Chapter 8 – The Economy as Subsystem: A Preliminary Analysis

Abstract The *economy* is a subsystem of the human social system, itself a subsystem of the whole Earth Ecos. Using the methods considered in chapters 5 and 7 we apply them to a preliminary examination of the global economy to demonstrate: 1) how those methods can be used to gain a deeper understanding of an extremely complex system; 2) how insights from this analysis lead to some very different theories and concepts regarding how economies work; and 3) provide a launching pad for future work in a much deeper analysis. The approach we will take in this chapter is to use a depth-first decomposition to look at arguably one of the most important aspects of the economy, the energy sector. Energy flow through the HSS is what supports the work done in all of the various subsystems we find in the HSS. One of the main tasks of the economy is to obtain energy and supply it to those other subsystems.

8.1. Purpose of the Chapter

This will necessarily be a long chapter. We can only apologize in advance. But the subject matter is extraordinarily complex. And huge. The strategy we have adopted is to do what amounts to a depth-first kind of analysis and we will focus specifically on what we think is probably the most important aspect of the economy; the one that is already becoming problematic for the HSS and will become increasingly problematic in the near future. We will focus on a deeper understanding of the energy "sector" of the economic system since a simple physical reality is that wealth is produced by processes that use energy to do physical work. Even thinking is physical (chemical) work. So, energy flows are fundamental to all economic activity. Classical economists have only just started understanding this and still have difficulty grasping the consequences of this fundamental reality[1].

First a side note and something of an apology. In this book we have a difficult problem in that we need to make use of complex, adaptive, and possibly evolvable systems prior to actually explaining what those systems are. We have introduced the concepts of CAESs in previous chapters (including the Introduction), but kept the explanations lightweight in order to not bog down the subjects of those chapters. The deeper explanations of CAES archetypes has been put off till Part 3 because we want to expound the models more thoroughly in one section. Nevertheless, in this chapter we are dealing with a high-order CAES and need to have some facility with using the CAES concepts in order to guide our analytic process. We will try to keep

[1] As will be much more thoroughly explained in Chapter 12, energy flow is the basis for all work that reduces the entropy of materials and messages (information into knowledge) for use in CAESs.

the details of CAES-based analysis to a minimum and not necessarily requiring the descriptions form Part 3. But if confusion does intrude, the reader may want to skip ahead to Chapter 9 for a summary of the gory details.

Systems (and systemness) are naturally recursive structures (and concepts). The purpose of this chapter is to demonstrate how the methods derived in chapters 5 and 7 can be used to tease apart a super-fuzzy complex system like the economy of the HSS introduced in Chapter 6. But this introduces an interesting complication. We will be using the archetype models as guides to doing so. And those archetype models require a priori explication!

Our approach is to proceed forward as if the reader is already somewhat familiar with the details of some examples of the various archetype models that, in combination, constitute whole complex systems. In Chapter 9 we will introduce several archetype models that are being applied in the analysis to be accomplished in this chapter. These will be the “master” archetype of complex adaptive and evolvable systems (CAS/CAES) and three sub-archetypes that constitute the major subsystems of any CAS/CAES. These are: agent (with agency), economy, and governance and were introduced cursorily in Chapter 5, Section 5.3.3.

For example, in order to talk about an economic system, we need to have a basic concept of what an economy is, and therein lies the rub. One of our premises is that using deep analysis will lead us to an understanding of what an HSS economic process should be and that is, potentially, different from what is currently considered (e.g. a market-based, capitalist economy). A systems economics will not necessarily be based on classical approaches to economics. This stems from a realization that an economy, as a subsystem of a larger complex adaptive (and possibly evolvable) system is, based on an archetype model of economics that should apply across the spectrum of CAS and CAES as we have already considered. That is to say, there is a general, universal, model of an economy that can be used as the basis for analyzing the specific HSS economy, as we are about to do.

In this chapter we will reference these archetype models without a great deal of explanation. For example, we frequently refer to “decision agents” in several different contexts. We assume for the moment that the general notion of an agent is sufficiently well understood that we need not belabor the concept in this chapter. We suggest, however, the reader be ready to page forward to Chapter 9 on occasion to consider more details of the archetype models. The intent of this chapter is to use the analytic techniques thus far described to tackle a beginning understanding that might be used to grapple with the CAES that is the HSS and its economy. We will restrict our analysis to a specific sub-subsystem, the energy acquisition and distribution sector, to show how the methods work and reveal previously hidden aspects that will turn out to be immensely important to the whole economy.

In Chapter 6, the Section 6.6, we treated the whole Earth Ecos as a system of interest and began a decomposition that identified, among other important subsystems in the biosphere subsystem, the human social system. That is, we treated the human species, along with its unique cultural attendants (e.g., artifacts and institutions) as a subsystem of interest[2]. It is doubtful that anyone would contest a claim that looking at the HSS as system of interest might be a fool's errand (except that branch of sociology called "World-Systems Analysis", Wallerstein, 2007). Even though we might be able to put a boundary around the HSS with respect to the rest of the Ecos environment, say for example if we had a complete inventory of the full repertoire of genes that make us human, the complexity of human affairs would make the notion of doing a deep analysis seem unimaginable. But that is really the point of this chapter, to show that not only is it imaginable, it is necessary. Already the various social sciences are attempting to ferret out the mechanisms and meanings of human ideas, behaviors, and cultures. They are already attempting to come to a deep understanding of the HSS (ibid). They are, however, going about it in a fractured, uncoordinated way which leaves gaps in our understanding between various sub-disciplines. The approach is essentially historical (not a bad thing since according to Equation 3.1, there is a 'history' object associated with a complex system). But the better approach needs to include analytical techniques borrowed from the physical sciences (c.f. Hodder, 2012 for a review of how archeology and systems methods produce a much deeper understanding of human cultures and co-evolution).

For a long time, economics and psychology were drilling down on two different phenomena in such a way that economists knew nothing about how people actually make decisions and psychologists knew nothing about how money, as one example, shaped and distorted people's attitudes, let alone decisions. Today that is changing. Today we have a field called behavioral economics[3] in which psychologists and economists (along with several other disciplines) work together to find out what people really do and how they really think when it comes to economic decision-making. So there has been significant process on the front of understanding humans as agents. Thus, when we look at their roles as agents in the economy we will have a much better idea of how decisions actually get made and what the consequences are.

Still, while things are changing toward more integration across disciplines, this is a reaction to an increasingly recognized need more than a principled approach. What we have been arguing is that using the systems approach through deep analysis would provide that principled approach to understanding, providing an overall framework to all of the sciences. It could provide guidance toward integration.

In this chapter we will begin a preliminary deep analysis of the HSS as an example of how the processes covered in Chapters 4, 5, and 7 can illuminate extremely complex systems internals that have been a struggle to comprehend by traditional social and natural sciences, with their knowledge silos. After an elementary decomposition of the HSS to establish the internal

[2] In Part 4 we call this an "Artifactual System" to denote the fact that the system is comprised of humans and the totality of their human-constructed (artifactual) world.

[3] See the Wikipedia article: https://en.wikipedia.org/wiki/Behavioral_economics for more background. Accessed 2/6/2018.

elements that will form some major aspects of the environment of our new SOI, we proceed to analyze the economic subsystem.

It goes without saying, though we mention it anyway to make sure the reader knows we are not caught in unbelievable hubris, that the analysis of the economy – doing the work of traditional approaches to economics in all its various schools – would require much more than a single chapter in a single book. Therefore, the approach we shall take is to use the method of depth-first analysis explained in Chapter 5, section 5.4.3.3 Recursive Deconstruction, on what we think is an extremely important subsystem of the economy, the energy sector.

The importance of the sector cannot be overstated in our view. Everything that happens in the HSS does so because of the flow of an appropriate form and power factor of energy. Everything we humans do, including and especially living, depends on the flow of energy through the system (Morowitz, 1968; Odum, 2007). It takes energy to do work. And everything that happens involves work, mechanical, chemical, or electrical, that changes or moves material. This is so fundamental that it is, on the one hand amazing that it has not been fully grasped by the social sciences in general, and on the other hand somewhat understandable that it has been taken for granted as it is what everyone experiences moment to moment.

What makes it essential to turn all eyes toward the energy sector today is that the HSS sources of suitable energy to run an advanced technological society are under threat of depletion. Over 80% of our industrial-grade energy comes from the burning of fossil fuels (Hall & Klitgaard, 2012), which are a fixed and finite resource. Since energy used to do work follows the Second Law of Thermodynamics (2^{nd} law)[4] the process doing the work degrades an equivalent amount of the energy flow to waste heat – energy that can no longer do useful work. That heat, as has been pointed out in Part 1, is dissipated to the environment and unrecoverable. Thus, unlike matter that can to some extent be recycled, energy gets effectively used up. Thus, burning the fuels means their energy contents are on a one-way trip to dissipation. Today, a large and growing number of people are hopeful that alternative energies such as solar photovoltaics and wind-generated electricity can replace the use of fossil fuels while continuing with our advanced living-standard societies (and while continuing the growth of developing economies as they seek to achieve the same standard enjoyed by the developed economies)[5]. Whether this is feasible is, unfortunately, still not known. There are scientifically-based arguments on all sides of this very complex issue. However, there is very little truly scientific (or systemic) evidence to support any particular conclusions. Below we will outline some of the challenges to obtaining that evidence

[4] We refer to the Second Law of Thermodynamics as a proper noun owing to its singular importance in the way the Universe works. Subsequently we will refer back to it using the shorthand form the 2^{nd} law. Not all writers use this convention.

[5] A second motivation, maybe equally important, is that burning fossil fuels produces CO_2 that is now definitively linked to global climate change.

and provide a systems approach suggestion for how the deep analysis could help policy makers make decisions about where it would be best to invest our dwindling resources.

Even though our focus will be primarily on the energy sector analysis, we will, nevertheless be touching on other important economic issues such as the nature of markets and money. The economy, as will be seen in our cursory analysis, is still an incredibly complex system in which many sub-subsystems are linked quite strongly. Some of these will be pointed out in this chapter.

What we will cover in this chapter is still relatively cursory, the energy sector and its importance to the rest of the HSS (indeed the whole Ecos) as well as its own complexity require a substantial research literature on its own. Nevertheless, we think that this demonstration of the process of deep understanding will be better realized by tackling a portion of the economic subsystem of this importance and complexity.

Note that what will be presented in this chapter is only a portion of work that has been done on what is called the "biophysical economy[6]" by the author and a growing number of researchers. The author's contribution to the field has been based on foregoing the use of classical economics approaches and theories (e.g. use of GDP as a measure of income) and applying strict systems principles to derive a better understanding of the economy unbiased by classical and neoclassical theories, for example of the nature of money. The author and others have been analyzing the many other subsystems in the economy. And some significant, though unfortunately minor, progress has been made. The author contemplates a future work devoted to developing the basic ideas in this chapter in the future.

8.2. Analytic Approaches

Before getting into the systems analysis of the economy it would be useful to consider several relevant perspectives to take. These will be expanded as the analysis proceeds.

8.2.1. From the Current Subsystem as We Find It

The first perspective is to take the current global economy as it is presently understood. That is to say we could accept the various positions of schools of economics as they have come to understand the system. This would presumably save us a great deal of time and energy. To some degree we will end up accepting some of the knowledge garnered by one or more of these schools, but only after establishing it as consistent with the analysis from a systems perspective.

[6] The name of a new kind of economics may have had several origins but is most identified with a systems ecologist and student of Howard T. Odum's, Charles A. S. Hall, Professor Emeritus, State University of New York, College of Environmental Studies and Forestry, at Syracuse NY (c.f. Hall & Klitgaard, 2012). The author had the privilege of spending a sabbatical leave with Dr. Hall in Syracuse in 2009, while developing some of the ideas presented in this chapter. Dr. Hall's work was extremely influential on that of the author's and has been equally so for the work of many other researchers in the nascent field of biophysical economics.

A great deal of motivation for insisting on doing an independent analysis and possibly deriving some different knowledge is that the science of economics has been struggling with its topic for quite a while (see Keen, 2011, Part 1). We gather, from the growing criticisms of neoclassical economics that there are some internal flaws with models and assumptions in the field that have caused it to fail in the construction of scenarios and predictions. Economists have become notoriously incapable of predicting recessions, for example[7]. For this reason, we will not take at face value those models and assumptions. Our goal is to derive a systems model of economies or the global economy from systems principles and the methodologies (at least the core ones) developed in this book.

In anticipation of what we will find, it is probably no surprise to state that the current economic system is quite dysfunctional with respect to its supposed purpose in supporting the livelihood of the HSS[8]. This will be seen in the energy sector analysis in particular but applies to other subsystems as well. And this raises the question of how the system could be made functional. The answer to that question involves systems engineering or designing and constructing a functional economic system that fulfills its function with respect to human beings, and also makes the HSS a compatible subsystem of the Ecos, i.e. does not pollute or over extract. Part 4 of the book will be devoted to demonstrating how this can be accomplished. We will use the systems principles and methodologies to design and engineer a workable economic system.

In this chapter we will employ two other perspectives to assist in the analysis. The first will also provide a way to see how the history object, introduced in Chapter 3 and described in previous chapters, is essential in determining the systemness of complex adaptive and *evolvable* systems.

8.2.2. From the Historical Evolution of the Subsystem[9]

This keeps us referring to the humanness of the enterprise…

Over the last several decades the historical record of the extraction of natural resources and the creation of wealth and its distribution through various forms of trade interactions has been greatly improved through the work of anthropologists, archeologists, and historians with the aid of other disciplines such as neuropsychology. It is now possible to paint a basic picture of how cultures themselves came to be, their ontogeny, and how practices evolved from the earliest

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[7] Keen (2011) and other "heterodox" economists are quick to point out that almost no one in the neoclassical school had predicted the meltdown of 2009, now known as the Great Recession (just short of a depression).

[8] That the economy of the HSS is not functioning properly with respect to its purpose is actually not really surprising. There are many kinds of complex systems that have been found to suffer various "pathologies" that cause the system to fail at some point. For example, a positive feedback loop not countered by a negative one will lead to exponential blow up, destabilization and ultimate destruction of the system.

[9] We are following a line of reasoning put forth by Karl Polanyi (2001) regarding the necessity to look as far back in the prehistory of *Homo sapiens* to understand social and psychological issues that then have relations to economic systems. See, especially, Polanyi (2001), Chapter 4, Societies and Economic Systems.

times in the late Pleistocene era right up to today. The historical perspective will help us analyze a number of economic phenomena that seem puzzling at times, such as the nature of "ownership" and "profit-taking".

Such a perspective will necessitate a background in human neuropsychology and behaviors. Since the human species is the reason that something like a society and an economy exists in the first place this cannot be avoided. We will, therefore, touch on some of the more direct factors in the nature of human beings that directly affect the analysis of the various subsystem institutions in the economy and the energy sector thereof.

Human beings are eusocial[10] beings; some have characterized it as hypersocial (Bourke, 2011; Buller, 2005; Harari, 2011; Sober & Wilson, 1998; Suddendorf, 2013; Tomasello, 2014). We humans are strongly motivated to cooperate on shared objectives. The basic set of objectives involve means of living and thriving, or the biological support. The evolutionary fitness of human beings comes from the ability to organize behaviors for this purpose. Part of our historical perspective will include what has come to be called the Agricultural Revolution as it relates to biological support. The invention of agriculture and animal husbandry is part of a larger mental capacity of humans to invent new ways of doing things. Specifically, humans find ways, and invent tools, to leverage their biological support. They learn to exploit new sources of energy and new materials, along with new ways to accomplish work using less of their own physiological energy. They have technology.

8.2.3. From the Ideal of a CAES

In Part 4 we will explore the concepts of systems design approaches to CAESs. We will use the archetype models as template models telling us what to put into our designs. We will, in fact, go through the design of an ideal HSS and its ideal economy. By 'ideal' we don't mean some kind of Socratic 'Form' as such. What we mean is that by using the economy archetype we can identify elements of the human economy that should be in place in order to achieve long-term viability. Clearly, exhausting our main source of high-grade energy, fossil fuels, is not a way to achieve long-term viability. So, we must consider alternatives. And, rather than automatically assuming that that means solar voltaic and wind sources, we will apply the systems analysis approach to see if these are, indeed, viable alternatives (we will ignore the hype and politics in doing so.)

8.3. The HSS Decomposed

Given the HSS as a subsystem of the Ecos we now proceed to investigate it systemically using the methods of deep analysis. This will serve two purposes. It is prelude to the environmental analysis phase when the Economy becomes the focus of investigation – the new

[10] Eusociality is the tendency for individuals to form social units through cooperation. See the Wikipedia article, https://en.wikipedia.org/wiki/Eusociality for background. Accessed 2/11/2018.

SOI at a deeper level. And it will offer an opportunity to further explore the methods of dealing with a very fuzzy system! The human components of the HSS are extremely variable and subject to evolution in the long run. In the short run, humans are continuously inventing new artifacts and new institutions which become part of the culture. Thus, the HSS, exemplar par excellence of a CAES, is overall fuzzy. But so are its component subsystems as we will soon see.

The first task is to find the boundary of the SOI. Immediately we run into difficulties. What shall we call the boundary of the economic subsystem? Figure 8.1[11] suggests the difficulty. In this figure we show the economy as a large (purple) oval intersecting many other entities we might treat as subsystems in their own rights. It might be interpreted that the economy is co-extensive with the whole of the HSS (largest purple dashed oval). However, this is not the case. Nor is the population of humans necessarily coextensive with the economy. Put another way, while the economy is clearly a major part of the social fabric it isn't all there is to human life or even the institutions that form part of that fabric[12]. As we will observe later, the HSS can be resolved into a set of fuzzy subsystems that organize around some major activities that are not, strictly speaking economic. All of these subsystems interact with each other, primarily through human biological and psychological processes. For example, a human can read a novel for pleasure (and perhaps some education) but the novel had to be written, published, and distributed. The reading is not necessarily an act of economic consequence, at least not directly or likely strongly. The writing is generally not motivated by direct economic considerations – J.K. Rowling didn't write Harry Potter books as a 'job', at least not the original one – even though writing a best-seller has obvious economic consequences. But the publishing and distribution of books is a set of work processes that are very much part of the economic engine. The firms that accomplish this work are expressly set up to accomplish this function. They consume energy and materials, produce product and deliver it, and generate waste heat and waste materials in the process. Peoples' desires to read novels along with a similarly psychologically-motivated desire to be expressive and tell a story (see the Section 8.3.2.1.2 below: Psychological Supports) created a need for an explicit set of work processes to be set up in order to couple these two desires. The activities associated with writing and reading are best concerned with the institutions we think of as the Humanities or Esthetics. The patterns of those activities may involve the doing of mental work, but nobody really pays themselves a salary for writing or reading a book. They may receive payment in royalties or they pay for the book in order to support the existence of an economic entity capable of making them possible.

