Biophysical Economics: The Economics Perspective

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5.1 Introduction

From its inception, biophysical economics has been dedicated to the unity of the approaches of natural and social science as a way to understand the interaction of humans and nature. This chapter explores methods of better accomplishing this goal. We believe that such a unity of methods of inquiry will produce a deeper understanding of the present and future problems that face us in a potentially energy-short and climate-compromised world. Usually the study of natural and social sciences is approached separately. Ecology and biophysics are studied as natural science while economics and social history as social sciences. Upon what grounds can we unify them?

This unification is not as simple as it may seem, as the methods differ greatly, not only between natural and social sciences but among social sciences themselves. Unlike many natural sciences, social sciences seldom rely on controlled laboratory experiments. If one wanted to test the proposition that lack of adequate nutrition adversely affects learning outcome in young children, it would be ethically suspect to set up a control group and feed them well and simultaneously deprive an experimental group of enough to eat. That would be considered morally reprehensible.

Along with consistent use of the scientific method, natural sciences have principles which all practitioners believe. All natural sciences must be consistent with the laws of thermodynamics and basic principles of evolution. The field of quantum mechanics unified physics and chemistry. All natural sciences share these starting points. The case is not the same with social sciences. Mainstream economists start with the idea that individuals are rational actors who respond to incentives. The goal is to find the right set of incentives to make people with self-regarding preferences cooperate with one another. However, many psychologists are reluctant to accept the rational actor model. Moreover, some try to prove what economists simply assume. Anthropologists study mainly small-scale societies and focus upon culture. Sociologists give primacy to large-scale modern societies. Political scientists believe that political processes determine behavior, while neoclassical economists place very little value on studying social or political institutions [1]. In addition, social sciences usually have a sense of purpose. But a sense of purpose implies delving into the messy world of actual human behavior and fundamental differences in what constitutes a good society. Is a good society one in which market principles are sufficient, or is it a collective society in which the government is the agent of the common good? Does voting imply democracy, or is a large-scale participation of all social classes necessary? Is a good society an equal society or one that rewards individual effort with great riches? Social sciences have debated these topics for ages, and they continue in the present day without being fundamentally resolved. We do not have definitive answers to these questions, but rather the perspective that the role played by energy in providing the material basis for our society needs to be part of the debate. Without understanding the crucial role of energy in transforming the way we do work, the way we consume, and the way we interact with one another, we doubt these debates can ever be resolved.

We cannot speak for all social sciences in this text, although as time passes, the incorporation of more social scientists and their varied approaches into biophysical economics is an important goal. A theoretically and methodologically diverse approach is capable of understanding more dimensions of complex problems than is a single, disciplinary approach. Rather we will focus on the integration of biophysical sciences with economic and historical analysis as we produce biophysical economics. Access to high-quality energy is crucially important in determining what can be produced and how. Discovering and exploiting energy resources takes place in an economic context. For example, coal is abundant and has an energy return on investment (EROI) that exceeds many forms of alternative energy such as wind and solar. Yet, at the same time, coal mines are shutting down, laying off workers, and filing for bankruptcy. Understanding this complex interaction between the possibilities found in nature and those in the human economy is the goal of biophysical economics.

In the previous chapter, we outlined a set of potential principles for biophysical economics from the perspective of biophysical science.

1. The inadequacy of neoclassical economics.
2. The need to incorporate biophysical realities into economics.
3. The importance of the fossil fuel revolution for economic growth.

4. Limits to Growth is a real (if complex) issue: peak oil and declining energy returns on investment (EROI). We must ask the question: Can renewables substitute for fossil fuels?
5. The need to improve and generate better estimates for EROI and equations for biophysical economics.

As we turn, in this chapter, to biophysical economics from a social science approach the list needs to be somewhat modified. The first principle is that biophysical economics needs to include economics. We need to study the economy in its own right and not reduce all human economic activity to questions of access to energy. The most important point is that social and economic principles *must be consistent* with the basic laws of science and with research in other behavioral sciences! With that said, let us now augment the above list.

1. Biophysical economics must go beyond a critique of neoclassical economics.
2. We have done that in many books and articles, including ► Chap. 3, already. Fundamentally, we need to transcend the orthodox ideas of the rational, self-interested, hedonistic, individualistic *homo economicus* operating in the idealized world of perfect competition and replace it with a broader understanding of actual humans who behave in social and institutional contexts. Moreover, biophysical economics needs to transcend the idea that the study of price formation should be the fundamental goal of economics.
3. Building upon point number one, we need to incorporate *economic reality* into biophysical economics.
4. We live in a world economy characterized by large-scale multinational corporations, which maximize profits in the long run and are often more powerful than the governments of the nations in which they operate. In addition, industrial corporations, and not just banks, are often complex financial institutions. General Motors' major profit source comes from its financing operations, General Motors Acceptance Corporation, which also sells home mortgages. We can no longer accept the notion that capital simply denotes means of production in an era where the share of gross domestic product claimed by the Finance, Insurance, and Real Estate (FIRE) sector has increased from about 30% in 1970 to more than 90% now [2]. The economics in biophysical economics must reflect the globalized, financialized, monopolized nature of the actual economy in which we live.
5. One can easily observe the connections between fossil fuel use and economic activity, but biophysical economics must explain the connection more deeply.
6. In other words, what are the causal mechanisms that link increased fuel use to overall economic performance and labor productivity? In ► Chap. 8, we develop such a link. The fundamental question is why did coal-driven steam engines displace water as a power source when coal was expensive and water power was essentially free, once the water wheel was constructed? The answer lies in the connection between human labor and fossil fuels. Water-powered factories were located primarily in rural areas where adequate and disciplined labor supplies were difficult to obtain. In urban centers, such as Manchester, England, large numbers of workers were ready and able to work for mere subsistence wages. The consistent power of a fossil fuel power source allowed manufacturers and inventors to produce self-acting machinery, replacing not only large numbers of workers but also reducing the need for skilled labor in the production process [3, 4]. Business leaders do not want to give up their plans for profit making, capital accumulation, and economic growth simply because high-quality energy is less available or energy prices higher. They will often reorganize the labor process spatially and in terms of skill requirements and number of workers to accomplish their goals. The causal link between fossil fuels and economic performance runs through human labor, and the transition from the solar flow to the terrestrial stock enabled a veritable revolution in labor productivity.
7. Limits to growth are economic as well as biophysical, in the sense that the process of capital accumulation is self-limiting, even without biophysical constraints.
8. There are many limits to growth built into the internal dynamics of the capital accumulation process, resulting in prolonged

periods of slow economic growth. Since the 1930s, economists have called this phenomenon "secular stagnation." Most schools of thought, from the most conservative to the most progressive, have weighed in on the causes of slow economic growth. We would like to assert that the best starting point for the development of a biophysical economic theory of stagnation, one which ties the biophysical limits to the internal dynamics of investment, lies in heterodox political economy and institutional economics, rather than in neoclassical theory. In this context, we will explore a more realistic explanation of the role that technological change plays in economic development based in epoch-making or Promethean innovations that fundamentally reorder economy and society. Answering questions about the adoption of alternative energy sources will require a realistic theory of technological change grounded in actual historical practices and power relations.

9. Developing a more formal analysis for biophysical economics is a good long-term goal, and a great deal of current research is directed toward this goal. However, there is a certain danger in a quest for a formal set of analytical tools in the absence of a solid conceptual model. Nobel Laureate Paul Krugman captured the essence of this problem when he stated: "the economics profession went astray because economists, as a group, mistook beauty, clad in impressive-looking mathematics, for truth" [5]. There are many equations in economics that constrain actual human behavior to fit the equations. If the results do not fit the idea that market economies produce efficiency, equity, and the maximum of human well-being, then the actual behavior is simply dismissed. Inclusion of concentrated industries (or monopoly power) does a great deal of harm to neoclassical theory. That is why monopolization is treated as an afterthought. On the other hand, mathematics can be very useful. It can allow one to put the barrage of data with which we are confronted into recognizable patterns that can be more easily analyzed. Mathematics alone, however, cannot substitute for a theory grounded in economic and biophysical reality. For that, we need to develop a rigorous conceptual model, whose pre-analytical vision is grounded in biophysical and economic reality. We will propose just such a set of models later in this chapter.

