so that land became a source of wealth as emphasized by economists at the inception of the industrial revolution. The energy of elevated water and fossil fuels increasingly generated the basis for wealth creation during the 19th and 20th century. Over time, the landed gentry who owned large solar-collecting estates were replaced at the top of the financial and social ladder by the new industrialists who directed new production systems using the more concentrated energies of coal and then oil. Therefore the physiocrats, such as Quesnay, were correct for the time and place in which they lived, when the land-derived capture of solar energy generated the most wealth. Adam Smith, a contemporary of Quesnay but living in England, was correct for the time and place in which *he* lived, when craft labor was increasingly the main way to generate wealth. Ninety years later, when artisans were replaced by unskilled factory operatives, and landed aristocrats were displaced by industrial capitalists, Marx was able to contribute penetrating insights into the relations of the new classes of people who controlled different types and quantities of energy flow. Perhaps today neoclassical economists are partially correct to put the focus on capital, i.e. in their view dollars but in ours the use of machines and ancillary equipment to do the jobs once done by labor -- although shouldn't they also include, or even emphasize, the *energy* used by capital that actually does the work? Finally as we have entered the electronic age it is increasingly the *quality* as well as the *quantity* of energy that generates wealth, with electricity of increasing value and with some considering information, which is energy-intensive to obtain, store and transfer to new minds, as the highest quality of energy. Nevertheless there is little room here for complacency with respect to our need for energy because, as we have emphasized elsewhere, for most countries there has been little or no reduction in the quantity of energy required for a unit of economic activity.

Thus what all of these "mainstream" production functions fail to emphasize is what every biophysical economist knows to be the truth: it is the *energy* that does the work of producing wealth, and is essential for its distribution as well, whether that energy is derived from land, labor or capital-assisted fossil fuels. Ayres (e.g. Ayres and Warr, 2005), Kuemmel (e.g. in Hall et al., 2001) and Hall and Ko (e.g. 2004) have shown that the production of wealth in industrial societies is almost perfectly a linear function of the energy use in those societies, and that the correlation gets tighter and tighter when proper corrections are made for the quality of the energy used (e.g. coal vs. electricity) and for the amount of energy actually applied to the process (e.g. electric arc vs. Bessemer furnaces). Much, perhaps most, technology is ultimately about these things.

It may seem obvious now that wealth is generated by the application of energy by human society to the exploitation of natural resources. Nature generates the raw materials with solar and geological energies, and human-directed “work processes” are used to bring those materials into the economy as goods and services. These processes have been made enormously more powerful over time through technologies that are mostly ways to use more or higher quality energies to do the job. Energy would be the *first* element to be considered for most natural scientists if they were asked to construct a production function because they are trained to think that way and because it is statistically the most important factor – more important empirically than *either* capital or labor (Hall et al., 2001). It should be emphasized that this view does not negate the importance of human preferences or of the market as a means to *allocate* goods and services. Rather, it focuses on the *source* of those goods and services and on our increasing vulnerability to the depletion of the critical high-grade fuels that we rely upon so heavily (Hall et al., 1986; Hall et al., 2003; Hallock et al., 2004). Where neoclassical economics treats production as just another case of the maximization of individual preferences, biophysical economics treats production as scientists treat work: the transformation of inputs into outputs using energy while subject to the laws of thermodynamics.

7. The problem with biophysical economics: can we fix it?

A problem with biophysical economics is that the theory is not yet nearly as well-developed as that of conventional economics – for example, there are few generally accepted equations, rules or concepts. A search of the world wide web on March 21, 2005 found more than 2000 entries for “Economics biophysical”, but most were to biophysical aspects that were being introduced into conventional economic analysis so that a dollar value could be assigned to them. While we believe this more appropriate than not doing so it is not what we mean here. The specific exceptions where a “true” biophysical analysis was being undertaken were mostly to those authors whose names are included in the bibliography below and several interesting-looking courses at Boston University, Leeds, Tufts and my own college.