Below, as we tease out the details of an economic subsystem, we will be concerned with another institution important for the development and growth of the economy, so we will include

[11] The figure shows eight ovals contained within the HSS boundary. Clearly this cannot be an exhaustive set of subsystems. We have chosen these as perhaps some of the most obvious, certainly among the most important, subsystems comprising the human social system.

[12] This is an observation made by Karl Polanyi (2001) in 1944.

it in our analysis while ignoring to a greater extent the other subsystems. Namely, as we decompose the energy sector, we will have to take note of the role of the Science & Engineering subsystem (see figures 8.1 and 8.2) since the access to energy reservoirs and the rates of flows of energies into the economy has been enabled by the activities in this subsystem. It is worth noting that the activity patterns we find in the other subsystems, other than the Economy or Humans, are primarily information processing work. In science, for example, the activities involve mental model building (hypotheses) and empirical verification or refuting. That activity also generates economic activity such as the construction of labs and libraries. As well, scientific discoveries may result in findings that can be exploited by economic work, e.g. a better understanding of thermodynamics led to improvements in steam engines (and all heat engines) resulting in more efficient mining. Scientists, at least historically, do not engage in science for economic purposes (what, for example is the economic purpose of knowing the mating habits of wild rabbits?) Engineers, similarly, tackle their work of creating new things, not because they intend to change the economic subsystem. They do so to solve localized problems set to them by economic concerns for economic entities (i.e. the owners of the firms in capitalist systems). But what they do is process data, produce information (e.g. specifications), and knowledge (designs)[13].

As you can see all of these institutions/subsystems of the HSS are intermingled in extremely complex ways. The only common thread here is the nature of human beings themselves and the kinds of mental and physical work they do as living creatures. In one sense, deconstructing the HSS might seem impossible given this level of complexity. But that is precisely the job we have to do if we are to manage our affairs on this planet. How, then, do we tackle the fuzziness of the HSS and its subsystems?

8.3.1. The Fuzziness of Systems

Figure 8.1 seeks to depict the way in which the HSS is constituted by a number of fuzzy subsystems. These subsystems overlap to some extent; the figure is similar to a Venn diagram in set theory, but cannot really depict the nature of the overlap in two dimensions, which is actually based on temporal factors as much as locations in space. Also, we would need to show overlaps (i.e. intersections) among all of the subsystems.

To see this consider the oval labelled Education. It overlaps with the Human (meaning the population of living beings), the Political, the Economy, and the Humanities, etc. ovals in the figure, but should also overlap with Governance, Healthcare, and Science & Engineering. A two-dimensional representation does not do justice to the relations actually had between these subsystems. The figure only seeks to suggest the fact that all of these subsystems of the HSS are fuzzy. Education means that system of schools and other institutions that are responsible for

[13] We hasten to note that this claim may need to be modified for the current situation. Historically scientists and engineers enjoyed the intrinsic values of the work. Today, in a climate where innovations is supposed to lead to the creation of new companies and eventual IPOs where the engineers or scientists should expect to get rich, it is not purely the case of doing the work for the love of the work.

preparing human young (students) to enter society as, hopefully, productive and thoughtful adults. But education plays a role in the economy just as the latter plays a role in the former. It plays a role in human life and vice versa. Clearly all of these systems interact in intimate ways that make it daunting, to say the least, to assign any kind of boundary conditions to any of them.

Nevertheless, that is exactly what we need to do in order to better understand what is really going on in each subsystem. And this circumscription must be done in such a way as to avoid the subject silos that have encumbered academia. First we should consider what we mean by claiming these examples as subsystems in the first place. We could possibly rely on common sense to realize that the names we have assigned to them are those in general use by everyone. Most people will know what we mean when we say "the education system" even if they do not exactly know where the boundary might be.

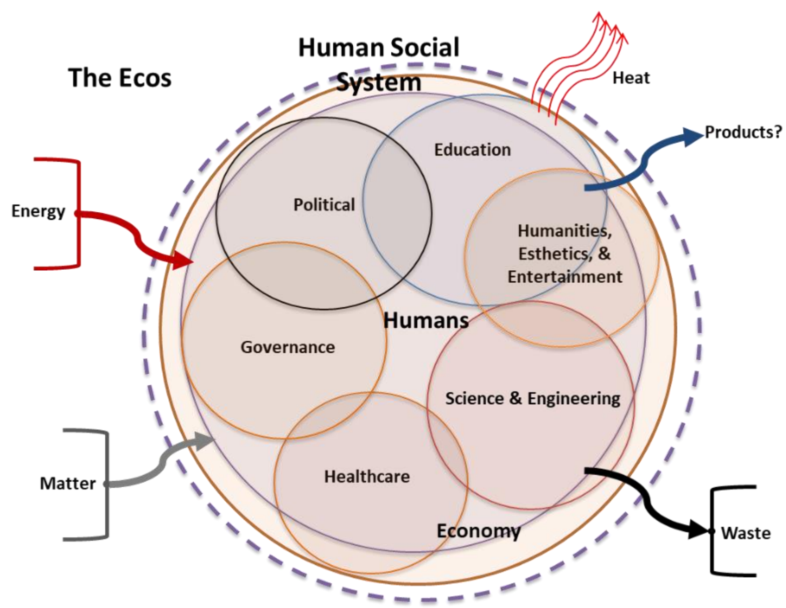

Fig. 8.1. The HSS seen as a fuzzy set of fuzzy subsystems. This is not really a Venn diagram since it does not show the complete overlapping of ovals. Nor is it meant to represent an exhaustive set. The Economy contains the main interfaces between the Ecos and the HSS.

One approach could be to start by considering what elements (components) of the subsystem of interest are not overlapping with any other subsystem. In Figure 8.2, for example, there are regions of several of the ovals that lie outside the economy. The implication is that there are components in those systems that do not directly interact with economic activities. This, of course, means that we have to clearly identify what we mean by economic activities so as to determine whether any component in a subsystem is not engaged.

As an example, consider the idea that an economic activity such as 'earning the highest wage one can' (what a rational utility maximizer would most likely seek) is generally not directly involved in the decision many people in the education field make to participate in it. There might be many arguments forwarded as to why teachers would choose their profession, which is generally lower pay than working in the 'private sector' that reconsider what is meant by 'rewards', e.g. intrinsic versus extrinsic. But that would change it from an economic decision to an esthetic one.

8.3.2. Defuzzification of the HSS

In Chapter 5 we devoted a section (5.9.1) to "Dealing with Fuzzy Systems" in analysis. Here we take a look at how that might proceed with respect to the very fuzzy set of subsystems of the HSS. The key here is to look at individual components within any subsystem and determine their membership function with respect to each subsystem. Many components might have membership functions that simply return unity (1) meaning they are always present with probability 1. But many components can effectively multiplex or serve roles in multiple subsystems at different times and with different probabilities. Our paradigm example is the way in which individual people move in and out of the HSS subsystems (except, of course the Human biological subsystem) at different times and with different likelihoods.

No one will claim that identification of when, where, and at what time a component will be in what subsystem will be easy. On the other hand we need not necessarily do so for each individual (or component). This is not too different from the problem raised in thermodynamics where temperature of a system is defined as a measure of the average translational kinetic energy of particles. Rather the analysis may, in many instances, rely on average component behaviors.

One way to handle defuzzification is to treat all subsystems as if they have concrete boundaries and interfaces through which components flow between subsystems. For example, human individuals, while certainly remaining humans, move between places and roles with some predictability. People become economic decision agents when they play the role of a consumer or that of a producer (in their job, for instance). But at other times they are playing other roles in other subsystems. For example, when a doctor is diagnosing a patient (in the healthcare system) she is not making explicit economic decisions. It may be true that these other roles may have economic consequences in the aggregate and over time, but we end up making things more complicated if we try to treat every action as being in the economic system[14]. The reasons will become clearer as we proceed.

Figure 8.2 shows the same HSS in Figure 8.1 but defuzzified by adopting the method of boundary and flow construction. The economy has been separated from the other subsystems and will become the new SOI for this chapter. We will examine the rest of the HSS as the environment of the economy as per the procedure in Chapter 5.

[14] It seems that an abundance of enthusiasm for market-based mechanisms applied to all other HSS subsystems has muddied the waters further in recent decades. As of this writing, for example, the Secretary of Education in the US Whitehouse is a strong believer in market solutions to education, i.e. the use of vouchers that allow parents to treat the choices of public schools as a "consumer choice."

The nine subsystems identified in figures 8.1 and 8.2 will be delineated. Note that in Figure 8.2 we have included another dashed oval labelled “Core Society”. Humans, the Political, the Governances, and most of the Economy are contained within this sphere. The term “political economy” used to be the name of the field of study of economics as it was seen to be deeply intertwined with politics and governance. Indeed, we could argue that the core society represents those close associations. However our reason for separating these from one another is that when human beings participate as components in each of these processes they are making different kinds of decisions as agents. We argue that a political decision is not the same as an economic one, or a governance one, even though they are strongly coupled in human minds. Below we will make the distinctions that should work to defuzzify these boundaries.

One other complication for all intentional CAESs exists that is not shown in the figures. The governance subsystem shown is not all there is to the governance of any such CAES (all of these subsystems are, themselves, intentional CAESs). The governance shown in the figures applies to the whole HSS but is only the government of the whole. Each subsystem has its own internal governance sub-subsystem that is for its own self-regulation. In Chapter 11 we will describe the architecture of a holistic governance system for any intentional CAES (and some applications for non-intentional CAESs such as an ecosystem). The situation with respect to the self-similar aspects of governance, that is governance of the whole and governance of the parts, will become much clearer then. Interested readers may wish to read that chapter first since so much of what goes on in the economy involves different governance mechanisms.

What we have done thus far is to do a functional/structural decomposition of the HSS considering the Ecos as the environment. Below we will consider the various entities in Figure 8.2, briefly, as if we had done a further analysis of them. This is especially relevant for the Human subsystem since humans are the main agents working in all of the other subsystems.

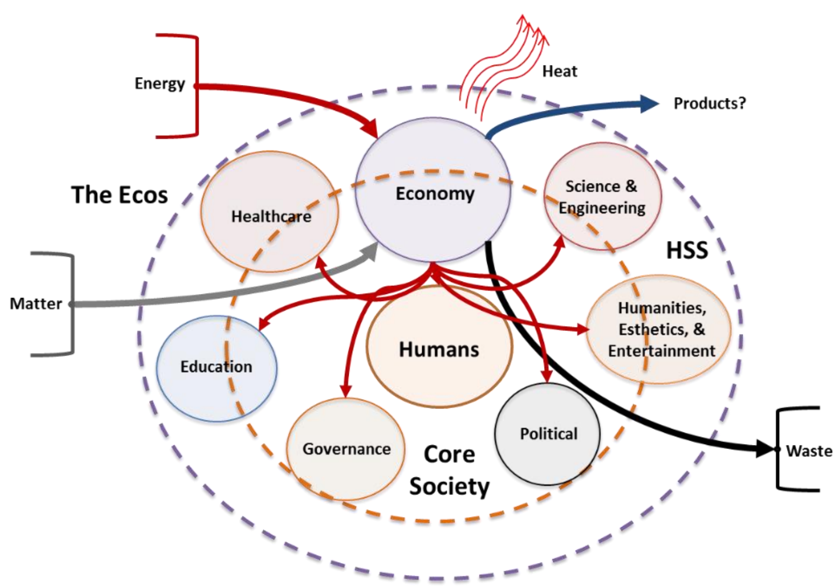

Fig. 8.2. The HSS defuzzified by firming boundaries and introducing flows (energy acquired by the economic subsystem distributed to other subsystems). Humans, their organization of governance, and political processes constitute a "core" of society (orange dashed oval). The economy and other subsystems are composed of many artifacts that sustain the core. Note the upper right arrow pointing to products (?). This poses the question: What products of use to the Ecos does the HSS produce?

8.3.2.1. The Human Subsystem and the Role of Humans

This is still more a question than a statement! In some sense the whole HSS is all about humans, or at least that is the classical humanist point of view. Everything we have invented and done has been about making more humans and living comfortably while doing so. Thus, humans provide the motivation for developing all of the other subsystems and especially the economy. Since so many books and journal articles, not to mention fiction stories in all genre, magazines, movies, etc. have been devoted to answering the basic question it would be the height of hubris to suggest the small section of this one work could even begin to provide an answer. Rather we will mention a few of the sub-subsystem aspects of human beings that seem most relevant to further examination of the economy itself.

The Human subsystem is comprised of all biomass and produced assets that are under the control of human beings – that is their physical bodies, their clothes, their shelters, their pets, their lawns (!), etc. etc. Basically the family possessions are considered in this subsystem. Humans are, by their own designation, consumers. In fact in our later modeling of the economy we see humans as the ultimate consumers. Whatever the economic engine produces it is meant to support humanity's consumption of stuff. Human possession and consumption provides the basic motive drive for everything else that goes on in the HSS.

Humans play another role besides consumption, however. They also supply their bodies and brains to do work within the other subsystems. That is, they temporarily become components of the other subsystems during the work day. The fuzzy membership function of an employee is approximated by a time-in-service equation. But there should be no confusion about the fact that the fuzziness of employment is not an insurmountable analysis hurdle. In fact, we can measure the actual amount of time-in-service for any worker. We may not, it's true, be able to discount time spent daydreaming or playing solitaire on the computer when no one is watching. But most organizations have the ability to record the amount of time their workers are on the job. That is how we calculate productivity values.

So when humans are buying goods and services to consume they are operating in the economy (even if shopping on-line). When humans are at work they are participating in the subsystem in which they are employed even when that work may have direct economic consequences.

Human characteristics that interact with the rest of the HSS and especially between humans are described briefly.

8.3.2.1.1. Biological Mandate

The first fact about human beings is that they are animals, living creatures that answer ultimately to the biological mandates to obtain physical resources, convert those into biomass, especially during development and growth, but also in reproduction, and, importantly, stay alive even in the face of competition, disease, and predation. This mandate is programmed deep in the human brain even when we are not consciously aware of it being the fundamental driving force behind our behavior[15]. We do not claim that the mandate causes us to choose as we do in every decision we make – one could not explain altruism easily if this were true. But we do claim that it provides an incredibly strong influence on our decision processes. What needs to be explained, especially in relation to economic decisions, are the basis of selfishness, say as it manifests itself in motives to "maximize profits" even at the expense of fellow humans. [See: Geary, 2005; Harari, 2011; Marcus, 2008; Maslow, 1943; Mithen, 1996; Sober & Wilson, 1998; Striedter, 2005 for more background].

8.3.2.1.2. Psychological Supports

The biological mandate might be thought of as the core of motivation for human behavior. But since the species strategy for achieving fitness is based on sociality and technology (instruments used as extensions and amplifications of our biological capabilities) humans rely heavily on a hierarchy of psychological supports that involve the generation of complex behaviors. Sometimes those behaviors do not seem directly connected to or even have anything to do with the biological mandate. But why a man would want to buy a massive (muscular) automobile can easily be linked to his desires to win at the reproduction race even if he is unaware of the influence of advertisements involving glamourous people.

Abraham Maslow, the father of 'positive psychology' developed a model of a hierarchy of needs, each higher need based on fulfilling the lower needs (Maslow, 1943)[16]. In Maslow's hierarchy Physiological, Safety, and Love/Belonging needs formed the lowest level; these correspond with the biological mandate with the need for food and water forming the base. Safety means having shelter and protection from the elements, predation, and disease. Love is somewhat transitional in that meeting this need is where human behavior starts to look a lot less like other animals. Courtship rituals and general inter-sex behaviors are much more complex in humans. Above love and belonging, Maslow saw humans needing Esteem, or positive relations with other humans in the social system. People work hard at being thought well of by other people; reputation can be everything in influencing how successful an individual is at obtaining the needed resources and potentials for mating.

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[15] Sigmund Freud may have intuited this deep, fundamental, drive behind human behavior at least insofar as reproduction was concerned.

[16] Also see the Wikipedia article: https://en.wikipedia.org/wiki/Maslow%27s_hierarchy_of_needs for additional background. Accessed 3/26/2018.

The highest level in Maslow's hierarchy he called "Self-actualization" or finding contentment in having succeeded meeting the lower level needs. Happiness.

Another way to look at this hierarchy is that the behaviors one generates at the higher levels can actually promote success at the lower levels. For example, people who are self-confident and seem happy with their situation in life seem also to be more capable of acquiring esteem of others and succeed in all the other levels of needs meeting. In other words, the causal arrow might just as well go downward as upward. Maslow envisioned the way it worked was that if someone were meeting their personal physiological needs – had enough food and water – they would be able to then take care of their safety needs. And accomplishing that, they would be able to turn attention to their love needs, and so on. For Maslow the arrow of causality pointed from the lowest level upward. But in societies, the causality may go both ways, up and down. Certain personalities, which may be largely influenced by genetic predispositions, just seem to be more successful at meeting needs.

In any case, human behavior is vastly more complex than other animals because the degrees of freedom in choices they can make as they seek to meet their needs are so great. And this is a source of complexity in considering the economic subsystem. Ultimately human behavior, from the top of the hierarchy (seeking happiness) downward is directed at making economic moves that fulfill all of these needs. In the modern, developed world economy, there is perhaps a greater emphasis on higher needs than the lower ones. The economic engines of modern societies has produced so much material wealth and has virtually guaranteed the meeting of lower level needs – it is pretty hard to starve to death in a developed society – so that most individuals concentrate of the acquisition of material goods and services that they believe will make them happy. We now know that this is not necessarily the case (Gilbert, 2006, Schwartz, 2004).

In the modern world, in the developed nations, we have used the economic engine to generate an array of products and services that go far beyond the mere needs of human beings. Having transcended the lower level needs via agriculture and technology, we have come to a point of focus on higher-level needs but transformed now into unconstrained wants. We are so thoroughly supported in terms of our baser needs that we have literally forgotten what it means to work on fulfilling those lower needs.

Something extraordinary happened in the evolution of Homo sapiens that made this possible. Below we survey a few of these aspects.

8.3.2.1.3. Creative Intelligence

There is probably little in the way of a rational argument against the idea that humans are a very special kind of animal. Humans assess the potentials of things in their environment and determine the usefulness of those things in helping them to carry out an objective. Humans are both unusually creative and unusually intelligent in terms of the pantheon of sentient creatures on the planet. The combination of creativity and intelligence (here meaning an ability to solve problems) is cleverness. Human beings see objectives (to fulfilling the biological mandate, for example), obstacles to reaching them, and then look for things in their environment and methods of using them that will allow them to overcome the obstacles and achieve the goals. Two capacities of cleverness are particularly important to economics.