5.2 A Selective History of Biophysical Economic Thought

In this section, we will review prior writing by the present authors and their colleagues on biophysical economics. Since biophysical economics has a historical approach as part of its core methodology, many of the articles mentioned contain reviews of a broader literature. The term biophysical economics was first used explicitly in the 1980s by Charles Hall and his colleagues Cutler Cleveland, Robert Costanza, and Robert Kaufmann. In a paper entitled "Energy and the U.S. Economy: A Biophysical Perspective" [6], the authors test several hypotheses relating energy use to economic activity and find that gross national product (GNP) and labor productivity are correlated closely with energy use, especially when corrected for energy quality.

5.2.1 Energy and the US Economy

The economic goals of stable prices, full employment, and increasing per capita wealth were met during the long expansion from 1940 to 1970. After 1973, however, these goals became incompatible. Increased spending produced not stable prices, full employment, and prosperity but simultaneous recession and unemployment. Keynesian tools no longer worked well, and Keynesian theory fell into disarray. The present authors propose alternative explanations to the beginning of the long period of post-1973 stagnation by introducing biophysical factors such as oil consumption, the energy return on investment, and improvements in resource quality into the argument. The paper lists several goals and hypotheses. The approach was to approach macroeconomics from a thermodynamic and production perspective rather than from the traditional neoclassical view of creating well-being by exchange of goods and services for money according to human preferences. In their view, productions upgrade the organizational structure of matter and energy into lower entropy goods and services. Production is a work process which necessitates available free energy. A comprehensive analysis of economic production needs to include the thermodynamics of work. Furthermore, changes in resource quality affect the ease, and cost, of extracting energy and the economic throughput of matter and energy.

They argue that economic policy must incorporate the physical properties of resources, lest the predictions and policy recommendations be less accurate and less effective. They examined the relations between fuel use, economic output, and labor productivity over the 90 years preceding the publication of the article by the method of ordinary least squares using both time series and cross-sectional analyses. They found a high coefficient of determination (R^2) of 0.98 for time series and cross-sectional estimates. This showed a strong link between economic output and fuel use. They found that a large degree of the increase of labor productivity was due to an increase in direct energy use as well as the indirect energy use embodied in capital equipment. This is an excellent example where an understanding of the biophysical basis (increasing energy used per worker per hour) of a social process (increasing labor productivity) is facilitated by a biophysical assessment. Furthermore, they found changes in the price level correlated with changes in the money supply relative to the physical supply of energy but expressed concern that the energy costs of locating, extracting, and refining fuel have risen despite significant technological changes. Technology made previously inaccessible resources economically feasible, but at the expense of increasing energy intensity of extraction. Economic output per unit of fuel use fell 60% since 1939. Oil discoveries peaked in the 1930s, and oil production peaked in the 1970s. Since then, energy returns on investment have fallen from 30:1 in the mid-1960s to 18:1 in 1977 and to 10:1 in 2007. They conclude that if the nation wishes to sustain economic growth, alternative fuels with the same EROI as fossil fuels must be found. In the absence of such discoveries, energy availability and quality will be a limiting factor in continued economic growth.

5.2.2 The Ecology of the Economic Process

Hall, Cleveland, and Kaufmann followed the 1984 *Science* paper with a book-length monograph called *Energy and Resource Quality: The Ecology of the Economic Process* [7] in 1986. In this book, they use the principles of systems ecology to analyze economic processes, defining in the economy how energy is used to transform natural resources into goods and services to meet society's material needs. Energy and economic systems comprise a fundamental, interacting, ecosystem whose mechanism cannot be understood by viewing ecosystems and economies in isolation. Understanding the role of energy in human affairs is tied to virtually all environmental and economic questions, so energy should be an analytical focal point. They state their motivations were a fascination with human-dominated ecosystems based upon fossil fuel consumption and a dissatisfaction with the state of current economic theory. They argued that the energy basis of economic activity, is not all that determines economic phenomena but should be a crucial component to supplement standard economic analysis. This book provided detailed analyses of thermodynamics, the energy requirements of human activity, and the concept of the energy return on investment, then expressed in kilocalories.

The book introduced the method of careful examination of schools of economic thought that could serve as alternatives to the inadequately developed neoclassical economics, including the well-known figures from classical political economy such as the Physiocrats, Adam Smith, David Ricardo, and Karl Marx, along with lesser known luminaries such as Sergei Podolinsky, Fred Cottrell, Frederick Soddy, and Wilhelm Ostwald who included biophysical phenomena in their social and economic analyses. They also included a series of diagrams and conceptual models, such as the economic activity as a continuous process from solar energy to extraction, to production, to consumption and waste, along with a model of an economy embedded within a flow of energy from the sun through the ecosystem through the economy, and finally to waste heat. These models appeared in other articles by Hall and colleagues, as well as in the pages the first edition of this book (Figs. 5.1, 5.2, and 5.3). At this early stage of theoretical development, they simply inserted a circular flow of exchange value into the biophysical flows of energy and materials. Later in this chapter, we will present some more sophisticated approaches. The book provides detailed analyses of the availability of many energy sources, from conventional oil to solar power, and very detailed studies of the EROIs of agriculture, imported oil, gas, coal, and nuclear power, including the then-unanticipated costs. The book continues with a section on the general impacts of burning fossil fuels, including changes in atmospheric concentrations of carbon dioxide, human effects upon the carbon cycle, ocean acidification, and crop production. The book ends with an editorial on the fading beacon of economic growth and the stark choices that face society as the availability and quantity of oil decline.

5.2.3 Historical Perspective and Current Research Trends

The next year Cutler Cleveland produced an essay on the historical perspective and current research trends in biophysical economics [8]. Here he augmented themes that first appeared in the 1984 and 1986 works with Hall, Kaufmann, and Costanza. Ignoring physical laws has prevented standard economics from understanding fully the economic significance of changes in energy quality upon basic support service and waste assimilation. Furthermore, economic factors of production such as labor and capital depend upon low-entropy matter and energy. Neither capital nor labor, alone or in combination, can create natural resources. Cleveland provides a more detailed history of economic analysis starting with the Physiocrats and classical political economists. He then integrates the laws of thermodynamics into economic theory in a more detailed manner with the work of Podolinsky and concludes that the ultimate limits to economic growth lay not in the relations of production but in physical and economic laws. Later in this chapter, we will argue that a more complete understanding of the growth process will stem from a fuller understanding of the interaction of biophysical and internal limits found in the relations of production. Cleveland expands his analysis by focusing on Frederick Soddy, who developed an economic analysis on biophysical first principles, Alfred Lotka who initiated the discussion of Maximum Power, and the technocratic movement, who advocated a society run by technocrats rather than politicians and businessmen. Special mention is reserved for M. King Hubbert, who first enunciated the theory of peak oil and asserted that the industrial and fossil fuel era is just a transitory phase in human history. The work of Hubbert and Lotka were reflected in the work of pioneering systems ecologist Howard T. Odum who developed a systematic methodology for using energy laws to analyze the combined system of humans and nature. The *Ecological Modelling* article shows how biophysical economics was enhance by the empirical work of Energy Resources Group at the University of Illinois who developed an input-output model based on energy flows from which to calculate direct and indirect energy costs.

Particular praise is heaped upon Nicholas Georgescu-Roegen and his student, Herman Daly, for formally incorporating the laws of thermodynamics, especially the entropy law, into economic theory. Georgescu-Roegen asserted that thermodynamics was the physics of economic value and that it was the most economic of all physical laws, as it came from Sadi Carnot's experiments upon that human creation: the steam engine. This rendered the economic process unidirectional and not circular, as low-entropy energy and matter are transformed into high-entropy waste in the process of production. But the steps in between are what interests humans. Yet human agency is required to produce happiness in the human world. Low-entropy matter and energy are necessary but not sufficient.