Nevertheless, a few comprehensive biophysical analyses exist (e.g. Hall, 2000). We have in press a synthesis of how to go about undertaking a biophysical analysis (Hall and LeClerc, in press), summarized rather simplistically below:

- Step 1. State your objectives and include analysts - both biophysically and economically trained - who truly understand the specific system under scrutiny.
- Step 2. Assemble a database of critical biophysical parameters and their interactions. Create a flow diagram of fundamental energy, resource and monetary flows.
- Step 3. Make an assessment of critical economic parameters and their explicit requirement for, and their specific relation to, the biophysical parameters. State these and other relations as testable hypotheses.
- Step 4. Examine the relation between various economic activities and the local and global biophysical resources they consume or degrade.

Express these biophysical requirements per monetary unit of economic activity.

Step 5. Construct a comprehensive simulation of the past, present (for validation) and the future. For example make projections of human demography, resource use (e.g. hectares of farmland, tons and grades of ores and fuels, inputs required and so on.). Generate per capita, as well as total, resource and economic projections.

Step 6. Examine the biophysical requirements for any suggested economic development plan. Examine, for example, how long resource availabilities (including e.g. global oil resources or the necessity for industrial inputs and the foreign exchange required for that) will allow that economic activity to take place

Step 7. Make decisions constrained by the biophysical possibilities and limitations

Step 8. Consider your policy decisions as hypotheses and state the expected results explicitly. Return to the issue in five years and see if your policy hypotheses are supported by the actual behavior of the economy.

These steps are, of course, not terribly different from any good common sense analysis using any system of economics. These explicit activities, however, allow one to understand much more clearly the constraints and opportunities available to e.g. a developing country. The failure to use these specifics in the past has resulted in a disastrous history of development plans that have, in general, left many poor nations ever more dependent upon imported industrial products, the expensive fuels that operate them and debt (Hall and LeClerc, in press). The relatively new and easily accessible databases available over the web make this process much easier, and to date a biophysical analysis of one sort or another has been applied in perhaps a dozen countries (e.g. Costa Rica, Korea, Eritrea, Nepal, Niger, Ecuador and the Philippines). We have generated many such analyses in the context and time frame of a Masters thesis or PhD dissertation with good students working on their own country's problems.

8. Biophysical economics vs. ecological economics: are they the same?

An obvious question for many readers of this article is the degree to which biophysical economics is, or overlaps with, ecological economics. If we accept the initial definition of ecological economics as the intellectual region where ecology and economics overlap, then biophysical economics is a subset of ecological economics. More accurately, however, biophysical economics begins with the recognition that an economy must live within, and is completely dependant upon, the resources and constraints of the local and ultimately global ecosystem. Unlike most of ecological economics, biophysical economics does not merely attach a dollar value to nature, moving nature within the boundaries of the economic system, but insists that economies be thought of as living *within* the global ecosystem, as that is the necessity and the reality. Certainly biophysical economics will not displace conventional economics overnight. However, we believe that given the increasing dissatisfaction of even relatively traditional economists with conventional economics (e.g. Mirowski, 1984;

Easterly, 2001; Stiglitz, 2004) there are many who are searching for a new economic approach. Biophysical economics offers neither a palliative nor a series of fixes to the conventional model; it is rather an entirely different basis for how to think about economics. And, unlike much of conventional economics, biophysical economics is explicitly consistent with our understanding of the immutable laws of nature and as such, it deserves our fullest attention.

Some form of biophysical analyses increasingly are being made a part of more comprehensive economic analyses (e.g. Foran et al., 2005, Goetz and Keusch, 2005; and other papers in recent issues of *Ecological Economics*). Whether these papers are real steps in the direction of biophysical economics or still simply and inadequately “putting a dollar value on the parrots and turning the same old neoclassical crank” probably depends on the critical assumptions as to boundaries, energy, and whether we continue to use market-derived procedures to generate our evaluative metrics. To us the latter question is critical in understanding the difference between much of ecological economics and biophysical economics, for to evaluate our fundamental life support systems or the results of billions of years of fine tuning through natural selection or (if you wish) any major component of God’s creation in terms of dollars is to us the exact opposite of what we should be doing. They have value so different from, and so much greater than, anything we can evaluate with mere dollars that it is absurd to even attempt to do so, despite its tactical practicality. Biophysical economics says “start with the essential process, value it on its own terms and on its contribution to the welfare of all creatures on this planet (including humans) and think about money only much later”.