8.3.2.1.3.1. Affordance

Affordance is the capacity to see a potential for use of a naturally occurring object to achieve an objective. Many animals, mammals and birds in particular but also some cephalopods like octopi, have an ability to reason about the use of natural (and artificial) objects to use as tools. The analysis of tool-ness will be handled below. But for now consider that any object that allows a sentient agent to obtain its goal (which is conditioned by the biological mandate) is to be called a 'tool.' A chimpanzee finds a way to arrange some branches and leaves into a nest in a naturally occurring cleft in a large branch of a tree. A hiker sees that a fallen tree makes a good seat to rest while climbing a steep trail.

8.3.2.1.3.2. Invention

As in the chimpanzee bed example, the capacity to see how to put several different things together for a new purpose is the essence of invention. In humans this capacity has far exceeded anything in the biological pantheon. Humans actively shape materials so as to create usability but much beyond a crow's ability to shape a stick to poke into tree bark or a chimpanzee's ability to strip leaves off of a twig to use the latter as a fishing instrument for termites. We humans create "compound tools." That is we bring together various elements to construct a *system*! In a very real sense, everything we humans do in the realm of invention is a form of systems engineering.

8.3.2.1.4. Knowledge and Communications

What most sets humans apart from the other sentient creatures on this planet is their ability to acquire and use complex knowledge. This ability rests on several component capabilities that set us apart from other species.

8.3.2.1.4.1. Beliefs

Knowledge isn't really knowledge in any absolute sense. It is just the best approximation of reality that we have induced through information receipt and structuring in our neural networks. But humans have an internal sense of certainty that is a kind of measure of how well that construction has been done. Unfortunately, the sense of certainty may not really correspond with the veracity of the knowledge (Burton, 2008). This is problematic in many ways in our modern world. Below we examine the role of ideologies in organizing our HSS.

8.3.2.1.4.2. Curiosity

Anyone who has owned a pet dog, cat, or even a fish, will know that curiosity is deeply ingrained in the animal brain. Animals, those that can learn from experience, depend heavily on a drive to examine any novel situation. In humans this has reached something of a crescendo. All one need do is observe a two-year old child for a small amount of time to verify this conclusion.

Curiosity drives us to exploration. We need to know. We have been described as informavores[17]! Recall from Chapter 2 that information is what drives the formation of knowledge. Therefore, curiosity, the drive to gain information, is the critical process that leads to increasing knowledge of how things work.

We are intensely curious about what the things in our world and what other human beings can do for us to fulfill our biological mandates. We want to know, how can we survive and thrive in whatever environment we find ourselves.

8.3.2.1.4.3. Science and Understanding the Natural World and Ourselves

Science is the embodiment of curiosity driving us to understand our world and our own selves. Science, as described in the Introduction, is our attempt to gain understanding of our world, what we are, and what our place in this world is. This is unlike anything we find in the rest of the sentient beings on this planet. What other species asks: What does it all mean? There is something very different going on here for human beings. We need to grasp it.

Our deep desire to exist, to extend ourselves (through reproduction), drives us to understanding so that we can anticipate future contingencies. Our capacity to understand through a structured methodology (science) gives us a potential advantage over mere sentience. If we can anticipate the future of the Ecos we might be able to avoid the fates of former life forms (e.g. extinction events).

8.3.2.1.4.4. Language

In Chapter 3 we saw that the key to human interactions and sharing of knowledge is communications through the use of language. No other sentient creature has the extent of communications of abstract ideas that we have achieved.

8.3.2.1.4.5. Shared Intentionality

One of the mental attributes that makes us different from our closest cousins in the phylogenetic tree is our mental ability to share intentions with our fellow (social) beings (Tomasello, 2014). We, unlike, say chimpanzees, are able to communicate with our fellows regarding our intentions to accomplish some particular task that cannot be accomplished by a single individual and elicit their help to do so. The evolution of language may have involved the deepening of our capacity to communicate our intentions and proposals for how to accomplish them. Today, of course, we take this ability for granted. But the need to cooperate to accomplish ends by mutually considered means was a deep part of human evolution and the reason that we developed the level of eusociality that we exhibit. We humans are first and foremost social

[17] See the Wikipedia article: https://en.wikipedia.org/wiki/Informavore for background. Accessed 2/9/2018.

beings. Out entire existence is predicated on working in social units to accomplish work that cannot be done by individuals.

8.3.2.1.4.6. Talents and Specialization

A peculiarity of human nature is the tendency for individuals to have variable talents for performing tasks. Some people are more capable of performing specific kinds of work than others[18]. Adam Smith (1778) recognized this as an important factor in the organization of work in his seminal work, *An Inquiry into the Nature and Causes of the Wealth of Nations*. He noted that individuals could become adept at specific tasks so that their "productivity" would increase and contribute to the productivity of the whole operation. Later we will consider this aspect of human nature and the role of human natures in organizing an economic system.

8.3.2.1.5. Role of the Economy

The Nobel Prize in Economics winner, Paul Krugman and co-author Robin Wells define economics as "the social science that studies the production, distribution, and consumption of goods and services (Krugman & Wells, 2012, p. 2)."

Economics is widely considered a social science since it involves so much of what society does and is formed by social factors such as the propensities of humans noted above. Nevertheless, the economy, studied as subsystem, is found to have internal structures and functions that are the result of factors that are not strictly-speaking, social.

The economy depicted in the figures above is a fiction for the present. There is no global systemic economy (see comment below re: no global governance either). Instead there are, at present, a diverse set of economic processes that are pursued by different nation states. These economic processes encompass the Krugman and Wells list of economy sub-processes. They vary based on how the economic processes are governed. Originally, economics was called "political economy[19]" since the political philosophies and beliefs (ideologies) held in different states factor strongly into how the economy operates in actuality. However, there is a generic pattern of economic systems that we need to consider. This pattern transcends the nature of specific political ideologies; it is valid for all economic processes. In fact, as we will explore later in this chapter, the ideologies that drive the political process and result in the kinds of governance we see (e.g. capitalism vs. socialism) are all too often the source of systemic pathologies and result in economic failures of various kinds. All economies appear to share certain repeating patterns of organization and function regardless of the organization of either the

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[18] Admittedly this is a near taboo subject in the world today. On the face of it, it appears to be a throwback to the nature vs. nurture arguments and is in direct conflict with popular theories of education. Nevertheless, the scientific evidence for variance in skills and talents is quite solid. So we will persist in requiring this as a factor.

[19] See the Wikipedia article: https://en.wikipedia.org/wiki/Political_economy for background. Accessed 5/19/2018.

political or governance corresponding subsystems. This not only the case for human economies but can be found true of all CAS/CAESs.

Chapter 9 provides a general economy model archetype. The claim, developed there, is that the human economy is just the expression of a deeper dynamic in all CAS/CAESs. The living molecular dynamics within a single cell – metabolism – is an economy, as is the physiology of a multicellular organism. The latter is a supra-system that extends the metabolic processes across cells, tissues, and organs. Physiology supports the metabolism of individual cells that have become specialized for specific tasks and would otherwise not be able to survive on their own. All of the cells/tissues are mutually supporting. So too, is the case of the human economy. We will see the pattern of a social group (or society) in which individuals have become specialized and need the rest of the society in order to provide for the supports that they themselves a.re not able to provide.

The economic process is what keeps a system *alive*. It imports energy, material, and information. It transforms materials such that they become more 'useful'; what we will call lower entropy wealth. It uses energy to accomplish these transformations and to generate forces for motion (e.g. animals). It stockpiles wealth for purposes of backup against times when resources might not be available. It distributes wealth appropriately in support of all member sub-processes. The living biomass in the system (all of us and our pets and ornamental plants) consumes some portion of the wealth to stay alive and reproduce next generations according to the biological mandate.

8.3.2.1.6. Role of Governance

The governance subsystem depicted in figures 8.1 and 8.2 is the whole societal governance, responsible for the regulation of all of the other subsystems for the purpose of fulfilling the HSS purpose (which you may recall we could not discover in Chapter 6!) The classical humanist view is that the HSS purpose ought to be to make every human being happy or some species-centric ultimate state. If that were true, then our species has failed miserably.

Governance as a process is the information and knowledge processing needed to regulate the dynamics of the economic system and the behaviors of the components of that system, particularly some individual humans who might have a disinclination to cooperate with others for mutual benefit. What a good governance system should do is keep the whole CAS/CAES operating as close to optimal as possible. For the HSS this would mean a global equitable distribution of wealth so that all humans would benefit.

One possible reason that this is not the case in our modern world is that throughout history we have never had a global governance function. The present United Nations does not even begin to qualify. However, it is interesting to note that there has been some tendency toward unifications of nations from principalities, for example. Nations becoming empires was a further attempt at some kind of "scaling up," though one that failed for good reasons. The creation of the European Union and the Eurozone was, perhaps the most recent attempt to unify a diverse body into one governance structure, but it too has had its problems (at this writing, Great Britain is going through withdrawal from the EU). And it is not quite a full governance structure.

To date all examples of governance, at least at large scales, have been dysfunctional. As with the case of economy there is a universal pattern of governance as a process. This should not be surprising since the two subsystems are so tightly coupled. Chapter 9 provides the basic model template of a CAS/CAES governance subsystem. Governance is a recursively implemented hierarchical cybernetic system. That is, the basic pattern is applied, fractal like, on many scales, from individual agents, through small social groups, through organizations, through large social groups, to whole societies such as nation states. It should be equally applicable to the whole of the HSS.

Chapter 9 shows how the governance process is applicable in several natural CAS/CAES. These complex systems, from the single cell up through the whole HSS are composed of myriad special sub-processes (specialists) who need to work together in a coordinated fashion in order for the whole system to be sustainable (Mobus, 2016). Failures of the governance system in place results in dysfunction of the economy and other non-economic processes that involves working together (e.g. the science process to produce new knowledge). If we examine the existing governance systems in our world today, we can easily find many deviations from the template model, especially at the largest scales. Much of the failures of the governance systems can be traced to faulty understanding of the model and the various ideological beliefs that have dominated the political process and hence shaping of the governance system.

As compared with natural governance subsystems, say for the governance of cellular metabolism or the body's physiology, the HSS governance subsystem is far from evolved to be structurally and functionally patterned after the template model. This subsystem along with the economic subsystem and the political subsystem (below) are undergoing coevolution to produce the kinds of cultures we witness. The human subsystem (the biological component) and the cultures are themselves locked in a kind of arms race.

At the same time another kind of unification process seems to be underway, going under the name of "globalization," meaning the organization of a global economic system. The governance of this economic system is based on the neoclassical economics belief in "free markets," coupled with multi-party agreements on trade policies and procedures. Free market solutions to all social problems is the ideology of libertarianism and the mechanism for attaining the rewards under a free market society is held to be some form of capitalism, of which there are several flavors.

The diversity of governance architectures among nation states is reminiscent of the trend toward specialization that led to economies in the first place. Globalization and the adoption of some form of capitalism may very well represent the setup for the kind of grand transition from local scale disparate individuals a large scale social cohesion. Time will tell.

8.3.2.1.7. Role of the Political System

The evolution of the governance subsystems within different groups in the HSS is a truly evolutionary process involving auto-organization, emergence, and selection (Mobus & Kalton, 2015, chapters 10 & 11) leading to variations on structures of hierarchical governance and coordination in economic processes. Throughout history human groups have been trying out different economic and governance processes that they 'invented' based on desires and intentions, but without the kinds of template models we get from systems science (as described in Chapter 9). It has been one grand experiment with ideas, one after another. As humans spread out over the world and as human groups continuously consolidated into larger economic units, many different 'theories' regarding how the social system should be managed have emerged and been tested, sometimes through competition, one with another, but as often by their fitness in the physical environment in which they developed (Diamond, 2005).

Perhaps the least understood subsystem of the HSS is the process by which humans make decisions regarding how governance should be performed and who will be responsible. We will claim that this problem exists because of a lack of deep understanding of the governance process itself – even when an exemplar appears to be successful. Even so, decisions about how to proceed must be made, with or without systems understanding.

The variations on political decision making are beyond the scope of this book. Human history provides the examples. From tribal councils to Devine Rights, to democracy, humans have been experimenting around with leadership authority models, probably since we became humans. These form the basis of a set of beliefs or ideologies about what is the right approach to setting up and running a governance subsystem. The political process is basically one of deciding for the HSS how that will be done.

In this sense, the product of the political subsystem is the set of instructions (policies) that will be put into positions of power, which is the government. As with the economy and the governance system, there has never been a single overarching political process (at least not one that didn't involve war).

Humans become participants in the political subsystem whenever they are concerned with decisions about governance or economic issues.

8.3.2.1.8. A Note on Ideologies

What makes the Core Society so fuzzy is the role of ideology in guiding human decision making. Ideological beliefs about human nature, how the economy should work, how the governance should work, and how governance decisions should be made have, so far, been the main source of influence on decision makers. The problem with that is that ideologies are historical artifacts – concepts that were someone's best guess at some time in the past that seemed to make sense in the context of the time but have generally been found insufficient in terms of scaling up toward global levels.

Contrast ideological beliefs with scientific theories and models. The latter are based on empirical research and mathematical rigor. The former are just guesses, sometimes informed by somewhat empirical evidence, but more often based on wishes. An ideology that results in a political or economic experiment is somewhat like a hypothesis. The problem is that an ideology is not thrown out when the experiment proves it invalid (falsified). Humans are bad at observing real dynamics of the very systems in which they are participant components and very good at inventing excuses. Ideologies are cherished because they work to help people define themselves along with their belonging to some group and so become part of our personas. Once held, it is extremely difficult to overthrow their influence on thinking.

Ideologies may be related to superstition, the development of a belief that is not grounded in reality. Humans notoriously form such beliefs when they think they apprehend a correlation as a causality and especially when they perceive some particular consequence that either serves their purposes or poses a threat. For example, most people strongly believe that economic growth is good and that an economy should go on growing forever. They believe that an end to growth portends economic collapse.

An ideology of particular significance in our assessment of the economy is the so-called neoliberal belief in "free markets[20]" and their ability to solve all economic problems (which, we must say, are to most economists all problems). This ideology has invaded the organizing processes for the other subsystems as previously noted. The subsystems of healthcare and education have been colonized in modern culture by attempts to model them as economic problems, but with the caveat that they should also operate as economic processes with at least cost minimization in mind, if not profit making.

8.3.2.1.9. Roles of Healthcare, Education, Science & Engineering, and Humanities, Esthetics, & Entertainment

The other subsystems shown in figures 8.1 and 8.2 are still part of and influence the core society functions. But each has its own purpose within the HSS. Whether they are fulfilling those purposes in the modern world may be coming under increasingly pressing question due to the colonization of neoclassical capitalistic economics. Even so, we have several centuries of experience with them and can fairly easily identify their purposes.

The Healthcare subsystem is responsible for keeping humans reasonably well and making sure that our reproductive functions are kept in working order. Humans, in the form of healthcare providers, enter the subsystem in the form of jobs (for which they receive remuneration). But they also enter as patients, dare we say, consumers of healthcare services.

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[20] The scare quotes used here serve two purposes. One is to remind us that a free market is just an idea and the other to recognize that no real instance of a truly free market has ever existed so far as we know. Thus the idea has never really been tested and empirically confirmed or rejected.

This might be an opportune moment to point out something about our modern economic system (at least in the developed world) that has very much contributed to the fuzziness of the HSS, and that is the invasion of a market-based approach to distribution of almost all social subsystems. It is the case that a market ideology has supplanted the social purposes and mechanisms for most, if not all, of our subsystems. While there are still some countries that maintain a healthcare system that does not depend (at least entirely) on market mechanisms of supply and demand discovering prices for services, in the United States, the invasion has been complete. A discussion of the market mechanism will be covered below, and in Chapter 9, as it pertains to one aspect of governance.

The education system is another process that is being invaded by market-style mechanisms[21]. The role of the education system has, historically, been the enculturation of children and preparing them for useful lives. That had meant developing their minds to be able to think about many kinds of social issues as well as be able to master skills deemed necessary for gainful employment. As schools are pushed (by well-meaning politicians and social thought leaders) to become more business-like, the emphasis has shifted to the latter aspect. Today, what it means to be educated, is very different from what it had meant through history. We should point out that there is no evidence that market mechanisms and capitalistic approaches have served the education subsystem well.

Science and engineering involves all of the sub-processes that expand human knowledge and its application to practical use. Part 4 is devoted to "Artifice" and will explore the design and engineering processes more deeply. As noted in the Introduction, scientists discover new knowledge and engineers determine ways to exploit it. Engineers have generally been more closely associated with the commercialization of knowledge and so have a very tight relation with the economy. But, if we consider that when an engineer is doing engineering (i.e. designing a new widget) they are performing a function that is not, strictly speaking, an economic decision[22]. Engineers, as a kind of human specialist, are more motivated to solving technical problems without necessarily considering costs as a primary driver. However, they are also consumers who need to eat and clothe, shelter, and otherwise provision their families. They need to do the job according to the constraints of the employer in order to keep their jobs.

Again we must note the invasion of market and capitalistic ideology into this arena as well. After World War II, especially in the US, agencies were created to fund research in major universities as part of a push to enhance innovation in technology and healthcare. Projects were

[21] At this writing, in the US, the push for vouchers and charter schools is strong at the national leadership level. But the notions of efficiency and productivity, etc. are overrunning the higher education world as well. C.f. (Washburn, 2005).

[22] There is a practice in engineering called "Value engineering" in which the design objective is to produce a product that will have least cost while not sacrificing functionality. Of late another branch of engineering practice, called "Life Cycle engineering" attempts to minimize up-front and end-of-life costs, including externalities such as disposal costs.

(and are) chosen on a competitive basis and money flows accordingly. This is actually one of the factors that is “businessifying” higher education – money must be attracted and managed.

The Humanities, Esthetics, and Entertainment, lumped together because you would think these would be very un-economic-like, are thought to have the purpose of maintaining human mental health. We study history, literature, and art for the sake of understanding ourselves. We produce plays and operas and concerts because these bring pleasure to us and soothe our demons. Humans enter these activities, as the others, as both producers and recipients of the works. Not all that long ago, these activities were supported financially by patrons (some still are to some extent). But today, they are, as with the other subsystems, being taken over by market and capital ideologies. Art is collected as much for profit as esthetic pleasure.

All of these activities have predated the market mentality and so our interest in tracing their histories should play an important role in decomposing them as subsystems of the HSS. They are among the most ancient activities of the HSS and one might easily argue that before they are given over entirely to market logic, we might wonder how they were so successful at helping human beings be fit before there was capitalism.

8.4. Deep Systems Analysis Applied to the Economic System

Now that we have tackled the problem of defuzzification of the HSS and shown how various subsystems might be delineated (or circumscribed) so that further decomposition (analysis) might be started, we can proceed. The HSS is, to be certain, an extremely complex adaptive (and evolvable) system. But that does not mean it is unamenable to analysis. If it were, then the whole program of the social sciences would be meaningless. There would be no point to doing social science if the HSS were inscrutable. Nor do we believe that is the case. The science might be very hard, indeed seem impossible at times without an overarching framework to guide the work, as we are proposing. Rather, we proceed to analyze the HSS as a system and hope to show that it is as understandable as any system in the Universe.