The article ends by enunciating the principle that the absence of biophysical principles renders economic growth theory unable to make viable predictions about long-term trends, given the large and unexplained statistical residuals that are attributed to a vague and simplistic notion of exogenous technological change. From a biophysical perspective, standard economic theory needs to pay attention to the economic impacts of how changes in resource quality affect humans.

5.2.4 The Need to Reintegrate the Natural Sciences with Economics

In 2001, Charles Hall and colleagues published an article in *BioScience* calling for less isolation among academic disciplines related to economics [9]. They begin by asserting that wealth that is distributed in markets must be produced in the natural world. As part of the natural world, production must obey the laws of physics, chemistry, and biology. Unfortunately, standard economic models disregard key aspects of production. This was not always the case, as the theories of classical political economy were more fundamentally grounded in nature. Physiocratic theory gave primacy to the land as the most fundamental component in the production of wealth. For classical political economists like Adam Smith, Thomas Malthus, and David Ricardo, land as a fixed factor of production gave rise to diminishing marginal returns and the tendency of wages to drop toward subsistence level. Karl Marx was probably the first political economist of the fossil fuel era, and he fully understood the potential of coal-driven machinery to augment, and sometimes displace, human labor, resulting in rising productivity. By the 1870s, classical political economy was supplanted by neoclassical economics, so today most of the world's economic decisions are based on models that are inconsistent with nature. Hall et al. argue neoclassical theory is inadequate because (1) it is not grounded in the biophysical world (2) the basic principles of economics are logical posits, not tested hypotheses. They do not contain a flow of energy through the system but focus entirely on markets and exchange. They suggest that the circular flow model be replaced by a model that embeds the economy in the necessary energy flows, the model first introduced in *Ecology of the Economic Process*. They also critique mainstream theory for its validation processes. The fundamental assumptions about human behavior, such as acquisitiveness, rationality, and self-regarding preferences, are never put to statistical testing. Economists assert these are "maintained hypotheses" that do not require testing. However, from the biophysical point of view, these assumptions should be subjected to empirical verification.

The authors then ask the question, why does neoclassical economics assign such a low value to nature? Conventional economists do so because advanced industrial economies spend only 5–6% of their economic output on energy, which therefore gives energy a low value by the economists' monetary criteria. Although fossil-derived energy gives each of us 70–80 "energy slaves" to do the hard physical labor of yesteryear, energy is usually not included whatsoever in neoclassical production functions. The article then extends the prior work of one of the coauthors, Reiner Kümmel, who inserted both energy and creativity into the basic production function postulated by Robert Solow in his famous 1956 article "A Contribution to the Theory of Economic Growth." Solow used capital and labor as the sole independent variables in his equation, and the equations were structured to allow ample substitution of inputs (by using a Cobb-Douglas production function). While the model produced a steady-state growth path in place of the volatility of earlier models by Roy Harrod and Evsey Domar, it also produced an unexplained residual of up to 70% which Solow attributed to technological improvement (this was called the "Solow residual"). When Kümmel and colleagues included energy and creativity in the list of independent variables, after taking the elasticities (or %Δ in result/%Δ in cause) of all independent variables, and testing them with a LINEX function, the residual virtually disappeared. Energy explained nearly all of the "Solow residual" and was more powerful than either capital or labor! The social implications include the prediction that expensive labor will continue to be replaced by cheap capital and energy. Price does not always reflect scarcity and importance, and the goal of sustainable development must be reconsidered carefully in the light of energy and materials requirements. In less developed nations, policies based on neoclassical economics may lead to an overexpansion of debt, and humans tend to seek political explanations for events precipitated by biophysical causes. Biological implications of the analysis are based on the fact that agriculture, medical technology, wildlife management, and conservation all require energy. Human well-being stems from the redirecting of energy from natural food chains and processes to human ends. Finally, overpopulation, groundwater pollution, and changes in the carbon cycle and composition of the atmosphere are not externalities but part of the fossil fuel system.

5.2.5 The Early History of Modern Ecological Economics

In 2004, Ingrid Røpke authored a review article on "The Early History of Ecological Economics" [10]. She raised several methodological issues about the social and internal process of research in a quest to trace the approach to intellectual rigor. She also included institutional contexts and political factors, as well as diffused social influences. She contends that early ecological economics was quite open to diverse ideas in its conference and the pages of its journal, *Ecological Economics*. Early ecological economics conceptualized the economy in terms used to describe nature, and the focus on thermodynamics revealed half-forgotten authors that not even Nicholas Georgescu-Roegen was aware of when he wrote *The Entropy Law and the Economic Process*. These many authors showed the groundbreaking work in the 1970s through the 1990s to ground economics in biophysical reality. This is, perhaps, best summed up by a quote from English economist Mick Common. "You can't understand the last 200 years of human history without understanding energy. We could have accumulated vast amounts of capital, but it wouldn't have done what it has done for us, had it not exploited fossil fuels. Energy is what you need to do work, and doing work is what economics is all about."

Røpke listed many important themes and observations, most of which have to do with energy quality. They included the ideas that the decline in energy used per unit of gross domestic product was the result of using higher-quality fuels. Regarding labor productivity, technological change relies on capital that uses more fossil fuels per laborer, so increased labor productivity can be attributed to fossil fuels. Agriculture captures solar energy, but modern, fossil fuel-driven agriculture is far less efficient. Empirical models, such as input-output, along with distribution theory analyze the effects of energy taxation. She also asks the questions: do prices correlate with direct and indirect energy inputs? Does embodied energy provide a good measure of the value of goods and service? Røpke discusses the role played by systems theory, especially that derived from the work of Ilya Prigogine, as well as by institutional economists such as the French Regulationist School, although she recognizes that environmental analyses played only a small part in many institutionalist journals. Early ecological economics was a meeting place for researchers committed to the idea that environmental issues and biophysical limits needed to be taken seriously.

5.2.6 A New Biophysically Based Paradigm

The 2006 publication of "The Need for a New, Biophysically-Based Paradigm in Economics for the Second Half of the Age of Oil" [11] marked the first scholarly collaboration between Charles Hall and Kent Klitgaard. The paper began with the familiar critique of neoclassical economics and indicated the skepticism of the basic conceptual model among prominent economists and Nobel Laureates. But the article also introduced a new critique of ecological economics. As seen in the Røpke survey article mentioned above, ecological economics began with a call for transdisciplinary research and a commitment to methodological pluralism. By 2006, according to the authors, ecological economics had abandoned its roots and has become, in essence, a branch of mainstream environmental economics specializing in putting a monetary value on ecosystem services and natural capital.

Hall and Klitgaard then reiterate the transition from a more biophysically-based approach that characterized classical political economy to the abandonment of biophysical reality with the transition to neoclassical economics that limited its research agenda to the study of the exchange process, based on hedonistic human behavior and perfectly competitive markets. The article criticized the use of neoclassical production functions for the exclusion of energy and energy quality as an independent variable, showing that such models did not produce accurate results or predictions. The authors asserted that economics should not be solely a social science at the expense of biophysical science; stated that the object of biophysical economics was to study the biological and physical properties, structures, and processes to the actual economy; and advocated the methods of systems ecology as a starting point. The paper ends by asking the question "are we optimistic or pessimistic?" The authors expressed optimism that there are far superior ways of using resources than those of the present but pessimistic in that the decisions are too often left to market processes.

5.2.7 EROI, Peak Oil, and the End of Economic Growth

The year 2011 saw the publication of 21 articles that showed the theoretical diversity that constitutes biophysical economics. David Murphy and Charles Hall collaborated on a paper in "Ecological Economic Reviews" asserting that the causes of the long-term economic slowdown and the financial crisis of 2008–2009 could be attributed to changes in energy supply and fuel prices [12]. For the past 40 years, increased use of fossil fuels has driven economic growth. The ability to increase the global supply in the future is doubtful, given the depletion of cheaper, and easier to access, conventional oil and their replacement with lower-quality unconventional, and more expensive, sources such as deepwater wells and Canadian oil sands. This situation creates a series of feedbacks that the authors term the economic growth paradox. Further increases in oil use, given the depletion of low-cost fuel sources, will require rising energy prices; the higher prices reduce quantities demanded of fuel which dampens economic growth. Consequently, the economic growth of the last 40 years is unlikely to continue without some remarkable change in how we manage the economy.