9. Final policy perspective

Thirty years ago, the United States and the world were engaged in intense debates about population and resources. Important publications from environmental leaders such as Paul Ehrlich and Donella and Dennis Meadows drew much-needed media attention to these issues and forced us to think carefully and critically about human population growth and its relation to resource availability. Now, perhaps with the exceptions of Jared Diamond’s new book *Collapse* and the continued efforts from the peak oil neo-Hubbertarians (both of whom are dismissed by conventional economists and reviewers – see e.g. Easterbrook, 2005), that debate has vanished from the national and world scene. It has been obliterated with seemingly well reasoned but entirely false or at least inadequate arguments from economists about markets, technology and the importance of human self interest, fueled by clever advertising that exploits our primal selves to encourage us to waste our one-time priceless repositories of natural resources on the most useless of toys. We are left with smug pronouncements from economists about the unending possibilities of technology and ‘economic growth’.

The resource constraintist perspective, one that we share, has been undermined by two main factors. The first was a rather foolish bet made with technological cornucopian Julian Simon in 1980 by otherwise brilliant (in our opinion) Paul Ehrlich and John Holdren that the price of five metals would increase over the next decade. The constraintists lost the bet, although they certainly would have won the bet at a later time period when the world

was not in post-oil shock recession, and Simon lost a similar bet with a forester about the price of timber. The second factor is the mistaken assumption that the ‘Limits to Growth’ model of Jay Forester and his students (e.g. Meadows et al., 1972) has failed, an erroneous perception shared even by most resource scientists. In fact after more than 30 years, that model is almost exactly on target for all 6 major entities simulated (at least if one assumes “resources” are equivalent to petroleum and “pollution” indicates CO₂, SO_x or NO_x). We encourage the reader to go back to the original edition of Limits to Growth (Meadows et al., 1972) and look at Figure 35. Use a ruler to determine the year 2005 on the x axis. After doing this, it should become obvious that the model is a very good predictor, at least so far. To our knowledge, this accuracy is unmatched by any economic prediction model that we have seen yet. Future investigators will be the ones who will see if the rocky future that this model predicts will come to pass. What we can say now, though, with respect to the model’s predictions, is “so far so good”. We need to give the Meadows group more credit, more thought and more visibility, which can be begun by reading their new book on the same subject.

According to Bridge (2001), “there is a postscarcity narrative – a postindustrial (market-generated) resource triumphalism – in which resource scarcity no longer poses a limiting factor to economic development... Neoliberal prescriptions for marketization and privatization have come to dominate nearly all areas of public policy over the last two decades.” Indeed, the material demands for societies continue to grow despite very little empirical data to support the popular idea that economies are becoming more efficient in turning resources into economic production. In fact, considerable empirical data actually suggests that many economies are becoming *less* efficient (see e.g. Ko et al., 1998; Tharakan et al., 2001; Hall and Ko, 2004) even while total consumption increases nearly everywhere. (One partial exception to this statement is seen in the U.S. economy since 1980, where GDP appears to be increasing somewhat more rapidly than the increase in resource use – although about half of that supposed increase in efficiency is through the increased proportional use of higher quality fuels such as primary electricity). An extremely important question becomes: is petroleum a transition element along the energy source road from slaves to draft animals to water power to coal to oil and gas to...something else? Or are liquid and gaseous petroleum one shot, extremely concentrated, relatively environmentally benign, high energy return on investment (EROI) premium fuels that we will never see again at such a large scale? We suspect the latter. A second critical question to which we do not yet know the answer is “which will win the race between innovation/substitution vs. depletion”. In the case of petroleum from the United States, Mother Nature seems to be winning, as the EROI has declined from at least 100 to 1 in 1930 to 18 to 1 in the late 1990s (Hall et al., 1986; Cleveland, 2005). When Cleveland made appropriate corrections for the fact that increasingly we are investing higher quality energies (e.g. electricity) into producing oil over time the “quality corrected” EROI has declined much more sharply, to about 11 to 1. The EROI is probably much lower for finding brand new oil in the United States (rather than for the total effort analyzed by Cleveland which includes mostly pumping out old fields), although I am unaware of any such analysis. Likewise the energy cost of getting a ton of pure copper in the United States has increased despite massive increases in technology because the best ores are long gone (Hall et al., 1986; Bridge 2001).