8.4.1. Analysis of the Environment

The first step is to situate the Economy as the SOI and delineate its Environment. From Figure 8.2 we can see that the Environment of the Economy will include the other subsystems of the HSS along with entities in the Ecos (summarized as energy, matter, heat, and wastes along with a question mark with respect to any products. Figure 8.3 shows the first step with the Economy treated as an opaque object. We proceed with analysis using sections 5.5 and 5.6 of Chapter 5, System Identification and Environment Analysis, respectively. Here we will collapse these two showing the final results of the Level -1 analysis. In the following figures we have also aggregated a number of flows of the same types rather than attempt to show all of the details. The purpose of this exercise is to illustrate the process of analysis of a CAES but not to produce a fully detailed one.

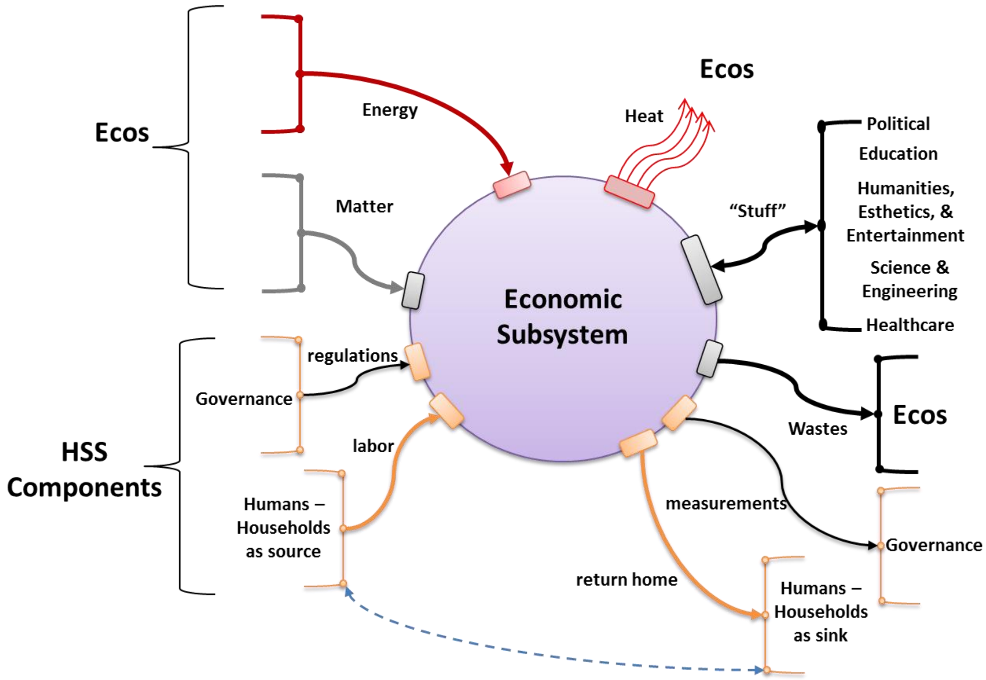

Fig. 8.3. An initial environmental analysis of the Economic subsystem reveals the major kinds of inputs and outputs, environmental entities and relations. Note the handling of the Humans – Households as both sources and sinks. Following the convention of inflows coming from the left and outflows going to the right, the dashed blue arrow indicates these two entities are one and the same.

Figure 8.4 shows a similar drawing for the Core Society. We will be increasingly focusing on the economy from the standpoint of the energy sector and how it affects interactions with the political, human, and governance subsystems along with considerations for the role that science and engineering play in the evolution of the economy. In particular the reader should attend to the red arrows, labeled "Energy" or "Energies" (since there may be several different forms) and also to the radiation of "Heat" from various subsystems as we proceed. The economy of a CAS/CAES is the engine that keeps the system alive and thriving. That is why we will focus on it in this chapter.

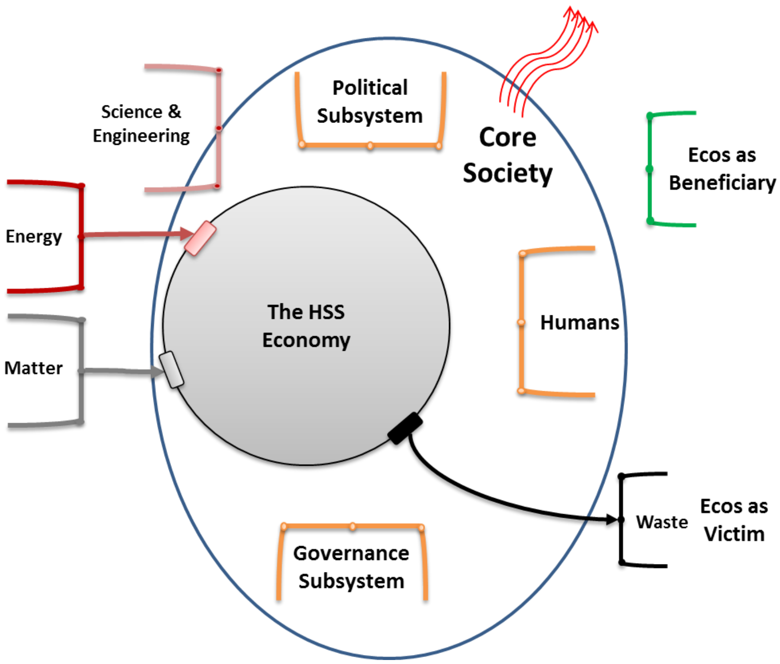

Fig. 8.4. The Economy is treated as the SOI. Sources and sinks include the other entities in the "core society" as well as in the Ecos. Also included is the Science & Engineering subsystem of the HSS. The "Ecos as Beneficiary" label replaces the question mark in Figure 8.2 with the provision that the HSS Economy might produce some product that is beneficial to the Ecos. Wastes are otherwise.

Figure 8.3 is admittedly a cartoon version of what a system level -1 map would look like. We've lumped like-type entities and flows together under the generic labels that categorize them, e.g. Energy constitutes all types of high potential energies that will enter the Economy. There isn't just one energy source (although one might argue that the sun almost is) or one flow of energy into the system. In figure 8.5 we will begin decomposing the energy flow concepts into particulars. Similarly Humans are not only sinks for consumer goods and services but also sources of labor and agency. As we proceed we will show more details of the various roles of the entities (discussed above) and break out specific flows as they pertain to the analysis of the Economy subsystem.

Figure 8.5 begins the process of discovering inflows and outflows as described in Chapter 5, section 5.4.3.2.1). We take the major categories and start to identify particular and specific flows from/to the Ecos. The few examples demonstrate how ontological general categories begin to be parsed into more specific categories until we get down to very specific ones. For example, in the figure the source called "hydrocarbons" would yield two (at least) sources and flows: oil and natural gas. Those, in turn, would be broken down into grades and reservoirs where found. We'll see this in greater detail as we drill down into the energy sector sub-subsystem below.

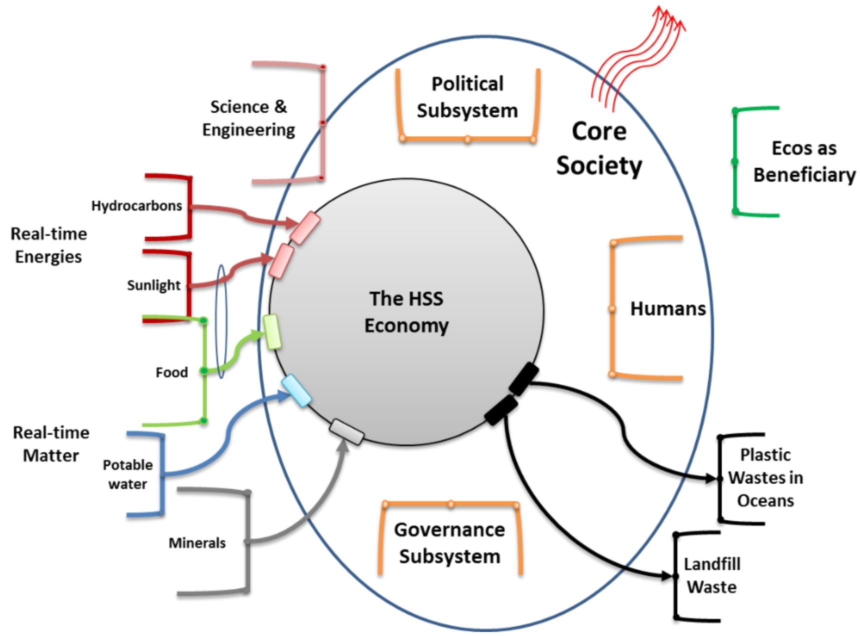

Fig. 8.5. The process of environment analysis and discovery of particular flows from or to environmental entities shows how categories can be broken into these particulars as described in Chapter 5. Energy sources have been broken into two straightforward real-time entities. Food is a general category that encompasses both energy and materials. The two flows are shown linked. Just two real-time matter flows have also been shown as sub-categories of material flows. The same is true of wastes. Interfaces for all of these kinds of flows have been preliminarily identified.

The next step in analysis of the environment of the Economy is to similarly find the flows to/from the other entities, the ones that constitute the Core Society, of course, but also all the other entities discovered in the HSS decomposition shown in Figure 8.2. The Economy interacts strongly with every other entity (we could use the term institution almost synonymously) in the HSS. For example the Economy is what delivers energy to the other entities. Another way of saying this is that the extraction and conversion of free energy to do work is an economic activity. In this example deconstruction we will focus on the energy sector primarily.

Figure 8.6 shows the analysis starting at the major outputs of the economy to the human households. Reference section 5.5.1.2.

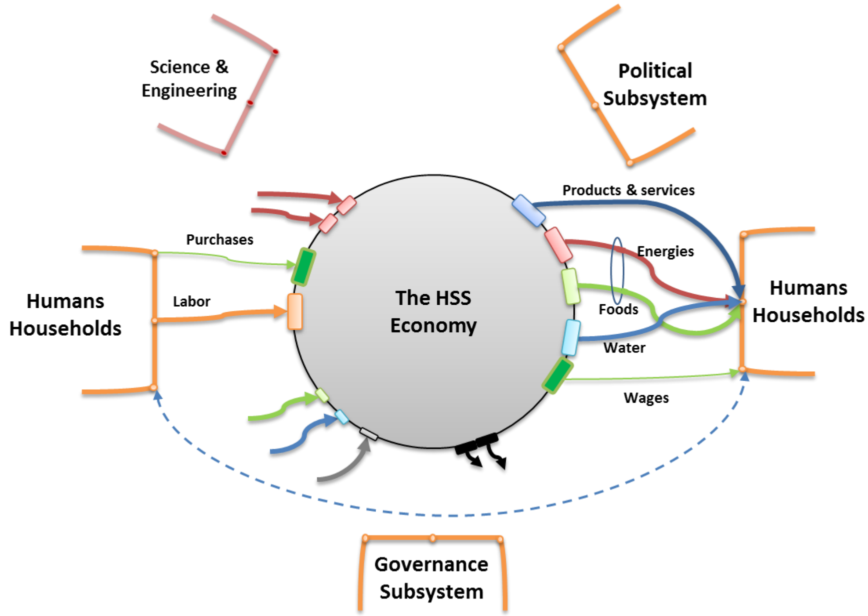

Fig. 8.6. Starting with the major outputs from the Economy to the Human Households, the sketch shows households receiving goods, services, energies, etc. Human Households show up twice, connected by the dashed blue arrow, because households act as sources for some things that enter the Economy and as sinks for some things that the Economy provides (see text for the explanation). Also shown are the other environment entities we will briefly consider in the analysis.

In the figure we also show the human households as both sinks for the products and as sources, at least for labor (actual humans going to work) and messages that request purchases (in other words, money). One of the outputs of the economy to the households is a similar message, in form, and is labeled “Wages”. Workers receive wages for the work they do while members of the economy. They reuse their stock of money to make purchases of goods and services.

In Figure 8.7 we shift our focus of interest to the interactions between the economy and the governance subsystems. We show only a few of those interactions. The primary flows from and to the governance subsystem are messages. Going to the governance system we find, for example, messages containing ‘Measurements’ that the governing process takes of activities and results from the economy. But we also note how the economy transfers some of its labor force to the governing process – it needs people to be the decision agents at all levels. Major inputs to the economy from the governance system are the various constraints, constitutional, laws, rules, and regulations that shape how the economy can work by determining what it cannot do. Note that for the purposes of this analysis we are counting monetary policies as part of the governance process. In the United States, monetary policy is largely left to a supposedly independent (from the official government) institution, the Federal Reserve. While this body is supposed to operate outside the influence of politics, it is still fulfilling a governance function, so we lump it in in our analysis. Besides, different nation-states have different means of setting monetary policies and they are all still part of governance.

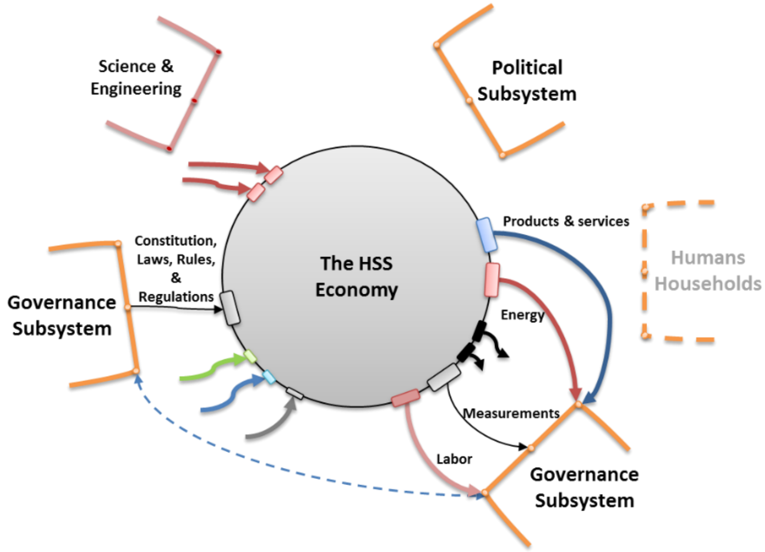

Fig. 8.7. Continuing the environment analysis, now focusing on the inputs and outputs from the Governance Subsystem, we find more inputs and outputs along with their interfaces.

8.4.2. Approximation of the System Function (see section 5.5.3)

8.5. Identification of the Economic Subsystem

In the following section we shall outline the system identification process for the HSS economic subsystem, which will become the system of interest. We start with the emergence of the HSS economic subsystem from the social context which constitutes the main strategy of the species. We work together in order to make a living.

8.5.1. The Emergence of the Socio-Economic System

Refer to Bourke, Morowitz, and Volk

8.5.2. The Historical Perspective

Karl Polanyi (2001)[23] asserted that to understand the modern economy (or the one extant in the 1940s) and its supposed basis in "the market" it is necessary to tease out the most fundamental elements of economic process and that this could be accomplished by observing the

[23] We are impressed by much of what Polanyi wrote regarding the evolution of the modern market-based economy. The world of the mid-20th century was already heavily industrial and the beliefs in market mechanisms had become entrenched. For him to have gained the many insights he did was quite an achievement.

economies of long ago that were not based on any notion of a market[24]. To this he turned to social anthropologists' descriptions of a number of contemporaneous "primitive" peoples. He identified a number of fundamental patterns among the various groups, regardless of the specific social organizations, that constituted economies.

Polanyi restricts the concept of an economy to situations of trade that involves the *profit motive*. We will examine this motive later in section 8.5.3.1 A Note on the Evolution. For him the more salient aspects of human transactions are based on reciprocity, redistribution, and householding (production for one's own benefit). The first two are based on a group phenomenon among social beings.

Homo sapiens evolved a fitness strategy based on cleverness and an ability to see how naturally occurring objects could be fashioned into tools that compensated for the species' lack of physique (e.g. lack of canine teeth). Tools are any object that assists the human pursue their biological mandate. They provide leverage allowing a relatively weak human to accomplish work that they would otherwise not be able to do. Figure 8.6 depicts a single individual as a unit of biological and 'cultural' work. The human gathers resources (like a rock), consumes food for energy, and does work on the rock, shaping it so that it can be used to do additional work, e.g. as an ax used to chop wood for the fire. Products of the work (like clothing and shelter) can accumulate as assets[25].

8.5.2.1. A Note on the Meaning of Tools

A class of assets that are very important is a *tool*. Any instrument or procedure that increases the efficiency of a work process is a tool. Tools provide leverage in the work process thereby increasing the efficiency of the work with respect to the amount of product relative to the inputs of matter and energy. Reducing scrap or heat waste in a process translates into increased productivity of the process. In thermodynamic terms, the same amount of output can be produced with reduced energy (e.g. labor) inputs to the process. This is the same thing as increasing the availability of total free energy to the system. If any given process requires less energy for the same output, then the saved free energy is available to either do more of the same work, or do different work

Tools are the key to understanding productivity, the ratio of outputs to inputs of energy and materials, and differentiation or the expansion of an economic system into different kinds of work. It is also the key to understanding economic growth and the accumulation of assets. If the use of a plow increases the agricultural yield of a farmer (per unit time), then the farmer can and

[24] Polanyi argued that the economy is not the same as the market(s). Economy, for him, is the natural result of social conditions and need not involve the kind of market mechanisms envisioned by the 19th century economists, one that is guided, as if by an invisible hand – or, in other words, a self-regulating mechanism.

[25] For a more comprehensive introduction to early humans and the evolution of living arrangements, a particularly good story is told by Yuval Noah Harari (2011, chapter 5).

will produce excess crops. In the case that the crops are grains like wheat or barely, which can be stored for long periods of time, the farmer is generally motivated to do so, rather than simply work less to produce the same output volume as before the plow. This propensity, which is driven by the biological mandate and the wisdom of storing excess food for emergency exigencies, will show itself later in the evolution of economic systems in the form of 'savings'.

8.5.2.2. Tools and Proto-capitalism

Tools come into existence by work done on some lesser organized material making it suitable to be used in other work. For example a farmer may devote some time and resources to gathering the materials needed to make a plow, shape them to the parts of the plow, and assemble the device. The resources came at a cost, as did the energy expended in the work. The farmer had to take time out from other work to make the plow. But all of this can be seen as investments since the result is more efficient production of food and potentially more excess. Generally tools will have long life spans relative to the overall amount of work they are put to. The plow should last the farmer many growing seasons before he might need to build another one. Thus the payoff extends over the long haul rather than just being a one-off event.

The fundamental notion that investment in tool creation has a payoff is at the root of the concept of capitalism as a way to make life better. The farmer had to save up energy and resources over some span of time until he could craft the plow, but afterward he reaped (pun intended) great rewards. He started with some capital (raw material assets and energy), made the investments to build the tool, and was rewarded doing so. He may even have been taking a risk in not doing more of his usual farming work that if the growing season turned bad he would have lost capital. These notions were surely held by early farming communities. They were certainly institutionalized as those communities coalesced into hierarchically organized civilizations (Nissen et al, 1993).