Historically, there has been a tight correlation between oil consumption and economic growth, and aside from a few interruptions, oil supplies have kept pace with demand. Since 1970, oil consumption has increased by 40% and GDP has tripled. However, since US oil production peaked in 1970, every oil price spike has been followed by a recession. The article shows that the 1973 oil shortage produced four effects.

1. There was a decline in oil consumption.
2. The capital stock and existing technologies became too expensive to operate at higher-energy prices.
3. Marginal cost increased for manufactured goods.
4. The cost of transport fuels rose.

Expansionary periods showed the opposite trends. Lower oil prices and higher consumption were indicative of a growing economy. During times of economic expansion, oil prices averaged $37 per barrel, while they averaged $58/barrel in times of recession. Oil consumption rose 2% per annum in expansionary years and declined by 3% during recessions. According to the authors, rising oil prices are not compatible with long-term expansion. Evidence for this proposition includes the fact that production now exceeds discoveries, oil production is flat despite rising oil prices, and most of the easy-to-find oil has already been found. Much of the increase in the world's oil supply in the period of 2004–2008 came not from increases in new sources but from a drawing down of Saudi spare capacity, which fell from 6% to 2% over these years. Oil production has leveled off despite higher prices, which is an empirical phenomenon in conflict with standard economic theory. Murphy and Hall respond to critics of peak oil theory by saying to the critics who believe sufficient substitutes will be forthcoming, given the correct price incentives, by stating "you can't produce what you can't find." There is no substitute for conventional oil at the same price and the same quality.

The paper then turns to an analysis of energy returns on investment. The authors cite energy analyst Nate Gagnon's research who states that the EROI for oil from all publicly traded international companies fell from 36:1 in the 1990s to 18:1 in 2004. That was due to the fact that new sources of oil are more energy intensive to produce than are old ones and that enhanced recovery techniques that boosted production for 4 years had a short life. Oil production in fields such as Mexico's Cantarell fell precipitously in this time period. The authors predict that the production of conventional oil will continue to decline in the coming years. This renders the business-as-usual strategy of pursuing economic growth untenable because of the economic growth paradox. The causes of economic stagnation and recession can be found in the biophysical explanation of this paradox. Economic growth spurs oil demand. Increased oil production can only be met from lower EROI sources. As extraction costs rise, so do oil prices. The price increases stall economic growth, and the contraction reduces the demand for oil. The reduced demand results in lower prices. Peak oil is likely to take the form of an "undulating plateau" instead of a nicely formed Gaussian maximum. But, in the end the higher prices of more costly, lower EROI, fuels will dampen future economic growth.

5.2.8 Ecological Economics and Institutional Change

Lisi Krall and Kent Klitgaard also published, in 2011, a biophysical critique of mainstream ecological economics and its inability to understand the changes necessary to achieve economic justice while living within the Earth's finite limits [13]. They begin by recognizing the importance of the embedded economy as a conceptual model. Yet they criticize ecological economics for allotting too much effort to finding the right price for nature in the form of valuing natural capital and ecosystem services, and too little to understanding the foundational underpinnings and internal logic of a capitalist economy This is due largely to the affinity of many ecological economists to neoclassical methods and to their reluctance to consider fundamental social and institutional change as necessary to achieve sustainability. This leads to a cursory understanding of the systems dynamics. For example, in Costanza et al.'s *Introduction to Ecological Economics*, the authors survey, as did Cleveland, earlier economic thought. However, the reader sees Smith without the division of labor, Malthus and Ricardo without the Corn Laws, and Marx without crisis theory, the essence of these authors analyses. The early ecological treatment of the history of political economy focused primarily on enunciating the biophysical principles found in classical political economy, but did so without a broad understanding of the political and economic conditions under which these theories were advanced. Furthermore, Daly provides the neoclassical criterion of setting marginal benefits equal to marginal costs to determine when to stop producing at the macroeconomic level. However, the problem is not just *when to stop, but how to stop.*

Krall and Klitgaard contend that ecological economics has split into two branches, one focusing on valuing natural capital and the second on developing steady-state economies, and that both flow from the original work of Herman Daly. Daly contends that an economy, when it is working well, does three things. It allocates goods and services, distributes income, and determines macroeconomic scale. He proposes standards and methods for evaluating these goals. Daly also asserts that these three categories can be separated analytically. The criterion for allocation is efficiency, which can best be left to markets. Distribution should be based on justice, and macroeconomic scale should be based on sustainability or living well within Earth's limits. These last two features need to be planned. But how does one plan for justice and the absence of growth in a system that produces inequality along with goods and services and depends upon growth, without subjecting the population to increased poverty, unemployment, and lack of opportunities? Moreover, in the actual economy, allocation, distribution, and macroeconomic scale are united in the process of the reinvestment of society's economic surplus. Herman Daly was not the first to separate these categories analytically. Paul Samuelson did much the same in 1947 with his "grand neoclassical synthesis." The differences between Samuelson and Daly were that Samuelson believed that income distribution problems could be solved by the market, as could allocation, and that the government should be responsible for promoting economic growth. Daly, instead, was a proponent of a steady-state, no-growth economy, where well-being and development could be divorced from economic growth by limiting the throughput of matter and energy to the economic system, while increasing its efficiency.

However, as business historian Alfred Chandler points out in *The Visible Hand*, the efficiency improvements of the industrial revolution came by means of *increasing throughput!* This creates a conflict between the firm's need to grow and the biophysical need to reduce growth. Moreover, the purpose of a capitalist enterprise, from the smallest entrepreneur to the largest multinational corporation, is to reduce costs, expand market share, and plow the profits into increased scale of operations. Krall and Klitgaard assert that the logic of profit making at the firm level is incompatible with eliminating growth at the macroeconomic level. To achieve a steady state and any hope of sustainability, the fundamental logic of the system must be brought to the fore. The authors make the case that ecological (and biophysical) economics would be best served by abandoning neoclassical ideology as soon as possible and build a better theory based on heterodox political economy and institutional economics. They give a brief introduction to the main heterodox and institutional schools that prevail today: Social Structure of Accumulation, the Monthly Review School, and the Development without

Growth approach. The emphasis is on the compatibility of the logic of capital accumulation and the social institutions that enable it. The article ends with a quote from Thomas Jefferson. "Laws and institutions must go hand in hand with the progress of the human mind. As that becomes more developed, more enlightened, as new discoveries are made, new truths disclosed, and manners and opinions change with the change in circumstances, institutions must advance also, to keep pace with the times."

5.2.9 Ecological Economics, Degrowth, and Institutional Change

The next year, Klitgaard and Krall followed their 2011 article with a more comprehensive explication of heterodox and institutional theories [14]. They present evidence, in the form of US and global rates of investment, profits, productivity, and gross domestic product, that the age of economic growth is coming to an end. They attribute this decline to both biophysical constraints of declining energy quality and rising cost and to the internal dynamics of the capital accumulation process. Evidence shows that the economic output has been increasing at a decreasing rate since the 1970s and that employment is linked to the percentage growth rate of investment and final demand. At the same time, total output has tripled since 1970. It is the absolute accumulation of the effluents of this growth that is pressuring the environment. This creates the dilemma that we are growing both too slowly and too fast at the same time. Economic growth rates are not sufficient to support increasing employment but are too fast to live within nature's biophysical limits. The authors contend that if ecological and biophysical economists do not pay adequate attention to the social dimensions of unemployment and economic stagnation, their valuable insights on living within the planet's biophysical limits will be ignored or rejected by the population as a whole. This creates a difficult situation in that, if the economic system reaches its internal limits at the same time the biophysical limits are reached, a transition to a sustainable economy will be exceedingly difficult. To understand the possible trajectories of transition at this historical moment, we must understand the interaction of the economy and the biophysical world as a complex system and understand the boundaries, inputs, outputs, and feedback mechanisms. Mainstream, neoclassical, and Keynesian economics do not provide an adequate basis for systematic analysis in the modern era. The authors reiterate their call for the adoption of models based in heterodox political economy and institutional economics as the basis of a viable model of the social component of biophysical economics. Neither mainstream Keynesianism nor neoclassical theory recognizes sufficiently the existence of internal limits to growth that accompany the biophysical limits to growth. Heterodox political economy and institutional economics build the social limits to growth into the core of their theories and are therefore more compatible with a biophysical approach than are mainstream analyses.