Essentially no resources today can be viewed as truly sustainable at present rates of production, consumption, and growth because all are subsidized by cheap petroleum. “Sustainability” projects such as those of ecotourism and, indeed, the entire economy of “sustainable” places such as Costa Rica (Hall, 2000) are not sustainable at all due to their ever-increasing dependency on petroleum and the debt that implies. The assumptions of growth-oriented economists have resulted in enormous economic and energy investments in developing tens of thousands of expensive resorts in many lovely but otherwise poverty-stricken tropical areas that are based on the assumption that the people that live there can and should live indefinitely on the crumbs that fall off the tables of the industrial world’s momentarily wealthy. As the supply of cheap petroleum is exhausted through the increased exploitation of the earth’s highest quality and most accessible energy resources while demand for its products continues to grow, the world will likely be in for some very rough sledding ahead. We as a society must recognize the need for a more biophysically-based economic system, which includes a focus on material things such as land, water, soil, food, timber, other fibers and, most importantly, *energy*. The economy must focus once again on the most fundamental issues of providing food, clothing, shelter, basic transportation and other necessities. It must come up with real solutions to the critical problems we face (e.g. energy depletion and impacts, soil erosion, over fishing, water management, massive inequity in the distribution of wealth etc.) that have been neglected thus far due to our temporary patch up “solutions” of cheap oil. We must rethink very carefully what any increase in efficiency might bring because of Jevon’s paradox (e.g. Hall, 2004). We must think about the critically-needed international development assistance in entirely new ways, and we cannot allow an unjustified faith in the supposed virtues of neoclassical economics mask where it is used to sanctify the massive neocolonialism sweeping the less developed world (LeClerc and Hall, in press). If in fact the grim results of the Limits to Growth do come to pass do we castigate those politicians who for “moral” reasons removed population from the agenda of the United States Government? How about those economists who argued foolishly against that model’s utility or, more generally, a biophysical approach to the Earth’s problems? Do we put them in jail for the lives lost and for encouraging us to make investments in the wrong places?

We are often asked whether we are optimistic or pessimistic about the future. Our answer is in theory optimistic, as there are many ways we can utilize and manage resources more intelligently and generate more sustainable societies through, especially, reductions in luxury consumption and the development of solar-based energy systems. But at the moment we are pessimistic as more and more of our fundamental issues and problems are turned over to market economics, which marginalizes the most important parts of our economy using a value system that has little to do with real value to our children, which uses positive discount rates when we should be insisting upon negative ones, also in deference to our children, which worships the false god of growth as providing solutions to the very problems that growth generates, and which assumes the worse in us as a basis for guiding us along the road to the future. If there ever was a recipe for disaster this is it. Future economists will not forgive us.

But at the same time we believe there is good reason to hope, and our next project speaks toward that. We are writing an introductory-level textbook on biophysical economics

(Hall and Klitgaard, in preparation). Neither of us believe that students should simply learn the basics of conventional economics and then take an upper division environmental economics, ecological economics, or even biophysical economics class at some later time to fill in the holes or correct what was learned in the original economics class. The “basics” are too often devoid of scientific data or hypothesis testing, and are often shrouded in myth. The most important principles that students learn should have relatively little to do with how supply and demand curves shift under different assumptions, nor should they be asked simply to accept a set of faith-based postulates on the authority of text and teacher. Rather they need a set of scientific tools that will give them the essence of reality and then allow them to inquire about the ways that humans interact with one another and with the natural world. If you think you might be interested in reading or using such a text, or if you would be interested in trying out a draft copy with your own students, please contact us.

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Additional appropriate references can be found at a supplement to our paper "Hydrocarbons and the Evolution of human culture (Nature 426 no. 6964. p. 318-322).
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