Figure 8.8 graphically summarizes the situation of the work of an individual hunter or agriculturist in the late Paleolithic to early Neolithic ages. Tools were primitive; the concepts of inventing tools was brand new but so also was the amount of effort that could be afforded investing in them. The figure captures the earliest relation between the Ecos and the human being and the origin of the capital-labor economy.

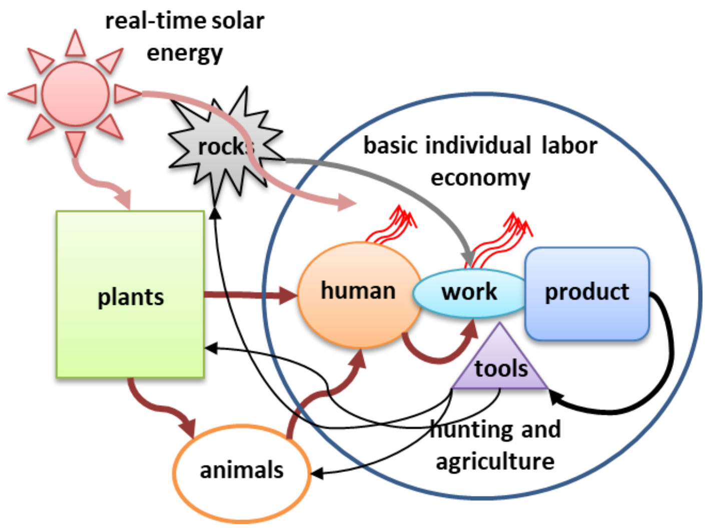

Fig. 8.8. A single individual unit of production doing work to fulfill part of the biological mandate.

Of course it is not really the case that only individuals did work and benefited from it as individuals. Humans were always social creatures, a trait inherited from their ancestral species and shared with many of their cousin species today. To really understand the ontogenesis of the capital-labor economy we have to look at early group economies.

8.5.2.3. Societies and Economies

An individual worker as shown in Figure 8.6 is largely a fictitious entity. The circumscription of a boundary around the individual is more an exercise in defuzzification. The main intent of the depiction is to recognize the self-sufficiency aspects of a biological unit. Humans, early in their evolution, adopted the strategy of working in groups or societies in order to greatly enhance their survivability, given their lack of individualistic ‘equipment’ for exploiting their African environment. Working together in coordination they were able to do things that no individual could have done alone[26].

The key to how this could work lay in the production of tools that could be shared. And that may have been enhanced by the propensity of individuals to exploit talents, to specialize. As Polanyi did, we can turn to cultural anthropologists and their studies of contemporaneous “primitive[27]” peoples to see this phenomenon in action. What we see in these societies is the division of labor along several dimensions, e.g. gender or age, and especially along lines of talent. Figure 8.9 depicts this situation in a simple four-person society. Each individual does necessary work and shares their output with others in the group, who, in turn, share their

[26] This is yet another example of the auto-organization – emergence process in the ontogenic cycle.

[27] The use of the term primitive here is conventional and not derogatory. Primitive tribes in many, especially, equatorial and tropical areas of the world are generally recognized to be pre-literate and their societies are based on technologies that date back to prehistoric times.

products with the others. As long as the basic needs of the biological mandate are filled, a society can exist in a stable group. Polanyi called this kind of transactional relation an economy but did not allow that this was a market.

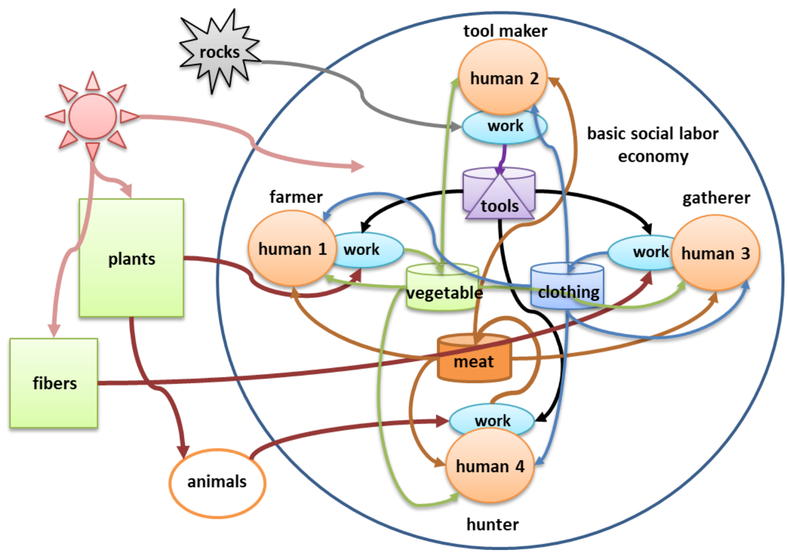

Fig. 8.9. A group of individuals specialize (to some degree) and trade their products with one another in the interest of the whole group.

While we are generally in alignment with Polanyi's requirements for the existence of a true market (i.e. the existence of barter trade and profit motives) we still note that from a systems perspective, the essence of the transactions that took place in such societies (e.g. reciprocity and redistribution as described by Polanyi) still forms a complex network of relations that are mediated by judgements of the individuals who are monitoring the equitability of the transactions.

In this kind of primitive society each individual has complete access to understanding the nature of the work that others needed to do to produce their products. Under this kind of complete transparency it is relatively easy to judge the fairness of trades. Human #3 has a pretty good idea of what it took for human #4 to bring home the meat. They are in a position to compare their efforts in gathering to #4's efforts in hunting. It doesn't have to be precise, of course. They can use proxy measures to make the assessment, such as how long were the hunters gone versus how long it took to collect all of the roots the gatherers obtained. People knew how much of various foods they needed to eat to survive, so subconsciously they could make these comparisons. Their implicit preferences would show up in their intuitions.

8.5.2.4. Tribes and Beyond

Clearly the human strategy of working in groups was wildly successful. Human beings became so adept at exploiting their environments that they were able to successfully migrate out of Africa (on several occasions it seems) and learn to live in a wide variety of environments. They also were successful in expanding their group sizes. Extended families became tribes in which the magic of cooperative production provided the species with a capacity to deepen its ability to exploit many different nuances of environments.

Eventually human beings discovered the ability to plant and reap, particularly grains. Once this threshold of exploitation was achieved we were seemingly no longer constrained in any practical sense. Grains are eminently preservable and techniques for preserving other food stuffs were developed, such as drying meats and pickling vegetables. The concepts of long-term storage of food stuffs, of producing long-lasting tools and shelters, of maintaining a geographical space for seasonal planting led quickly to the notion of permanence of location and the growth of groups into many-family tribes. Humans have a natural desire to identify with their group and so for tribal groups larger than, say several hundred, it became the custom to share practices and beliefs about the nature of the world in order to bond the tribe into a cohesive 'cultural' unit with a sense of identity and place.

The key economic aspects of the growing size of tribes were two-dimensional. In one dimension the tendency for individuals to exploit variations in talents to become specialized in the kinds of work processes they would excel in continued and refined, as technologies gradually improved. In the other dimension, the overall management of the tribe also benefited from specialization in decision-type space (recall the separation of decision types discussed in section [Management (Agent) Decision Types in the HCGS]. In this dimension the separation of roles falls largely along the categories of ages. Adult members of a tribe might be categorized as young (just having gone through some kind of transition ritual), middle aged (child-rearing and general work processes for the tribe), and the elders (usually characterized as wizened). Figure 8.8 depicts these two dimensions of tribal organization along with communications lines needed to cooperate among specialty work processes and among those who organize and manage work and those who make long-term decisions for the tribe[28].

[28] Again, the reader will need to refer to Chapter 11 in order to get background on the management aspects of this hierarchical arrangement.

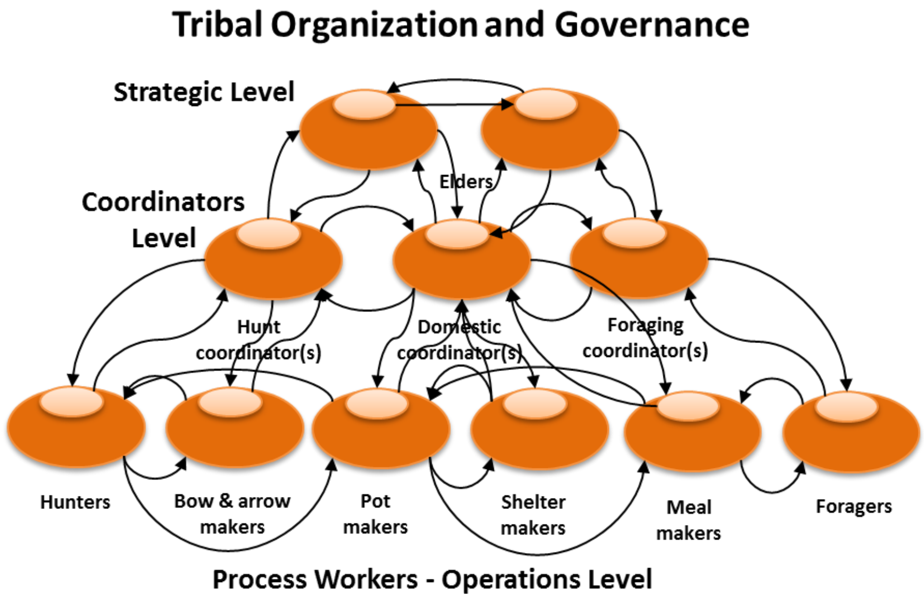

Fig. 8.10. Human communities grew and individuals within a tribe could become specialists (at least to some degree) to gain efficiencies in work. The tribal organization, still found in communities in various parts of the world today, shows the beginnings of both the distribution of work and of organizational governance. In this figure each process is seen to have its own internal governance subsystem reflecting the fractal-like structure of the HCGS covered in Chapter 11.

8.5.2.5. Settlements, Communities, Trade, and Early Markets

The Agricultural Revolution, with its resultant emphasis on larger-scale societies, settlement (and consequent magnification of territorial senses), and continued specialization of work led ultimately to social organizations that Harari (2011) called 'Kingdoms'. These were city-state operations (best examples coming from the Middle East; Babylonia, etc.). We know for a fact that peoples from many regions were traveling and in contact with other kingdoms. We know that they traded specialty goods such as fabrics and spices. So very early on, human beings were developing trading relations that involved transactions based on perceived value of those goods.

Even within a given kingdom a vibrant place for trading goods produced within the kingdom by specialists was developing. Producers of goods (and services) gathered in a specific geographical area of cities, bringing their wares and produce to be offered for trade. It is likely that the first markets were based on barter, but we know from records (cuneiform and later more sophisticated numerical representations etched in clay and marked on papyrus) that humans in these communities were already sophisticated enough, 6 – 8 thousand years ago to count and measure quantities of commodities as a means of keeping track of transactions. Some forms of these records constituted IOUs that, while not yet money, did allow people to trade symbols representing value. As kingdoms evolved in sophistication of writing and numeracy, eventually these symbols were incorporated into stylized tokens that represented quantities of commodities of value to the general population. The idea of token trade for value emerged on the scene of human economy not too long after the whole concept of controlling the production of food and the subsequent support of the biological mandate arose.

Very many modern notions of what an economy is emerged in that early time. Economic ideas have evolved since then in much the same way that biological species have evolved once life actually emerged some 3.5 billion years ago and much the same way languages have evolved among humans as they spread out over the globe. When we take a careful look at economic activity in the modern world we need to keep this in mind. There is a reason why some particular economic process, like capitalistic or socialistic operations, are the way they are today based on these origins. We need to turn now to the modern perspective with this in mind.

8.5.3. A Modern Perspective

We switch now to a modern perspective on the HSS Economy as a subsystem. The objective of this section is to do a top-down decomposition of the modern economy. We will not be guided in following this procedure by what the current science of economics says we'll find. Rather we are going to be guided by systems principles and the methodologies covered in previous chapters. In doing so we will see most of the same sorts of subsystems, such as corporations and markets, but we will also see new relations and functions that have been masked in standard economics by assumptions and premises which turn out to be invalid from the systems view. We will also uncover a few systemic pathologies that may not be readily recognized as such because they have been a part of societies for so long that their manifestations are considered normal.

The HSS began much as described in section [The Historical Perspective] above and has evolved into what we find today. We should take a look at a few aspects of that evolution to better understand what the pathologies are.

8.5.3.1. A Note on the Evolution of the HSS Economic System

In the historical perspective above we presented a model of the earliest small human group economic system, in a tribe. This economy was most likely based on sharing and considerable cooperation among the members of the group. It depended on some degree of specialization, however it was also likely that most members of the tribal unit were capable of doing a variety of tasks if needed – call it weak specialization. In these earliest societies the individual agents probably had a pretty good idea of the value of products and services since they might have had to produce and serve themselves at times.

The question about the history of the HSS economy is how did it evolve from this simple set of relations to become the complex network of highly specialized producers and general consumers that we see today? The answer to that question involves the realization that the ontogenesis of the HSS economy and its continuing evolution was a result of 1) residual (from the biological mandate) motivation to possess[29], 2) intentional creations meant to solve some local problem at a given time, and 3) ignorance on the part of intentional agents with respect to how those solutions would create new and additional problems for the social units (Tainter, 1988). Human agents invented not just technologies but also institutions, procedures, and transient organizations in order to meet an immediate need or solve problems seen from a limited perspective and time scale. The number of possible interrelations between human groups and these inventions exploded exponentially even while there was no particular set of constraints on what could be tried out. As a result, almost everything was tried and so-called solutions were not necessarily tested by some encompassing environment, for it was the HSS itself that constituted the environment of the evolving economy and that enwrapping environment has acted as a buffer for the economic experiments. The testing agents, being ignorant, could not truly test and select against anything. So the kinds of combinations of pre-existing solutions were never adequately tested until, of course, the society in which they were tried finally collapsed as a result of failures of the economic system to provide the same kind of stable, resilient, and sustainable metabolism-like support for the society.

Over the millennia and centuries a number of socio-economic model systems have been tried out more or less by happenstance. That is, "it seemed like a good idea at the time." Few have survived to the modern period. Under the influence of the agricultural revolution, which actually developed over several millennia, small groups evolved into larger groups, villages into towns, towns into city states, eventually amalgamations of near neighbor trading city states gave rise to nations or federations and, eventually, empires that learned to foster internal cooperation among significantly many more individuals than the tribal Dunbar's number. But, in addition to cooperation, the larger the scale of societies the more they incorporated coercion to foster harmony and economic stability (Scott, 2017[30]).

Throughout the history of state economic systems in various parts of the world the interplay between the economic system and the governance system (and both with the tightly-coupled political system) has always been authoritarian and hierarchical with those at the top of the pecking order holding considerable wealth compared with the common workers, free or slave. The idea of a hierarchical arrangement in the governance process reflects the needs for instantiating a hierarchical cybernetic governance architecture, as covered in Chapter 9. A complex system cannot operate without such as arrangement. However, the non-egalitarian

[29] Under conditions of cultural pressures that seem to sanctify greed, this residual motivation is amplified far beyond mere biological needs. The current neoliberal capitalist system seems to have provided the epitome of such a culture. See, for example, Piketty, 2014, for a very deep and wide exposition of the disposition of wealth in such a culture.

[30] Scott points out that the evolution from small gatherings to empires was not a smooth transition in scale. Rather the up-scaling seems to have developed in fits and starts with many communities forming and growing but within as few as three or four generations collapsing. The rise of Bronze Age states was filled with attempts here and there, trying different formulas for governance (mostly coercive), and always fragile against climate, disease, and wars. Even so, it is clear that the trend toward larger coordinated units of populations was the rule globally.

distribution of wealth as well as the use of top-down coercion to achieve the objectives of governance, a command-and-control method of management, are due to the three factors mentioned above. So, some parts of the design and implementation of the socio-economic system within large-scale states is a natural evolution of the necessary architecture of complex adaptive and evolvable systems (CAS/CAESs; see Chapter 9 for a full description of these systems). But the amplification of the motive to possess and to power, along with the unconstrained inventiveness of the HSS's evolvability produced many unsustainable subsystems, most of which unfairly favored some members of the society. Slavery is possibly the most blatant example of institutions that arose to accomplish the promotion and support of a few at the terrible expense of many. Modern humans (hopefully, the majority anyway) have finally come to recognize this horrible mistake, both from a moral perspective and from the social consequences with which societies still deal. Unfortunately, in a seemingly milder form, the class system, the same kinds of inequities and systemic dysfunctions appear to be in full form in most, supposedly enlightened societies (Piketty, 2014).

The current global human economic system is replete with examples of dysfunctional subsystems that are imposed upon otherwise natural CAS/CAES organization. It would be very difficult to even mention these let alone do an analysis that would supply satisfactory guidance in how to design of a truly functional system (even so we have undertaken the project elsewhere and will provide a preliminary look at a socio-political-economic designed based on CAS/CAES principles in the near future).

We will draw upon three examples of sub-subsystems of the HSS economy to demonstrate how ignorance, excessive biological mandate, and intentional invention have conspired to create the institutions we have today, all so complex as to be nearly incomprehensible in terms of the roles they were first designed to play in a reasonable economic architecture. The first is the mechanism used in the market economy to signal supply and demand – money. The second is closely related but supported by a logic all its own that does not correspond with anything recognizable in a CAS/CAES economy – debt financing. The third, deriving directly from the biological mandate, is the concept of profit making.

8.5.3.1.1. Money

In Chapter 12, section [Inter-process Communications and Cooperation] we show how signals (messages sent along defined channels) are used to control the distribution of materials and energies amongst a network of work processes. In that chapter we provide an overall model of how those messages are determined by agents governing economic processes. In the case of single cell metabolism this signaling is based on relative concentrations of specific molecules such as ADP and ATP. In the early HSS economy after the advent of the rise of agriculture-based communities the role of a currency (flow of energy) fell to commodity food products, specifically grains[31]. According to scholars such as James Scott (2017) the advent of sedentary pre- and true state communities was made possible primarily because of the nature of various grains (grasses such as barley and wheat) that could be harvested and stored for long periods before being used. Grains, unlike tubers, fruits, or cows, are nearly fluid, that is each element is small and, in bulk, are easily partitioned, stored, and transported. They could be contained in unit vessels and units equated to work effort (the calories in a unit equating roughly to those needed to supply the next unit of labor). They supported life, though with some nutritional deficits compared with a wide variety of meats and vegetables on the menu for hunter-gatherers. Nevertheless, the convenience of grains in terms of storage, transport, and nutrition seems to have won out[32].