Political economists have been writing about the economy as a system since the 1700s. Smith, Ricardo, John Stuart Mill, and Marx all presented comprehensive, systematic expositions of how the economy works. In the late 1930s and immediate post-Second World War period, Keynesian economists such as Evsey Domar, Alvin Hansen, and Roy Harrod presented analyses as to how the internal dynamics of the investment process led to cyclical instability and long-term stagnation. Political economists Paul Baran and Paul Sweezy surveyed the work of these economists, plus the writings in the Austrian, Marxist, and institutional traditions to produce a theory that because of the ability to produce a surplus, the problem was one of how that surplus could be spent. If not enough ways to spend the surplus could be found, the result would be chronic stagnation or low growth rates. In the 1980s, a school of thought called the *Social Structure of Accumulation* evolved from studies of how changes in the institutions of the labor process and labor markets impacted the long swings of prosperity and stagnation. By the 1990s, this analysis was elevated to include more macroeconomic variables. They recognize the advent of neoliberalism, based on privatization, remilitarization, and the distribution of wealth from labor to capital which heralded the emergence of a new Social Structure of Accumulation in the top tiers of society. The neoliberal era was grounded in growth-oriented policies that could not produce growth. The average growth rate in the decade of the 2000s, when many neoliberal policies were implemented, was a mere one-tenth of 1% higher than was the growth rate of the depression decade of the 1930s. Neoliberals call for a return to market principles of price competition to restore economic growth and stability. Historically, however, the regulatory mechanism has been one of the periodic depressions rather than subtle price adjustments driven by competition. Klitgaard and Krall end their article with a call for a new economic framework that focuses on the interaction between the internal and biophysical limits to growth. They question whether the present institutional arrangements of globalized and monopolized multinational corporations and governments that serve their interests can provide enough employment while sustaining the biophysical integrity of the planet.

5.3 Hydrocarbons and the Illusion of Sustainability

In 2016, Kent Klitgaard published an article entitled "Hydrocarbons and the Illusion of Sustainability" [15] in the special issue of *Monthly Review*, commemorating the 50th anniversary of the publication of Baran and Sweezy's *Monopoly Capital*. Klitgaard contends that although energy issues played but a minor role in Baran and Sweezy's *opus*, they presented an excellent method by which to analyze current energy dilemmas and biophysical limits, within a context of the limits found in the dynamics of the capital accumulation process. He chronicles recent declines in resource quality, the economic effects of oil price spikes, and the recent bankruptcies of coal companies. After a brief summary of the theory of monopoly capital, Klitgaard goes on to argue that the formation of monopolies went hand in hand with hydrocarbon development, from the mid-1500s when the London Hostmen's guild gained control of the British coal trade in order to restrict output and maintain prices to the role of Standard Oil in forming a domestic monopoly and becoming the world's first powerful multinational corporation. He incorporates the theory of fossil capital to argue that without access to coal to power industrial machinery, the industrial revolution would probably never have occurred. It was the switch from the solar flow to the terrestrial stock that allowed early industrialists to discipline labor adequately, drive down wages, and reduce the price of wage goods.

If, as Baran and Sweezy argue, the normal stage of monopoly capitalism is economic stagnation, what accounts for periods of prosperity? The authors of *Monopoly Capital* provide evidence that war and its aftermath and epoch-making innovations propel periods of above-normal growth. Klitgaard points out that all the epoch-making innovations that drive prosperity, the steam engine, the railroad, and the automobile, were fossil fuel intensive. He also referred to a letter from Sweezy to Nicholas Georgescu-Roegen (graciously given to Kent Klitgaard by John Gowdy, Georgescu-Roegen's PhD student) that showed not only the close personal and professional connection between Sweezy and Georgescu but also the close connection between epoch-making innovations and the species-altering "Promethean Innovations" developed by Georgescu-Roegen. In one of Sweezy's last *Monthly Review* articles, entitled "Capitalism and the Environment," Sweezy attributed growing environmental destruction to not only the increase in fossil fuel consumption but to the dynamics of capital accumulation itself. Capitalism depends upon capital accumulation, and degrowth and the steady-state economy needed to achieve life within biophysical limits are incompatible with a system that needs to grow forever. We need a system based upon decent work, equitable distribution, and respect for nature's limits, not one based on inequality and endless expansion.

5.4 Toward an Economic Theory for Biophysical Economics

A biophysical economic theory must be consistent with the principles of biophysical science. Such a theory must also be grounded in a solid historical understanding of how an actual economy works. The economic arguments of biophysical economics to date have dwelled mostly with the shortcoming of neoclassical economics and with a search for elements of greater understanding in classical political economy that preceded neoclassical economics. As seen in ► Chap. 2, classical political economists mostly lived in a world that either predated the world of fossil energy or was written at the formative years of the fossil economy. For them, land was a fixed factor of production that begrudgingly yielded its output. The transition to the tremendously productive power embodied in the chemical bonds of hydrogen and carbon allowed economists to stop thinking about the constraints of absolute scarcity, subsistence wages, and the inevitable arrival of the stationary state. Now all scarcity was relative to individuals' supposedly insatiable need for material comforts. Economics became the study of exchange processes and price formation. This critique has appeared regularly in the biophysical economic literature since the 1980s. The boundaries of the neoclassical system are drawn incorrectly as they do not include inputs of high-quality energy nor heat waste. Neoclassical economics ignores the second law of thermodynamics. The neoclassical framework is dominated by negative or self-canceling feedback mechanisms. Without these, self-regulation would be impossible. Moreover, neoclassical analysis ignores positive feedbacks. Positive or self-perpetuating feedbacks potentially produce tipping points and the need for fundamental, systemic, change. Maurice Dobb [16] makes the point that all new theories begin with a critique of the old. Yet it is now time to start building a biophysical theory on new methods and new ideas. In short, it is time to link theoretically the internal limits to real-world economic systems with the biophysical limits. While it is certainly possible that contemporary neoclassical economists could contribute to biophysical economics, or that the techniques of the paradigm may be useful, biophysical economics tends to reject the dominant neoclassical framework due to its inconsistencies with biophysical science. We, for example, do not advocate a rejection of all standard approaches to the quantification of money. Where then can one find a sophisticated framework by which one can make the causal link between energy quality and availability and economic outcomes?

It is now time to begin constructing such a theory. We propose that the theory starts with the actual economy that we experience today. The economy is global, concentrated, and driven by the needs of finance. It is time to abandon the unrealistic abstraction of perfect competition. A viable biophysical economic theory must be consistent with the known laws of science and the current level of research in other social science disciplines such as anthropology, political science, psychology, and sociology. It includes the notion of the embedded economy, in which the economy is a subsystem of both society and nature. The idea of an economy embedded in a larger society dates back to Karl Polanyi, and the notion of an economy embedded in a biophysical system and its energy flows traces back to at least Nicholas Georgescu-Roegen and his student Herman Daly. These ideas are abstractions, but much more realistic and complete abstractions than are those of the pure exchange economy. Biophysical economics should also include a theory of technological change, whereby changes in technology are both embodied in the economy, rather than appearing as "manna from heaven" as in much neoclassical growth theory, and can result in profound social and geographical reorganization of the economy and of society. A biophysical economic theory should also realize that the slow growth of the past four decades is not simply an aberration nor the result of poor policy choices. Rather, secular stagnation is as embedded in our current system as the economy is in nature. Slow growth is the result of changes in the accumulation process. These changes began to occur even before the age of declining resource quality and falling EROI. The economy has its own internal dynamic that operates in conjunction with biophysical constraints. It is crucial to understand both sets of limits to growth to address the problems of providing reasonable incomes and decent work to the majority of the world's population as we approach the world of the future that is likely to be slow growing, energy short, and climate compromised.