Over the course of several millennia communities grew and the with the increasing emphasis on additional tools, housing, and other forms of wealth produced by specialists communities developed trade markets in which, originally, barter was used to distribute goods (and services) to all members of the community. Grains, being easily handled, became a common denominator trade. One jar of grain for one chicken! Moreover, as communities evolved in terms of governance, with specialists taking over the roles of logistics and tactical managers (as described in Chapter 9) there was a need to support these non-farming agents by collecting a ‘tax’ of some portion of grains from each farmer belonging to the community. Community and government granaries collected these taxes and the wealth was used to support the governance functions[33].

Jars of grains were somewhat convenient for lubricating trade and collecting taxes but not completely so. They were still bulky. We now know from archeological evidence that sometime relatively early in the Agricultural Revolution and the advent of state-like communities the practice of making marks on the outside of wet clay jars that were to hold a commodity, like barely, allowed an abstract representational form of that wealth – the first form of writing. Cuneiform marks could designate contents, who owned the contents, and other accounting information needed to dispose of the contents. It was not long after that that scribes took to accounting for the wealth using marks in clay tablets, divorced from the actual jars holding the

[31] In hunter-gatherer societies, the human being was embedded in the ecological food web. Humans are extreme omnivores and used many strategies for food-getting. With agriculture, humans extracted themselves from the natural ecosystem, creating their own system, which many have noted is highly impoverished from a nutritional point of view. However, what humans gave up in the nature of a broad array of nutrient sources, they made up for in terms of consistency of supply.

[32] Very telling in this account is the fact that civilizational states arose in geographic locations where grains could easily be grown such as the Tigris-Euphrates alluvium (the Fertile Crescent) and the Nile flood plains.

[33] On a somewhat darker note, it appears that as communities of this sort grew and became more ‘state’-like, they acquired slaves and non-remunerated (corvée) labor that also had to be fed (and clothed and sheltered). Thus the taxation process developed so that not only the governance agents were supported, but so too were the workers who performed ‘extra’ duties that were not, strictly speaking, governance activities. Those filling governance agent roles apparently started seeing themselves as ‘important’ and deserving of certain ‘frills’ as additional compensation. This is the weak link in the governance structure that the decision agents have always been human individuals who seem to be susceptible to the allure of ‘power.’

wealth (Nissen, Damerow, & Englund, 1993)[34]. And from there trade could be carried out in an abstract conceptual space! Clay tablets could be delivered, for example to the temples indicating the value of taxes collected.

It was relatively easy to develop more convenient and transferable representations of wealth such as grains, cattle, and slaves in cuneiform tablets. These could be traded instead of bringing all of these wealth objects to a market and bartering them. Essentially these were 'IOUs'. Whoever held the tablet could claim the grains (or other commodities in storage). At some point in the late Neolithic or early Bronze Age the idea of embossing a value mark equivalent to some standard quantity of a commodity (again usually barley) on small clay balls or metal coins to represent a more generic representation of wealth took hold. The advantage of these early forms of money as an abstract representation of wealth is that the markers were no longer tied to specific wealth forms, such as grains. Rather they represented amounts of abstract value and could be used to replace the clay tablets; the actual forms of wealth could be denominated in these markers – five markers might buy a chicken or a small chunk of beef[35].

The key point here is that these markers or 'chits' came to represent an amount of work that either had been done, as in the fashioning of a tool, or the amount of work that could be done, as in the caloric content of a food commodity. These markers represented energy, kinetic or potential, and that is what gave them value. At the time of their invention as abstract representations no one had any notion of energy or work as we know it now from physics. But every person certainly had a clear idea of "effort" needed to sustain their own and their family's lives. So the evaluation of value was pretty clear. The chits, the new invention, money, was linked to real wealth, which for Neolithic peoples meant sustenance.

The problem was who would have the authority to validate the claims of value? Who would say that *x* number of these markers were worth some quantity of grain or a chicken? At the same time that people were experimenting with various kinds of IOUs like this, communities had evolved into more complex social hierarchical states with bureaucracies and state heads. These states represented the evolution of governance structures needed to coordinate the activities of increasingly complex social systems and especially the complex activities of maintaining agricultural production. Most importantly, the heads of states, and their underlings, had 'authority.' They commanded respect and fealty. They could authorize the value marks on the markers. They could determine how many such markers should be in circulation (the accounting systems being used to manage agricultural production and peripheral work had grown quite

[34] The trick worked for more than just jars of grains. These agriculturists invented counting and number systems that let them keep track of how many oxen or goats belonged to whomever. Those number systems would then be applied to the accounting of ownership in general, especially of the possession of land units. Arithmetic and even geometry emerged relatively early in this period and provided the basis (though not the motivation) for statehood to develop.

[35] This might be the origin of the concept of "price". A single marker could still stand for a unit of grain so that the price of anything else traded was tied to the grain by some integer number.

sophisticated by this time). Fiat money was born as a tool to measure the amount of wealth. Prices could be established in the marketplaces to establish relative values among wealth types. In the Bronze Age, the use of metals, perceived as valuable in their own right (intrinsic value), the development of coinage was accepted as a direct way to produce markers for wealth. Gold and silver coins eventually became the norm for quantifying purchasing power even though the metals themselves weren't much good for anything other than making jewelry. Somehow people came to equate rareness and beauty with worth. And thus began a long and unfortunate history of the stuff we called money.

Money, in the form of coinage, became a facilitating tool for promoting trade of goods and services, which in turn, allowed an expansion of marketplace transactions. In systems terminology, money provided the signal path for a positive feedback loop. Easier trade led to expansion of trade, which, in turn, led to the need for more money in circulation.

The role of money, at this stage, in facilitating trade, was acting as a regulator on the activity of work processes. Or, rather, it allowed consumption agents (households) to signal demand for specific kinds of work to be done. If a family got into the habit of eating a lot of bread, then they would be spending more money on bread, or wheat, or flour and, thus, the wheat farmer, miller, and baker would receive more coins and conclude that they should produce even more of their products.

This was all well and good for marketplace transactions, but there was a problem with the use of fiat money in that the governments of these forming states did not really know how to determine the actual volume of monetary units relative to the total wealth that could be traded. If they produced too little money, the prices of goods and services tended downward. If they produced too much, prices tended upward. In other words, the price structure of markets was not stable given the ignorance of the governing agents.

Today the role of money is an extremely complex proposition. Many, many authors and academics have tried to tease out the complexities of what the various roles of a monetary system might play. The most obvious role of money is as a means to purchase goods or services in a market economy[36]. But money is also considered to be a "storehouse of value", or of wealth. As it turns out, in analyzing the situation in modern economies, this is really not the case. The existence of phenomena such as inflation or deflation clearly show that units of a money doesn't hold stable with respect to purchasing power. What this means is that a given unit of money has a time-sensitive measure of value.

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[36] The term 'market' as used here is very broad and means that buyers can find and buy goods and service among many competing sellers. This model is true for a wide variety of ideological socio-economic versions such as communism or capitalism. In all such systems people use money to buy from sellers. How prices are set is another matter. In a so-called free market, the prices are presumably set by supply and demand pressures. But that is another story.

This, however, is a relatively recent monetary phenomenon. For most of the history of money, it actually did provide a stable representation of purchasing power (value).

The modern problem with the role of money in the economy comes not from the nature of money itself, not even from the commodity backing of monetary value. It is the result of how money is created (i.e. “printed”). Fiat money, created by states, could be a storehouse of value if the state accounting system took a realistic measure of actual wealth that exists in the community[37]. For example, if the state took care to measure the actual production of grains and cattle (say in ancient Egypt) and then produced only enough coins to represent that amount of wealth, then the money would have had a realistic backing. Unfortunately, this was not and is not today the case.

The creation of money in much of modern history has been turned over to the banking system[38]. The governments still print a fiat cash which is circulated, of course. But the real action, the real volume of monetary production, is due to how banks treat the primary cash. As with so many other economic phenomena, this started out innocently enough. But the decisions agents have made regarding how to proceed have turned out to be devastating.

8.5.3.1.2. Debt-based Financing

Closely related to money is the use of promissory notes to acquire assets in the short-term[39]. The notes signify a promise to pay back the value of the asset, usually along with a premium paid for usage, in the future as soon as an income from the use of the asset is realized[40]. The wealth to be realized is an expectation of future work processes that would generate sufficiently more profit that the debt could be paid back with interest. This is very different from the method of financing the acquisition of assets via savings. Historically, that was the ‘normal’ approach.

In the early days of agricultural societies, grains could be stored in communal or state-controlled granaries. In good years of harvest there would be excess over what would be needed in the current year to feed the population. The accumulation of excess over time was savings. During times of expansion (say of the population), it was possible to support the creation of new farmlands by loaning grains directly to, for example, young new farmers starting their own operations. The new farmers promised to pay back the loan of grain seeds from their harvests because those savings could very well be needed in the future when harvests were not as good.

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[37] The gold standard was actually an attempt to accomplish this even though misguided in terms of what actually amounted to real wealth that could back the currency. Gold is an artificial value base. But it was convenient, and in the view of many rulers of the time, it was ‘valuable.’

[38] And, as we will see directly, this is an illusion that completely distorts the role of money in signaling work and consumption processes regarding what work gets done in the economy.

[39] Indeed there are authors who insist that all money is actually based on debt. As argued here, the pattern of borrowing assets did not start as borrowing from the future, however. It is this latter pattern of behavior that has gotten us into deep trouble.

[40] In other words, this is the classical idea of investment.

These savings acted as insurance against bad times, which were almost certain to happen. The granary operators acted somewhat like bankers. The grains in their care belonged to the collective or state controllers, but were not needed just then. If the loan was paid back, everybody would be restored to their rightful shares and a new unit of production would have been created in the meanwhile. This is financing growth from savings.

As societies evolved and money became the major representation of wealth (e.g. amount of grain in the granary) it was a relatively easy step to go from granaries to monetary banks once money forms took on the responsibility for representing that wealth. Someone took on the responsibility for holding on to excess cash and protecting it as a service. But bankers soon realized they too could loan some fraction of their deposits to new ventures, say to finance a ship sailing to the Spice Islands to bring back cargos of desired spices. The sale of the cargo would produce something we now call a “profit” which would then be used to pay back the bank (with interest) while giving the entrepreneur an income. This was, of course, possible as long as the recipients of the spices held them in high value relative to the efforts paid for by the original loan. History is replete with adventures in trade driven by the thrill of customers to have something really new and exclusive, thus highly valuable and worth giving over more money than perhaps the goods were worth in terms of efforts to get. Herein lay the central fallacy of commercialism – a matter of ignorance of value.

Fractional reserve banking became a widespread practice along with the development of capitalism (another form of loaning money to ventures for profit). All of these mechanisms had the effect of creating new money that was not directly related to the fiat cash produced by the states. Money had morphed (evolved?) into something new, partly a promise of the state that the representation (coins or bills, later) actually were worth something, for example some weight in a precious metal like gold, and partly a relative value based solely on perceptions of buyers and sellers. The creation of money ad hoc, with fractional reserve banking for example, complicated the whole notion of valuation via denominations. The true value of a monetary unit (like a dollar) no longer had any real meaning. In massive markets the value of anything was no longer based on some intrinsic quantity, such as the amount of energy needed to grow and harvest a bushel of grain. Rather it became so abstract that it was deemed to be worth whatever a buyer was willing to pay for it (in the nominal currency).

The evolution of the economy has produced a world in which the value of anything is now arbitrary and not directly accessible. Mostly this is a result of ignorance but also the result of intentional manipulations of buyers, sellers, bankers, and governments who have all tried to take advantage of the decreasing visibility of real value to obtain a higher profit on their sides of transactions.

Eventually, in the more modern world, money was deemed a mere commodity much as the grain it originally was meant to represent. Its value was to be set by market forces (whatever those are) and currencies from different nations could be traded in international markets

In today's world the idea of financing operations using promissory notes is de rigueur practice. Corporations think nothing of paying employees with borrowed money on the premise that someday in the future they will be able to pay back that loan because future profits will more than cover the principle plus interest, but also contribute to net profits. As experiences in the last half of the 20th Century and the first decades of the 21st Century attest, that isn't really working out in most industries. Corporate debt is building apace.

8.5.3.1.3. Profits and the Profit Motive

The concept of profit seems so completely natural to most people that they could not imagine an economic system not driven by the desire to "make money." There are several reasons, however, that this naturalistic concept is invalid from a systems perspective. First, as already noted one does not "make" money except, to be discussed below, in relation to the amount of free energy that has become available to the system. If the flow of energy is going up (and as we will see shortly it is starting to do just the opposite) then the monetary authority can create additional amounts to represent the increasing capacity to do useful work. But if it remains the same rate of flow, then there should not be an increase in the supply.

When stocks in a corporation are sold or bonds are issued this is a form of debt creation of money in the sense that the corporation promises to repay the principal as well as, perhaps, a dividend so the buyer treats the stock certificate or bond as an asset. Nevertheless the corporation can now spend the money as they choose (supposedly on capital goods). The theory is that they will use the money for productive investment, meaning that their operations will produce excess money above what they spent which will allow for the retirement of bonds and paying of dividends to the investors. There is a fly in the ointment, however. There is no upper limit placed on how much profit one can make. If one can manage to hide one's costs and the market is still willing to pay high prices for the good or service, then the seller can pocket the excess, pay higher dividends, perhaps, or, as has been happening in the capitalist world, paying incredible salaries and bonuses to the geniuses who engineered this marvel.

Profits are probably not inherently evil, but when they become the single largest motivating factor in operating businesses then a systemic pathology enters the dynamics. The pursuit of higher profits, especially when those at the top stand to reap larger rewards for doing so, can lead to behaviors such as cutting corners, externalities (like dumping pollutants in the river without having to pay the cleanup costs), outright fraud (anyone remember Enron), and other bad behaviors that lead to lesser actual value of the product or service and exporting the true costs to other subsystems[41].

In the section above [The Historical Perspective] we referred to Karl Polanyi's differentiation between a profit-based market system and an actual economy. In his view an economy is more like what we have outlined in the next chapter. The addition of profit seeking

[41] For example paying low wages to workers increasing the disparity between the haves and have-nots.

beyond what is needed to create and maintain a buffer against down-turns or simply to pay off debt, is not really part of an economy and, in fact, distorts our perceptions of what an economy is. What parts of the modern economy are, in fact, economic and what parts are something else?

The profit motive is a derivative of the biological mandate to grow during development. The HSS has been and is still developing, albeit more slowly (Gordon, 2016), and so the impetus to grow has motivated much of the collective drive to acquire more and more. This translates from the collective drive to the individual drive. CEO's believe they are owed larger bonuses. Workers are ticked off because they believe they should be getting bigger annual raises[42]. The whole zeitgeist of the society becomes one of belief that growth entitles individuals to have more. The perception is that the "pie" is growing so everybody should enjoy a bigger slice, but the reality is quite different. As long as the population grows the effective pie is actually shrinking (see the section below on the [Biophysical Economy]). Each slice of the pie, the per capita wealth, for the vast majority of humans is also shrinking (Piketty, 2014).

8.5.3.2. Decomposing the Modern Economic System

We start in Figure 8.11 below.

This is a reconstruction of Figure 8.3 above with the Economic subsystem fully established as the SOI. The dashed oval in the figure represents the starting place for the part of the economy that most interests us at present – the energy sector.

[42] Which, coincidentally, contribute to inflationary pressures, which then motivate the US Federal Reserve Committee to push up interest rates, which then drives up the cost of money, which then results in … This loop is very complicated but the bottom line is dampening the growth of the economy and future raises.

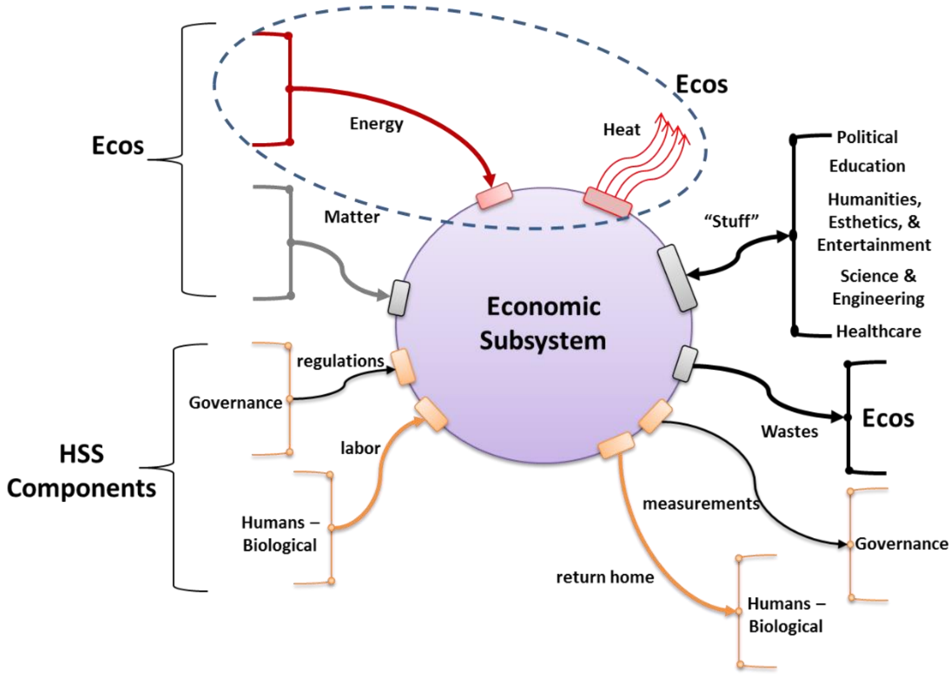

Fig. 8.11. The economic subsystem is now the system of interest. The analysis of the environment shows the relation to entities in the Ecos (outside the boundary of the HSS) and other subsystems within the HSS. These flows are merely illustrative. For example, the flow of humans into the economic system, as labor, and its return to home (e.g. in the evening) would be accounted for with an appropriate membership function and flow descriptors. The dashed blue oval focuses attention on the energy "sector" of the economic subsystem.

In Figure 8.6 we establish level 0 (SOI) of the economic subsystem along with its level -1, its environment. We will drop the 'sub' prefix since this becomes our focus of interest.

The environment has been divided into two parts. The Ecos, external to the HSS itself, is the source of energy and material resources, shown lumped in the figure. It is also the sink for wastes that are not explicitly recycled within the economic system. The other part of the environment of the economy is the collection of other subsystems in the HSS. In the figure, the Human (biological) and the Governance subsystems are shown explicitly with the relevant flows (people and messages). All of the other subsystems are shown lumped together with "stuff" being produced by the economic system flowing to them. Stuff means the products and services that support those systems.

The energy sector of the economy is circled in Figure 8.11; that is what we will be decomposing in particular. It consists of energy capture and conversion interfaces able to channel appropriate forms of energy into the economic system. From the level 0 perspective, the energy sector also has to provide for the removal of waste heat when necessary. Often waste heat will simply radiate into the atmosphere (or hydrosphere) and eventually into space (otherwise the Earth's temperature would rise, not because of greenhouse gasses but due to thermal pollution).

In Figure 8.12 we show a schematic view of the economy as a transparent box. In this figure we have not specified the boundary. The energy resources (the sun symbol) are captured, converted, and distributed by the red oval. Energy flows to every component in the economy, the various other extraction and work processes as well as to the human subsystem for consumption (e.g. home heating). Human beings provide what we have labeled as "labor" flowing to all of the internal work processes. Labor involves not just the capacity to do physical work, but to have a self-controlling worker, with a mind sufficient to provide work guidance. Human workers bring both physical work capacity and mental models of how that work should be done to the other work processes, e.g. to the extraction and various manufacturing processes.

But humans are also ultimate consumers of all wealth that the economy produces, directly or indirectly. Note that the flow of material and energy is consistently, on net, from the extraction (left side) to the consumption end with wastes being removed and dumped into the Ecos.

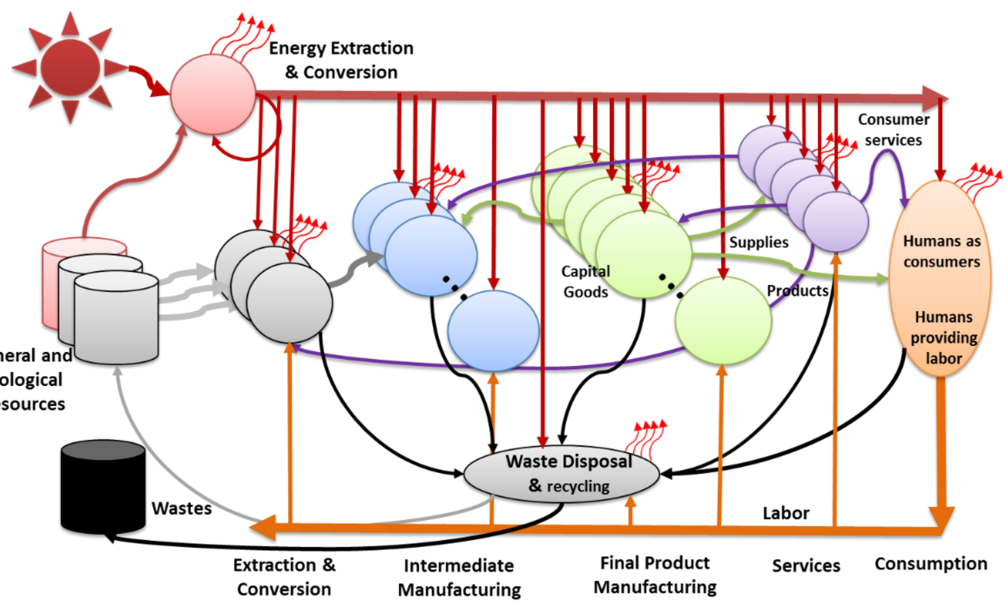

Fig. 8.12. A schematic of the modern economy.

The schematic representation in the figure shows that products and services that are ultimately consumed (the black arrows represent the resulting wastes) are produced in a staged process. Raw materials are extracted from the environment (e.g. metal ore mining), processed initially (e.g. metal smelting), then progressively those lower-entropy (more organized) materials are assembled into usable products and various classes of assets (e.g. fixed assets like buildings needed in which to do the manufacturing). Even services ultimately depend on the manufacture of physical goods like computers or paper.

The multiple ovals in each of these pass-through stages represent the fact that there are both many kinds of intermediate and final products being produced and that even within any given kind of product (or service) there will be multiple producers who, as a rule, compete with one another for a share of the market, a subject to which we will return below. This latter aspect is modeled in a manner similar to the Leontief Input-Output model of an economy[43], which is the closest thing to a systems representation of an economy.

8.6. The Energy Sector and Biophysical Economic Factors

We will now focus on what is arguably the most significant sub-subsystem of the economic subsystem, identified in Figure 8.11 above, the energy extraction, distribution, and removal process. The reason energy is so important in considerations of the economic subsystem is actually very simple. It takes a flow of the right kind and potential of energy through a material system to drive the work processes that result in the construction of usable materials – the materials that go to make our "products", "services", and what we generally think of as wealth. According to Harold Morowitz (1968, p2): "…the flow of energy through a system acts to organize that system." Of course it takes more than just energy flow. It takes controlled and regulated channels for both energy and material flows as well, and that takes decision agents sending messages to actuators, etc. to guide the application of energies to the right materials at the right time. Recall from Chapter 2 (especially figures 2.9 – 2.11) the basic concept of a component work process that can use energy flow to transform materials, other energies, or messages (data) into useful outputs. The HSS can be considered as a huge and extremely complex work process converting Ecos resources into human biomass and material wealth, along with waste by-products. The economy is composed of all of the internal work sub-processes and all of them depend on the flows and proper channeling of energy[44]. The HSS economy, as with cellular metabolism, is fundamentally a machine for doing work to lower the overall entropy of the system, even at the production of greater entropy in the Universe, including parts of the Ecos. Thus, economics is a study in non-equilibrium thermodynamics.

8.6.1. Basics of Thermodynamics, Energy Flows, Work, and the Production of Wealth

We start with a basic definition of wealth; that is *any object or substance that provides support for human life*. This includes material goods, natural resources, and accessible knowledge (in peoples' heads or in documented form). We also call these things assets. The *value* of any piece of wealth depends on two things, the low level of entropy in its arrangement of atoms and the degree to which it helps reduce entropy in the human person and human environment (recall the section above on the significance of tools [A Note on the Meaning of Tools]. This is a rather different view of both the concept of wealth and that of value, but the

[43] See the Wikipedia article: https://en.wikipedia.org/wiki/Input%E2%80%93output_model for background. Accessed 3/30/2018.

[44] For a more detailed example the Wikipedia article, https://en.wikipedia.org/wiki/Energy_in_the_United_States provides a picture of sources of energy and uses in the United States. Accessed 11/11/2018.

reader is invited to check these aspects against anything they personally consider wealth, with one caveat.

What we leave out of the definition is *money*, and that is for a reason that will become clearer later. For now we simply say that money *represents* wealth, but is not itself wealth[45]. This is one of the first real differences between classical economic thought and a systems result.

Let's consider a few examples of what we consider wealth and see how the notion of reducing entropy in human affairs plays out. From a biological perspective the first form of wealth is the food that a family has controlling access to. Food is, after all, biological materials that are very low entropy substances. Moreover, the best foods are those that allow the body to most efficiently maintain the low entropy state of one's own body.

Other forms of wealth come as 'hard' assets, for example a house (or shelter). This object is not some random arrangement of materials (even a cave exhibits a low entropy compared with, say, crevices in stone), but a highly organized arrangement of materials that provide shelter from the elements and spaces in which particular activities take place (e.g. the hearth). A shelter reduces the loss of heat from the bodies of the occupants, thus increasing the free energy available for useful work, among other things. The degree to which a shelter provides these services determines how valuable it is perceived to be by potential possessors. For example, a shelter that provides different spaces for different various activities, e.g. cooking versus sleeping, versus workshop, allows the accouterments of those activities to be organized appropriately and reduces the effort needed to transition from one activity to another; such a shelter might be considered more valuable than a simple hut with one room used for all of those purposes.

Clothing might be considered as assets that are intermediate in terms of value in increasing useful free energy (keeping the body warm outside of the shelter). They are not as transient as foodstuffs, which are consumed in the short-term; if they are well made they will last many years.

What about land? Certainly subsequent to the sedentary settlements wrought by the Agricultural Revolution, the possession of land became particularly important. Land is an asset insofar as it can support agriculture (or support an ecosystem that provides hunter-gatherers, in which case it is a territory). And land generally needs to be improved (e.g. planted, irrigated, etc. or built upon). The value of land is also based on its relative entropic condition. A rubble field is not a great place to plant or build a home. Fertile soils are extremely complex environments that must be carefully husbanded in order to yield a maximum food, forest, or fiber products.

Then there is the assets that are buried in some particular lands, such as metal or other mineral deposits that can be mined. The concentrations of specific metal oxides, for example, in

[45] Money is sometimes called a "storehouse of value" in the sense that if you have a lot of money in the bank you might feel wealthy. But in reality you have simply accumulated a storehouse of purchasing power that generally should be convertible into actual wealth.

ore veins are actually low entropy products of geochemical/thermal processes that did the work of concentration in the fluxes of heat through the mantel (e.g. volcanism). These resources are already in a form that makes them relatively easy to refine and use. Thus, land that harbors such resources is also valuable. The products that can be made from the refined products, e.g. tin or iron, for a small investment in work/energy are, themselves, tools for improving life. The iron blade of an oxen-pulled plow is, perhaps, the quintessential example.

Wealth is produced by work processes that have been designed or have evolved so that material objects and, especially, tools have been organized to facilitate the work flow. Raw materials (or subassemblies) are brought into the work process at one end. Energy of the right type and quality, i.e. high potential, is also brought in to drive the tools under the supervision of operations decision agents. We should note that work can be done on not just materials but on messages (data) and other energies. Again we refer back to figures 2.10 and 2.11, which show some of these kinds of work processes at atomic levels. But all work requires the flow of high-grade energy in a form that is coupled with the moving parts of the tool(s). When work is done, a significant amount of the incoming energy is transformed into non-recoverable heat; that is it is now energy from which no further work can be gotten. It is only good for exciting air molecules (raising the ambient temperature a bit) and eventually radiating into deep space.

All activity in the HSS is based on this universal pattern. The economy is now seen as the systems organization of all such activities in support of human life (excepting the various dysfunctions that take human life, such as using guns to kill people instead of wild game – these are believed to be anomalies, the results of failures of some peoples' brains).

Figure 8.13 provides a view of the economic activities that support human life as a form of extra-somatic (outside the body) metabolism. These are the activities organized within the economy framework that keep people alive and thriving. The diagram is more representative of a developed country's capacity to support life, but some form of each of these activities can be found in even developing societies, even if in a reduced or primitive form.

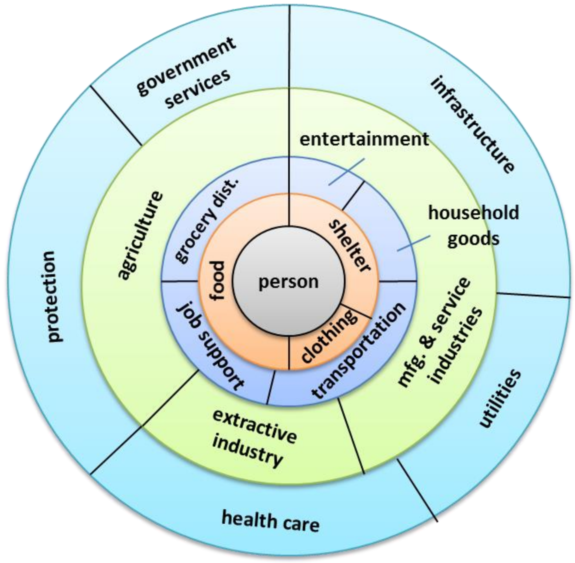

Fig. 8.13. Every person in a social system exists within a cocoon of extra-somatic metabolic-like activities we call the economy. For advanced economies these services are extensive and sophisticated. For less advanced economies such services, if they even exist, are primitive and simple.

Another view of a social system economy is given schematically in Figure 8.14. Here only the major categories of activities are shown lumped into ovals with flows from left to right representing the value added chain that eventually leads to households for consumption and use. The economy is shown in relation to the natural world – the rest of the Ecos wherefrom material resources are extracted. Shown in this representation is the flows of messages that help to coordinate and regulate the general flows (described more below). There are basically two kinds of messages that can be found in this system. The black (skinny) arrows represent the sorts of complex messages that supply processes with detailed information about the situation. Examples are purchase orders, shipping documents, contracts, etc. The green arrows represent a more abstract, and ultimately less informational kind of message that is mediated by the flow of money. These are used to transfer value from, say, consumers to producers for purchases of products and services, and from producers to households to purchase labor (and intelligence).

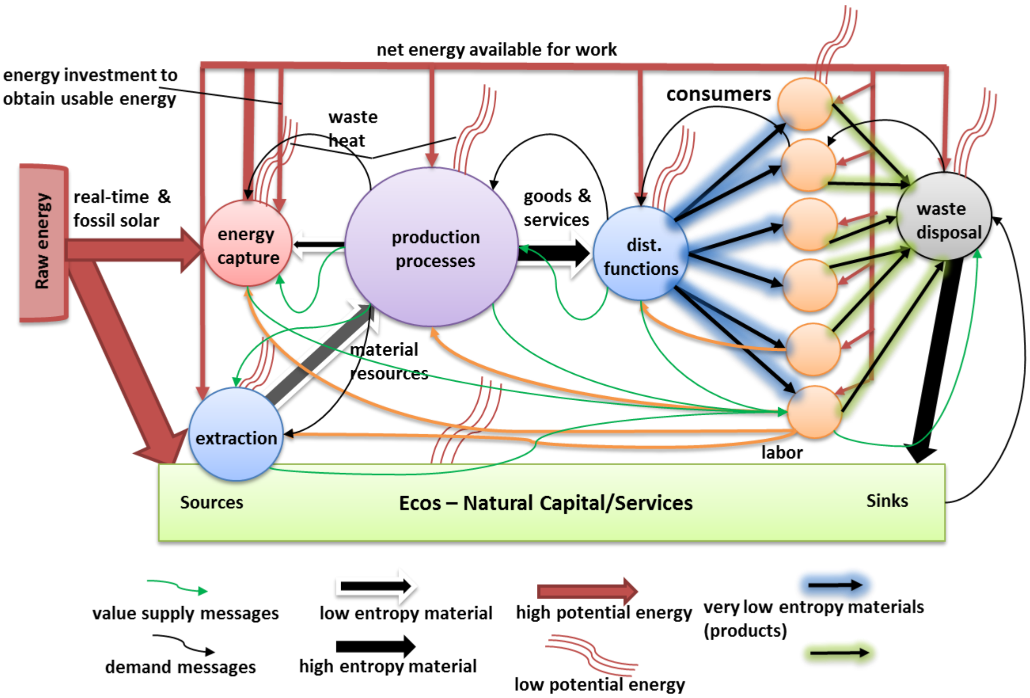

Fig 8.14. A further abstraction of an economy. The orange ovals on the right side represent households that both consume the products of the economy, the low entropy objects and services, and provide the human labor needed to operate the economic production and distribution functions. Money flows in the direction of energy or intelligence sources, i.e., from consumers to production processes and from those processes toward labor.

8.6.1.1. Energy Sources for the HSS Economy: Dynamics and Economic Effects

Over the course of human history there has been an evolution of our capacity to extract free energy from our environment to power the production of human biomass and cultural artifacts or wealth. From the origin of the genus Homo, our mammalian-kind have depended first on the availability of suitable organic sources of energy, otherwise known as food. At some point in the evolution of the genus, presumably *Homo erectus*, we sentient beings discovered the taming of fire. This was momentous, possibly the most momentous event in human history[46] if not in the history of all life. Fire, for example the burning of wood, is the essence of extracting energy to increase the free energy available to humans for other work. At the very least fire keeps people warm against a cold climate, thus letting them use their own internal energies for more 'productive' work. It also allows for the cooking of food materials, releasing additional calories that would not have been available to predecessors. Cooking is generally recognized as the

[46] Or, actually prehistory. *Homo erectus* is considered the most likely predecessor of *Homo sapiens*, as well as *Homo neanderthalis*, and other species (or sub-species) of humans some 400,000 years BCE. It is believed that *erectus* had realized the ability to manage fire and that capability was then inherited by the subsequent species such as our own.

condition that gave rise to the more cognitive versions of *Homo*, us in particular. It is important because the expansion of availability of free energies in foods is directly responsible for the ability of humans to occupy many new ecosystems beyond the African savanna.

Fire is the essence of energy sources for the economics of the HSS. Fuels, first in the form of wood but later in the form of hydrocarbon fuels, have made it possible for humans to evolve a complex society and technology. Fuels embody free energy in chemical bonds of hydrogen and carbon, which, when oxidized, release substantial amounts of energy in the form of high temperature flows. When coupled with the phase transition capacities of water (liquid to gas phases), and the explosive expansions resulting, gave rise to the steam engine and the transformation of heat at high temperatures into mechanical work. Thus was born the Industrial Revolution!

Today, the economic subsystem of the HSS is still largely dependent on the phase transitions of material systems due to thermal processes. The internal combustion engine (and its variants) is another version. The turbine engine is another version of dependence on the explosive oxidation of hydrocarbons. All of these forms of fire power modern society[47].

And that leads us to a huge problem. The amount of hydrocarbon fuels buried in the Earth's mantle is finite. To be sure, there is a tremendous amount of such fuels, coal, oil, and natural gas, still in the Earth. But it is still finite in quantity.

There is another problem with these fuels. We have to use energy doing work to extract them. In other words, it takes energy to get energy. The energy net of the work needed to extract it is what counts. We have to drill and extract these fuels at a price. And, as we use up the easy-to-extract sources, we have to increase the energy expended to obtain the harder-to-extract sources. For example, a conventional oil well on land produces 20 times (at least) more energy than it takes to drill the well, set up the pump, extract it, and move the oil from the well to a refinery. But when we have to go out to the ocean platforms to extract the same volume of oil, we get only 5-10 times as much energy. When we have to extract oil from bitumen in Canada, the ratio goes down to 2-5 times.

There might still be a net energy return on the energy invested (EROI). But it is declining over time toward zero net. We are doing more work, extracting energy resources, than we had to in the past. And the problem is this: The civilization we built over the last several hundred years was based on an energy return of between 20 and 100 to 1. The infrastructure we have built probably requires a minimum of 10 to 1 just to maintain. Even with better technology new infrastructure would need the older 20 to 1 or more[48]. That is a monumental problem.

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[47] 86.4% of primary energy in the world comes from fossil fuels (the rest from hydro and nuclear with a tiny percent coming from alternatives and combustible fuels like wood). Source: Wikipedia https://en.wikipedia.org/wiki/Fossil_fuel Accessed 11/2/2018.

[48] It might even be worse. The newer technologies that make the drilling/pumping/refining more efficient actually represent a greater expenditure of energy in inventing/building manufacturing capacity/delivery, etc. The

What about alternative energy sources? Why can't we switch to solar electric or wind[49]? Well we might be able to do so to some extent. But the conversion of raw energies in solar inputs require substantial technologically-dependent tools. It is one thing to simply burn a hydrocarbon fuel to produce a huge temperature difference that causes a phase transition and to transform a low potential energy form into a high potential form. Solar energy, for example, is actually extremely weak; you can walk around in sunlight without being cooked. You can walk around in a high wind without being terribly disturbed. But consider walking around in a coal-fired furnace in contrast! No way. The thermodynamics of producing free energy are not favorable for just collecting solar energy. It takes a huge land area of collectors, even if they have efficiencies of greater than 15-20 percent, and a lot of technology to derive enough free energy to drive an economic system such as is possessed by the developed economies.