5.5 Secular Stagnation, the Theory of Monopoly Capital, and the Institutions of Accumulation

The term "secular stagnation" was coined by Alvin Harvey Hansen in his 1938 book *Full Recovery or Stagnation*, meant to explain the second crash of the Great Depression and extend Keynes' idea of an underemployment equilibrium to the long term [17]. US unemployment in 1937 rose from a level of 14% that year to 19% in 1938 and not falling into "single digits" until the Second World War began. In Hansen's terminology, the Recession of 1937 commenced long before "full recovery" occurred. Hansen believed that a mature economy, whose basic industrial infrastructure had long ago been "built from scratch," would face limited investment opportunities in the future. The epoch-making innovations of the past, such as the railroads and automobiles, were unlikely to provide for vibrant investment in the future. Furthermore, the geographical frontiers of the country had been reached, and population growth was in decline. Parenthetically, after the war when the "baby boom" began, Hansen wrote an article in *Life* Magazine declaring that kids were a built-in tool to fight recession, as the spending to support them would increase aggregate demand. He argued that stagnation was caused by shortfalls in investment and these could be caused by a number of reasons including income inequality that limits purchasing power and consumption demand, excess capacity, and market saturation. With investment opportunities vanishing, Hansen called for policies of constant and large-scale deficit spending on the part of the government to provide the demand that the private sector could not. The long postwar expansion and a new automobile boom seemed to relegate Hansen's theory to an interesting theory of the past until the economy began to stagnate in the 1970s. Forty-five years later, Lawrence Summers, former Harvard president, vice-president of the World Bank, and architect of neoliberalism, told the Federal Reserve Board that the country was, once again, in a state of secular stagnation. The response of mainstream economists ranged from dismissal to embrace. Mainstream critiques, dubbed Mainstream Ideas of Secular Stagnation (MISS), fell into two camps. Conservative economists tended to blame the slowdown in growth on exogenous, supply-side factors that would limit productivity growth such as an antibusiness climate and government regulations that raised business costs, a dysfunctional labor market where workers' skills were mismatched with available jobs, a lack of infrastructure spending, and stasis in retailing. None mention declining energy quality as a supply constraint. Liberal economists tended to favor demand-side explanations such as a reduction in capital investment associated with the digital economy (a server bank and internet connection requires fewer investment funds than does a steel mill or power plant), a debt overhang from the previous financial explosion, and credit markets that are insufficiently flexible to allow an interest rate that is low enough (essentially negative) to enable monetary policy to produce full employment [18]. Hans Despain contends that neither liberal nor conservative mainstream approaches capture the essence of the problem: that secular stagnation is built into the dynamics of the capital accumulation process.

Scholars of the left have understood this connection since the early 1930s. Michael Kalecki, a contemporary of Keynes who had published Keynes' entire system, and more, in Polish 3 years before the publication of the *General Theory*, asserted that the natural outcome of competition is monopoly concentration. The degree of monopoly could be calculated by measuring the ability to mark up prices over prime costs such as labor, machinery, and energy. This is a crucial element for a biophysical economic theory as it means in the modern economy prices are administered and not set by supply and demand. If biophysical economics is to be more than just another branch of mainstream economics, it needs to develop a sophisticated theory of administered pricing, especially as regards energy. Kalecki also recognized that the great tragedy of investment was that it was useful and could be easily overbuilt. He also realized that business cycles, in the age of demand management and fiat money, are political and can be manipulated by government policy. Josef Steindl, following in Kalecki's footsteps, asserted that endogenous factors, especially the concentration of oligopolies, were the root cause of long-term stagnation. In a competitive economy, falling profit margins due to unused productive capacity would mean bankruptcy. But in a concentrated economy, large corporations adjust to market conditions by reducing quantity not reducing prices. The increase in monopolization thereby raises profit margins but also increases excess capacity. Although gross profits may rise, excess capacity reduces net profit margins and investment stagnates because investors do not see sufficient profits forthcoming by building new capital equipment when they can utilize what they already have [18].

Paul Baran and Paul Sweezy also analyzed the mature capitalist economy in their 1966 work, *Monopoly Capital*. Their book provoked considerable controversy among political economists because they argued that Marx's observation of the tendency for the rate of profit to fall was driven by price competition. But once Marx's prediction that competitive firms were replaced by concentrated and centralized industries (now called oligopolies), the tendency for the rate of profit to fall should be replaced by the tendency of the economic surplus to rise. Starting from the classical notion of economic surplus, or the difference between the value of the output and the sum of subsistence consumption and replacement investment, they argued that modern capitalism is dominated by giant corporations (or oligopolies) which maximize long-term profits by administering prices, avoiding price competition, extending market share, and reducing the cost of production. This hypothesis of the 1960s is backed up by considerable evidence in the second decade of the twenty-first century. The number of industries in which the top four firms control 50% or more of the market has risen from 5 to 185 since the 1950s. Gross profits of the top 200 US corporations have risen from about 14% in 1950 to approximately 30% in 2008.

As a result, the economic surplus tends to rise and needs to be absorbed by finding adequate spending outlets. If it is not, production will decline and chronic stagnation will appear. Baran and Sweezy stated that there were three methods of absorbing this rising economic surplus: it could be consumed, invested, or simply wasted. To analyze the increase in consumption to levels sufficient to avoid stagnation, Baran and Sweezy chronicle the development of the "sales effort." Mass consumption was not the result of rational consumers maximizing their subjective utilities subject to limited incomes, but a conscious effort on the part of profit-seeking corporations and the state to assure that consumption levels are adequate to absorb economic surplus by creating needs that did not exist in the past and products to fulfill them. Investment directly absorbs the economic surplus but simultaneously creates more surplus to be absorbed in the next period. Waste such as planned obsolescence or excessive military spending could also serve as a potential absorber as well as war itself. Baran and Sweezy show that a market economy would succumb to long-term stagnation in the absence of waste. If they are correct, moving toward sustainability by reducing waste may exacerbate the economic stagnation that is already occurring within our current economic structure. If the economy depends upon ever-growing consumption, then it will be quite difficult to live well within nature's limits, especially as the fossil energy needed to produce the goods and services is declining in quality. It is certainly possible to see the overextension of credit in our present era in the same vein. Certainly, in a rationally planned economy, employment could be boosted, and the environment improved, by large-scale public investment in nonfossil transportation and the construction of a nonfossil infrastructure. However, Baran and Sweezy argue that large-scale public investment would not absorb sufficiently the economic surplus generated by the economy because of the power relations of monopoly capitalism. Public investment that competed effectively with the private sector would be kept within limits. Their argument seems to have contemporary relevance, as the role of the government as a demand manager is being debated both in the United States and in Europe at the present time.

Because of the chronically unabsorbed surplus, the normal state of a concentrated industrial economy is slow growth, or secular stagnation, not the assumed steady-state growth path of neoclassical economics. In fact, the economic literature also refers to secular stagnation as the "Sweezy normal state." However, if stagnation is the normal state of the economy, how would one explain periods of prosperity such as those that occurred in the 1960s? One biophysical explanation is low oil prices for a prolonged period that allowed for the increase in labor productivity. Yet the theory of monopoly capitalism adds a different dimension. Baran and Sweezy attributed prosperity to either war and its aftermath or epoch-making innovations. The end of the Second World War saw the United States rise to the position of global hegemon. It controlled the world's financial system, had sole possession of nuclear weapons until the late 1940s, and had the world's only viable industry after the war. By the 1970s, the international monetary accords had fallen apart, Germany and Japan had caught up industrially with the United States, and the United States spent billions of dollars fighting wars in Southeast Asia. Epoch-making innovations that stimulate demand and employment, absorb vast quantities of investment capital, create myriad peripheral industries, and result in large-scale geographic shifts are few and far between. Baran and Sweezy list only three: the steam engine, the railroad, and the automobile. All these innovations were propelled by cheap and available fossil fuel. Without the automobile, we would not have the shopping mall, suburban housing, fast food, nor the soccer mom. In the era of declining energy quality and availability, will there be an alternative vehicle by which to absorb surplus? Certainly, the Internet and social media have provided nowhere near the same levels of employment and investment, although they are a ubiquitous part of the lives of many today. Biophysical economics would be well served by developing a theory that links fossil fuel use to the institutions of accumulation and the needs for employment.

In the 1980s, Sweezy and Harry Magdoff turned their attention to the rise of financial institutions in the pages of their journal, *Monthly Review*. They argued against the mainstream proposition that the exploding number of financial instruments were dragging down real investment. Rather they asserted, and backed with considerable statistical evidence, that investment funds were flowing toward Finance, Insurance, and Real Estate (FIRE) precisely because the real economy was stagnant and profitable investments were not forthcoming, especially in the second half of the age of oil. The share of GDP accruing to the FIRE sector increased from about 30% at the start of the second half of the age of oil (1970) to more than 90% by 2010 [2]. To put the matter bluntly, the economy was kept from even more serious stagnation by a combination of military spending, financial speculation, and conspicuous consumption. How is sustainability to be accomplished without a fundamental reorganization of society's institutions when these are the primary drivers of even sluggish growth?

5.6 The Social Structure of Accumulation

Further explorations in political economy and institutional economics have focused upon the interaction of short-term business cycles, long-term trends of expansion and stagnation, and the institutional structure in which economic activity takes place. One of the most fruitful of these explorations is the work of the Social Structure of Accumulation theorists. The many economists writing in this tradition define a Social Structure of Accumulation as the institutional context in which profit making occurs. Unlike Baran, Sweezy and Magdoff, who came of age during the Great Depression, they represent a new generation who came to academic maturity in the long post-Second World War expansion and questioned the idea of secular stagnation. Instead, they embraced Nikolai Kondratieff's theory of long waves and began to link their phases of expansion and contraction to changes in the conditions of labor. Kondratieff's theory was embraced by Harvard economist Joseph Schumpeter as an alternative explanation for long-term decline to that of Hansen, his great intellectual rival. Although Schumpeter was himself very conservative, he nurtured and supported young scholars of all political inclinations, including Paul Sweezy, Paul Samuelson, and Nicholas Georgescu-Roegen. The roots of liberal neoclassicism, neo-Marxism, and biophysical economics all trace in a way back to Schumpeter.

The institutional revival of the 1970s and 1980s showed that the functioning of markets is embedded within a context of social institutions. Just like embedding the economy in a finite and nongrowing biophysical system forces us to think about the limits of the primary system, embedding the functioning of markets within a social system forces us to think about the interaction of markets with the broader set of institutions. David Gordon and colleagues termed this interaction of macroeconomic cycles and the institutional context the Social Structure of Accumulation (SSA). An SSA is the institutional context in which capital accumulation occurs. In some historical eras, the institutions are broadly supportive of profit making, and the SSA enters an expansion phase. The economy enters a long swing of growth [19]. At some point, however, the institutional conditions change, and the SSA collapses, leaving a decline of roughly 20–25 years in its wake. Phillip O'Hara summarizes this position succinctly when he states: "The system requires certain 'public goods' or systems functions to promote accord, agreement, organization, communication, and information to moderate conflict and instability that so-called 'free markets' would otherwise largely be without" [20].

SSAs go through distinct phases of exploration, consolidation, and decay. A long wave with an undertone of stagnation coincides with collapse of an SSA, for example, the SSA of the early twentieth century industrial revolution collapsed in the Great Depression. Progressive capitalists explore innovative ways of conducting production and marketing. As they become successful, a new set of institutional arrangements are consolidated and become the basis of a long period of growth. Eventually, after 20 some years, changes in variables such as technology, world power arrangements, and labor organization cause the SSA to decay. In the decay, the world economy begins to stagnate and a new long wave with an undertone of stagnation ensues.

Bowles, Gordon, and Weisskopf [21] extended the determinants of a Social Structure of Accumulation from the conditions of labor to broader categories of world relations and domestic considerations. A postwar SSA was constructed based on US hegemony, the recognition of unions in a limited capital-labor accord, the limitation of price competition among large firms, and a capital-citizen accord based on the politics of economic growth. The postwar SSA could not survive the early 1970s with the collapse of the Bretton Woods accords, the peak and beginning of the decline of US oil production, and the era of stagflation. The conflict was between a system that needed growth for economic and political purposes but simply could not produce it. After a period of impasse, a new, neoliberal SSA began to be constructed upon more conservative goals of (1) removal of international barriers to the free movement of commodities and capital, (2) the withdrawal of the state from regulatory activity, (3) privatization of state enterprises and public services, (4) a shift to regressive taxation, (5) the end of the capital-labor accord, (6) the replacement of corespective oligopoly behavior by renewed competition, and (7) a faith in entrepreneurial spirit and free market ideology [21]. The most recent SSA is coming to an end as inequality, stagnation, increasing resource scarcity, and the exaggerated positive feedback loops, exacerbated by speculative finance, create untenable conditions for the long-term stability of the system [22].

The SSA is supposed to provide the institutional framework for long-term sustainable growth, at least until it breaks down. Yet if, as seems likely, every scientific measure of human impact upon nature indicates that we are in overshoot, then there is no possibility of configuring a new Social Structure of Accumulation based on renewed growth. Rather degrowth is demanded, a social structure of deaccumulation. But at the same time, the main power structures of government and corporations and their supporting institutional structures believe that growth is needed to achieve a stable prosperous economy, with the absence of growth seen as economic crisis. Wolfson and Kotz state the matter forthrightly: "Capitalism does indeed display a powerful accumulation drive. That drive is one of its central features. It is doubtful whether capitalism could survive without the accumulation of capital—it would be torn apart by the conflict without an 'expanding pie'" [23].

The fundamental differences between the Monthly Review School and the Social Structure of Accumulation approach are secular stagnation vs. long waves and, epoch-making innovations vs. institutional restructuring. The Social Structure of Accumulation school believes that the global economy is seeing renewed competition where the Monthly Review school sees another form of oligopolistic rivalry. The SSA school also believes that the right set of social institutions can produce another period of long-term growth. That is harder to believe in the age of declining resource quality, but there are many important lessons to be learned from both approaches. Most importantly, these examples ground their theories in actually existing economies that change historically and within the context of social institutions. We believe that they could serve as a good starting point, although not the definitive ending point, of a viable theory of growth for biophysical economics.

5.7 Equations and the Conceptual Model

Before we rush headlong into formalizing a set of equations by which to describe biophysical economics, we should first establish a solid conceptual model. The equations of mainstream economics are derived from the pre-analytical vision that the economy is self-contained and self-regulating by means of price competition. We reject both of those notions. Rather than reproduce equations based on a faulty conceptual model, it is time to advance candidates for a better starting point.

In ► Chap. 3, we presented a model in which the economy was embedded in a larger biophysical system that was dependent upon a flow of solar energy, entering as visible light and exiting as waste heat. However, that model, first advanced in *Energy and Resource Quality: The Ecology of the Economic Process*, places a simple circular flow model within the economy which is also embedded within the environment. Subsequent research has shown that the circular flow is an inadequate way to model the complex interactions of a biophysical economy grounded in solar flow, fossil

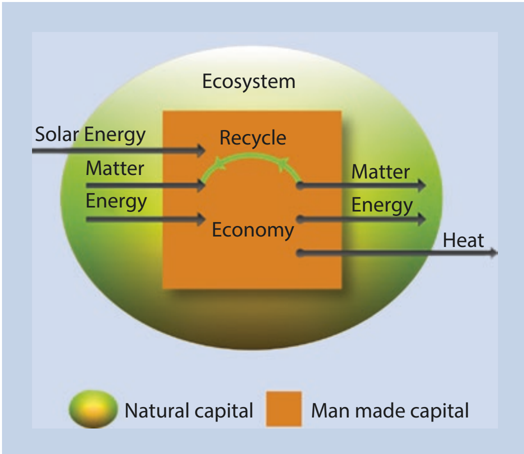

Fig. 5.1 This figure is a depiction of the basic ecological economics model developed by Herman Daly. It shows that the economy is embedded within in the ecosystem, and also shows the transformation of low-entropy solar energy into high-entropy heat

fuels, extraction, production, distribution, and waste. There is no role for institutions or actual human behavior in this model. We must do better.

We would like to advance three candidates for the conceptual starting point of biophysical economics. The first is an early visual model that was advanced by ecological economist Herman Daly [24; Fig 5.1]. The modeling of an embedded economy is one of his greatest accomplishments. Daly puts a growing, open economy inside a finite and nongrowing ecosystem. He then differentiates between an empty world, filled with natural capital but largely devoid of human-made capital, and a full world that is abundant with human-made capital but in which the products of nature have become seriously depleted. The primary purpose of the model was to show the need for a steady-state economy that operates within nature's finite limits. This model has been also developed by Hall et al. as given in Fig. 3.3.

The second was another visual model developed by Neva Goodwin, Jonathan Harris and their colleagues at the Global Development and Environment Institute (GDAE) associated with Tufts University in Medford, Massachusetts, USA [25; Fig. 5.2]. The model embeds the economy

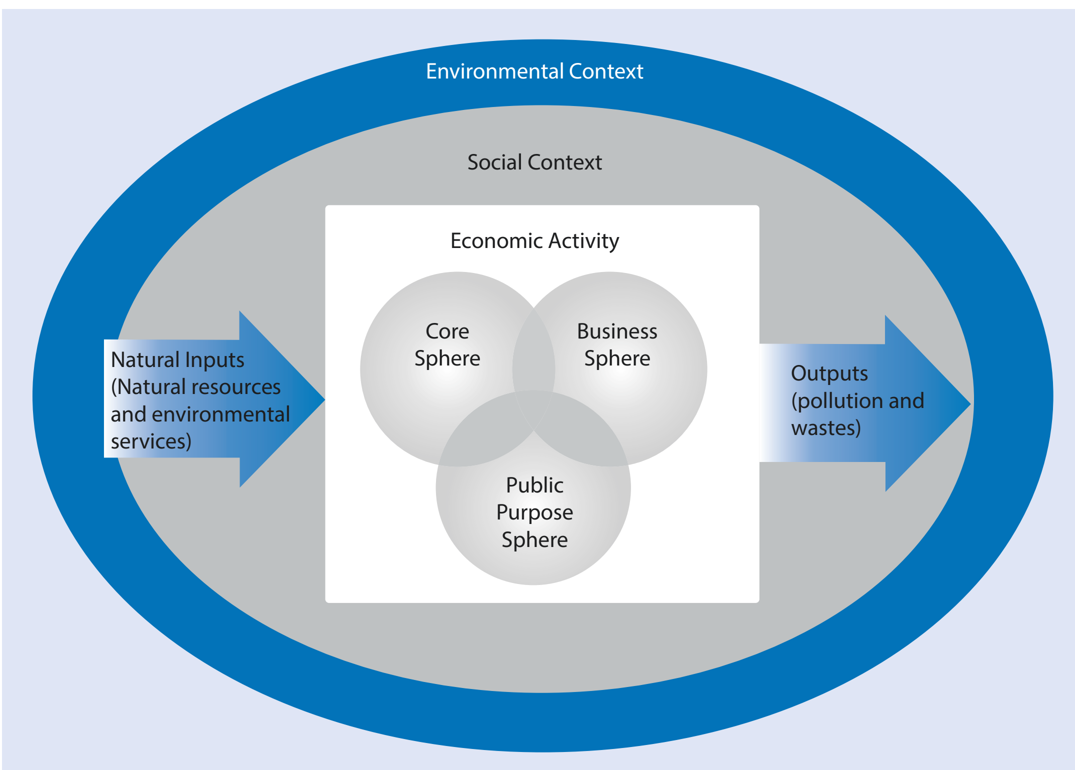

Fig. 5.2 The model embeds the economy not only in an ecological context but also in a social context (Neva Goodwin [25])

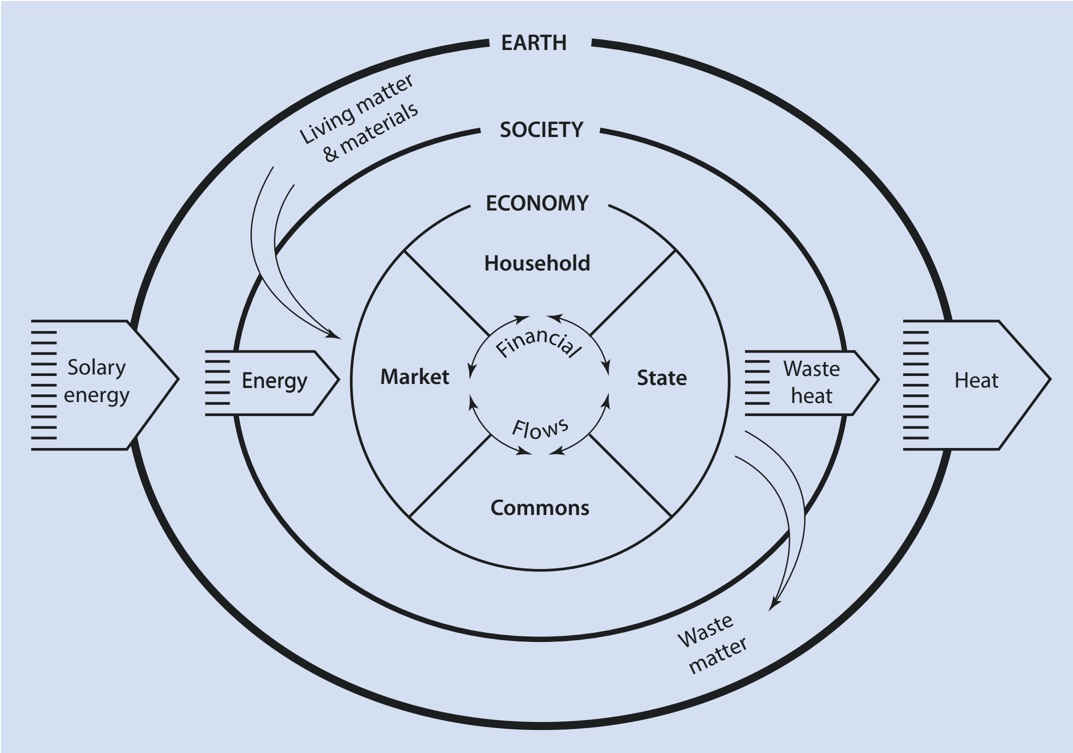

Fig. 5.3 Shows an economy that includes not just the market but also household production, the government, and the all-important commons (Kate Raworth [26])

not only in an ecological context but also in a social context. Not all human interactions are exchange relations. In the real world, there are interpersonal interactions that do not involve the transfer of money. This part of the economy is termed the core sector. The part of the economy modeled by mainstream economics is called the business sector, while the model adds a public purpose sector of governments, nongovernmental organizations, and not-for-profit enterprises. The use of Venn diagrams shows direct, personal interaction among the sectors, not just indirect interaction mediated by markets.

A third, but similar, approach is the brainchild of development economist Kate Raworth and is used to model her commitment to a safe and just operating space for humanity [26]. She asserts that the visual pictures of neoclassical economics are all wrong and need to be replaced by images that see the big picture, nurture human nature, and show skepticism about economic growth. Her conceptual model shows an economy that includes not just the market but also household production, the government, and the all-important commons. The recent work of GDAE-affiliated public policy analyst June Sekera [27] shows clearly how the very notion of public service and the commons have taken a beating in the neoliberal era. Restoring the commons to a prominent place in the pre-analytical vision is a welcome addition in our opinion.

None of these models fits the exact needs of biophysical economics. All are rather vague about the role of energy. Yet they are a much better starting point than is the circular flow model based on hedonistic human behavior, perfect competition, and pure exchange. When we get the conceptual model specified sufficiently, a set of equations will be forthcoming.

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