For example consider a simple *thought experiment.* Can a solar photovoltaic plant provide enough energy to support an ordinary society and enough additional energy to reproduce itself, that is produce its replacement over its lifecycle? At current levels of the technology there is no evidence that this is even feasible let alone settled. And yet this is exactly what will be necessary in order that society, as it currently works, could achieve stable existence based on solar energy.

Ultimately, the economy depends entirely on the flow of high potential energy through it. It is a system that does work by virtue of the availablility of free energy as we have covered in this book. Yet currently two factors are at work in the mainstream energy sector of fossil fuels. First the fuels are finite and diminishing. The peak of production of so-called conventional, land-based oil, has come and gone. Every year, globally on average, conventional oil production declines[50]. This same phenomenon will follow in non-conventional sources such as deep-water, shale, and bitumen mining, which are the sources that have kept total oil production up (actually growing slightly). There is already evidence that the phenomenon of peak oil is approaching for certain shale fields; the early production was extremely high but the production rate seems to fall off much more rapidly compared with conventional wells. The inference from this is that these wells will ultimately not produce as much total volume as conventional ones. Moreover, the number of highly productive geographical sweet spots where drilling is successful in a field are limited. So the methods of horizontal drilling and use of water and sand to fracture the shale rocks, initially looking promising, now appears to be nearing its peak as well, after which

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costs are amortized over all of the drilling operations. They are diffused in the energy sector and only show up in terms of capital equipment on various oil company balance sheets. Many advanced technologies rely on, for example, exotic metals which are very energy intensive to mine and refine. So the real energy used to get one unit of energy is basically unknown.

[49] Actually, wind is a solar energy! It is the climate – the effects of the sun on the Earth – that drives wind patterns and wind forces. The same is true for hydroelectric power. The sun drives most energy flows on the surface of the planet. The Moon drives tidal cycles and core thermal processes drive hydrothermal cycles, but these are relatively minor compared with the influence of direct solar energy.

[50] There are regions in which oil production is still rising due to geopolitical consequences. However, total production for the globe is in decline.

production will also decline year after year. No new technology is on the horizon that might significantly change that.

The second factor is that EROI decline mentioned above. As with financial investments that fail to make an acceptable return, as the EROI declines, as it must with the growing reliance on non-conventional wells and bitumen mining, at some point the returns of energy on energy expended fall below what is needed to do the physical work of society. At that point, even with lots of oil still in the ground, we have to give up on energy from oil (and gas and even coal). How will we replace the over 80% share of primary energy? How soon can we. And this isn't even about getting off carbon to save the environment. This is just the plain thermodynamics of the energy sector itself.

Graph 8.1, below, shows the dynamics of the extraction of a finite energy reserve. The structure of the model is shown in figures 8.11 and 8.13. What is happening in this model is that the reserve of, say oil, is fixed and finite (or "stock-limited" in the language of system dynamics), represented by the barrel (stock) of fuel, labeled "Gross Energy". As oil is extracted there is a kind of "back pressure" that increases. That is it is harder and harder to do the extraction, i.e. it takes more energy to do the same job. The blue curve in Graph 8.1 represents the dynamical behavior of obtaining raw oil, say[51]. Note that in Figure 8.11 the barrel is large and in the next figure it is shrunk, representing a diminished supply over time. Also note the red arrows that are reentrant from "Extraction" to itself. In Figure 8.11 the thickness of the arrow represents the fact that not that much energy is required to do the work of extraction, whereas in Figure 8.13, that arrow's thickness is greater representing the fact that the amount of work to do the same extraction has increased significantly.

Then compare the red arrows labelled "Net Produced" in both figures. In 8.11 the arrow is thick representing a significant amount of net energy being provided to the social system, "Society", primarily to support the reproduction of biomass – the population of human beings.

What Graph 8.1 demonstrates is the relations between the growth of energy production, energy costs of production and net energy available to society to support growth. The dynamics are dramatic. As the economic system extracts more and more energy from its finite reservoir the curve initially rises exponentially – the more energy we extract in excess of what we use, the more energy we have to do more extraction. Also the demand for energy in the society puts a positive pressure on the extraction process. The green curve tracks the rise of net energy which is going to support the economy and increasing the biomass of humanity.

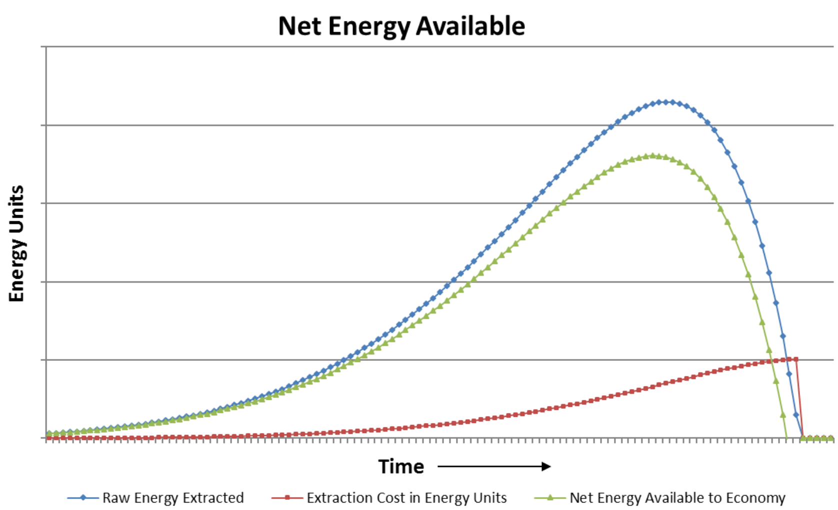
But as time proceeds the energetic costs of extraction (red curve), rising due to the increasing difficulty of extraction, lessens the net energy relative to the gross energy resulting in an increasing gap between the blue and green curves. And then the finitude of the resource

[51] The same basic arguments apply to a number of mineral resources such as coal and metals, but we are limiting our argument to energy resources. Thus the same dynamics are applicable to natural gas as well.

comes to bear. The interactions between diminishing reserves and increasing costs result in a diminishing return on investment (the green curve tails off before the blue curve shows diminishment). This is subtle but important. Due to that finitude, the blue curve reaches a maximum, a peak, after which it begins to decline. And according to the model parameters it declines far faster than it rose. Yet because of the declining EROI (rising cost curve) the net energy actually peaks before the gross energy curve. The free energy to society stops growing and starts declining even before the gross energy supply curve starts to decline. We reach peak net energy earlier in time than we reach peak total energy production.

This is why that phenomenon has gone undetected. Our economic sector economists track gross energy, i.e. total primary energy produced. They do not consider net energy available for useful work because they do not grasp that it is the latter that actually counts toward producing real wealth. Economists are not, typically, physicists, and they definitely are not systems scientists.

It gets worse. Recall that one of the main outcomes of increasing wealth is the support of an expanding population (biomass of humanity[52]). Thus we need to consider in our economic modeling the effects of net energy per capita. The curve in Graph 8.1 is scary because it suggests that in the not-too-distant future we are going to run out of energy and at a dizzying rate. But given that over the last several millennia we have increased our populations dependent on that energy, it should not be surprising that the amount of free energy available to each individual has been declining precipitously.



[52] We should probably note that it isn't just the biomass of humanity that constitutes societies. It also includes the biomass of all of our pets and lawns. We probably ought to also include domesticated animals of all types, e.g. farm animals, since these are all biomass under the ultimate control of human society.

Graph 8.1. The dynamics of extracting a fixed, finite energy source (like oil) over time, and the effect of increasing costs of extraction lead to more rapidly diminishing net free energy for society, i.e. economic work.

Between Figure 8.15 and 8.16 we see the operational changes that occur in this system over time as a result of the twin effects of declining EROI and depletion of reservoirs (peak production). Society gets bigger while the energy source diminishes. Meanwhile, the cost of extraction of gross energy increases causing a decline in net energy available. And, meanwhile, the population has increased so that the net effect is a diminishing of net energy per person.

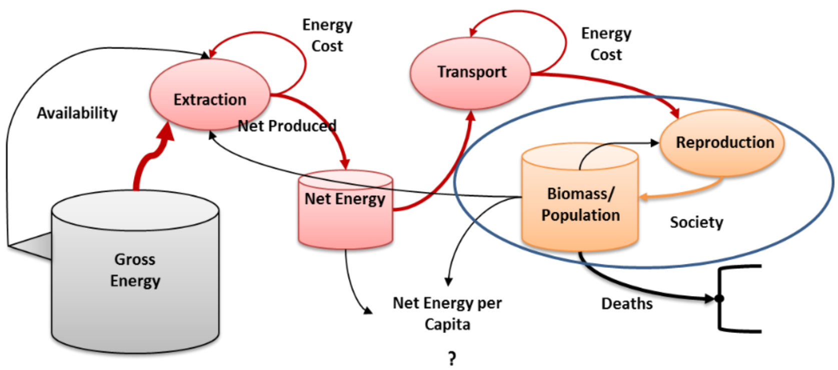


Fig. 8.15. The situation with the extraction of a fixed, finite source of energy (e.g. oil). The gross energy source has to be extracted (and converted to usable form). The extraction work takes energy (cost) to produce a net energy reservoir (e.g. tanks of gasoline). It needs to be transported to points of use, where the work gets done. From a societal perspective, the use of energy helps support the biological function of reproduction leading to an increase in population.

Effectively every individual is marginally poorer since energy is the source of wealth production.

In Figure 8.16 we see a thickening of the energy cost flow which means the net energy to society is less of the total flow out of Extraction. These relations are proportions not actual amounts. Total energy extraction might actually increase, but the portion left for Transport to support the reproduction of Biomass[53] is is in decline proportionally. Since the biomass increases, even if at a lower rate today, the question is whether the net energy growth can outpace the growth of the biomass/population.

[53] The focus on biomass as opposed to just population is that it is the total of biomass production, whether through individual reproduction or body weight production, depends on energy input. For example, even though the reproduction rate in Yemen has been higher than other places in the world, due to famine individuals' body weight is less than for an average person, this largely due to the on-going conflict in the country. If energy resources per capita or per unit of existing biomass falls below that needed to sustain growth, than we eventually see reductions in both population and total biomass.

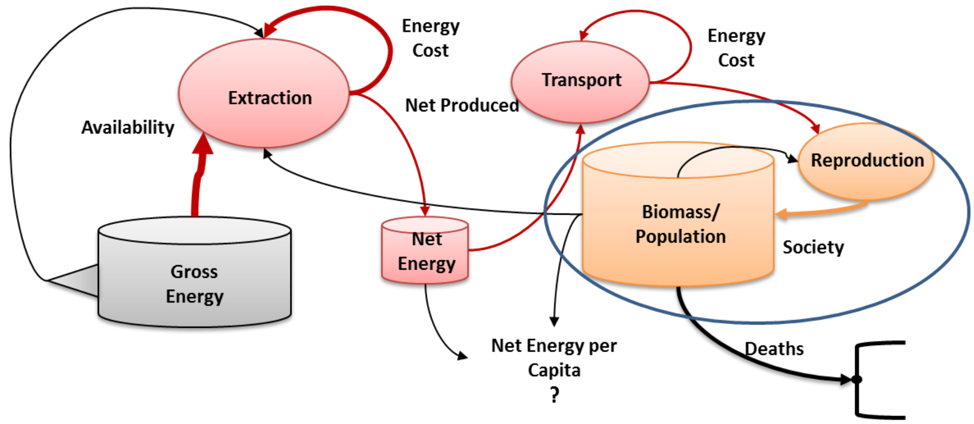
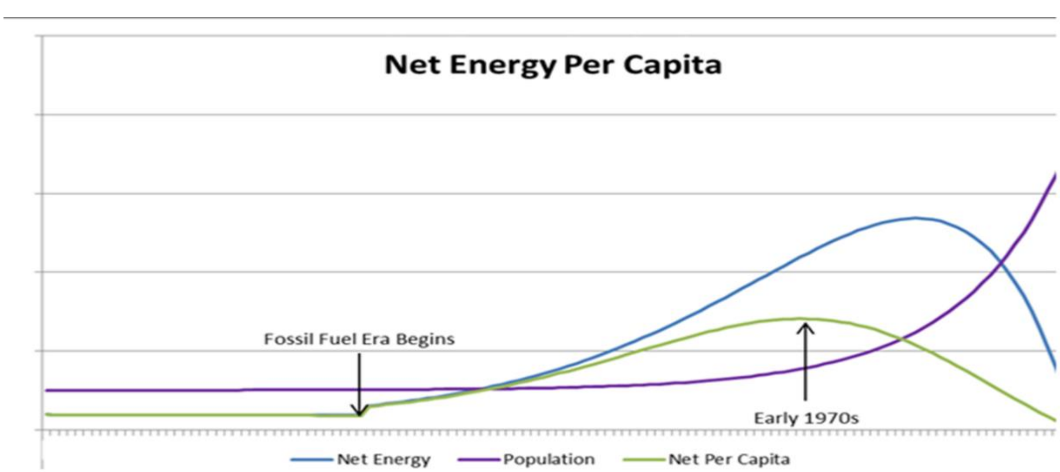


Fig. 8.16. As the source of Gross Energy depletes (a smaller reservoir as compared to that in Figure 8.15) Extraction work gets harder – more effort is required – and the Energy Cost needed to power that work goes up. This means less Net Energy available for society. If the biomass of society grows at a rate greater than the growth of energy production, then the net energy per capita (or unit of biomass) declines.

Graph 8.2 now looks at the effects of the dynamics of Graph 8.1, but on a per capita basis. Though we use the more familiar term “per captia” which means per person generally, the term “capita” can actually refer to physical capital, in this case something like average biomass per individual. There is a direct relation between free energy and biomass production. However, people will be concerned with how much energy is available per person, so we will stick with that meaning.

The graph comes from a model that spans the period prior to the beginning of oil age, through the oil boom and peak oil, projecting into the future. We did not include a feedback loop from the effects of reduction in net energy per capita to the population growth so the graph makes it appear that the population keeps growing in spite of the falloff in net energy per capita. The important dynamic to note in this graph is that net energy per capita (green line) peaks and then declines much earlier than total net energy (blue line) and at a much lower level than total net energy (under these assumptions about population increases).



Graph. 8.2. This model suggests that net energy per capita (global average) declines earlier than total net energy due to the affects of continued population increase. The model does not include feedback from that decline to affect the population growth. That assumption is unrealistic, of course, and actual experience has shown that population growth rates in many parts of the world have actually declined over the last several decades (the purple line should actually form a logistic curve, bending toward a more flattened form shortly after crossing the green line). The position of the presumptive calendar date of 1970s is explained in the text.

The marking of the "Early 1970s" indicates that in this scenario the peaking of net energy per capita happens in the early part of that decade. What might be the consequences of the peaking in that timeframe and might it correspond to our actual experiences?

Clearly if there is less actual net energy to produce assets (as in Graph 8.1), then fewer assets (goods and services) can be produced and translated into the model of Graph 8.2 this would mean fewer assets per person on average globally. The effects of this might not be readily recognized by economists who do not yet grasp the relationship between free energy and asset production capacity. But it would show up as a positive influence on inflation, positive in the sense of promoting it. With more people clamoring for more stuff and a production system less capable of producing apace, prices on things in general will be pressured in an upward direction. Of course, declining net energy per capita is not the only cause of inflation. But it provides a steady upward nudge. Then other positive feedback loops, the ones, for example, that the Federal Reserve Bank Committee pays attention to, begin to act to amplify the effects. As inflation begins to diminish purchasing power of the average household, the clamor for wage increases to compensate eventually drives wages upward. But that just ends up eating into profits so companies eventually have to raise their prices for the goods and services they produce. And so a difficult-to-control spiral upward is triggered, buoyed always by gradually increasing energy costs (decreasing EROI and peaking of reservoir production).

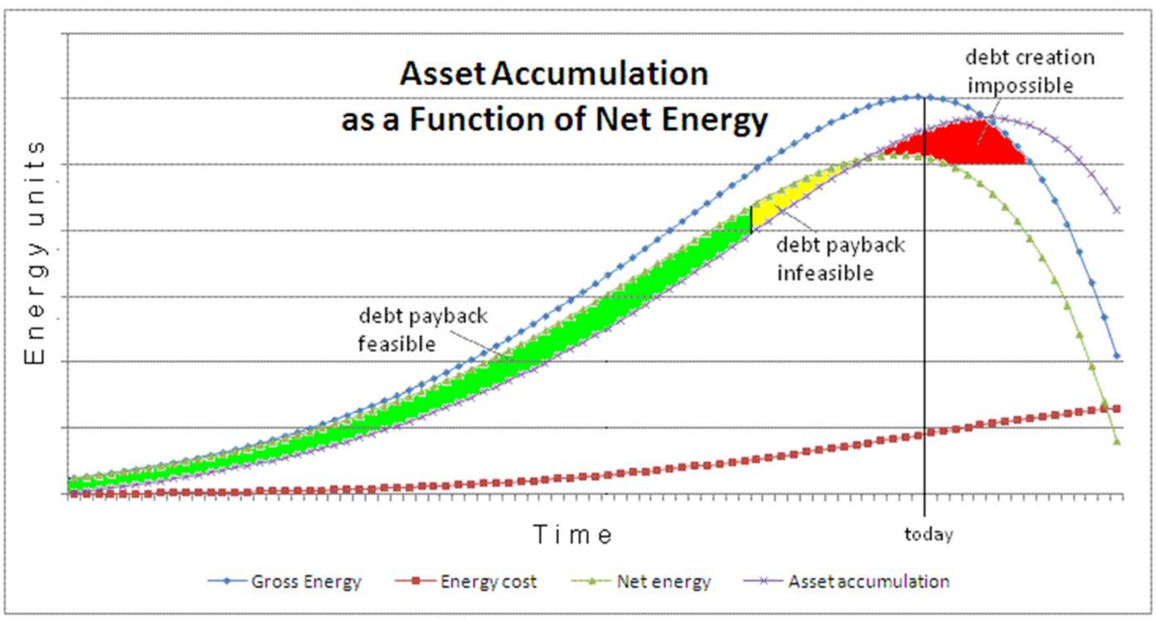
If we reflect on the actual economy evolution from the end of the 19th century to the present we note that there was a significant growth in terms of increasing wealth production from the onset of the industrial revolution and a sharp upturn with the advent of the oil age just at the end of the 19th century. After that, combined with the developments of technologies such as transportation, communications, metallurgy, and others (more lately computation), growth of wealth, particularly in the Western world, increased exponentially. Even factoring in the effects of two world wars and a "cold war" western affluence increased as measured by both GDP and productivity. That growth exceeded the growth in population so that per capita wealth grew providing for a more affluent middle class lifestyle.

Then something happened in the early-mid 1970s. Growth rates in GDP and productivity began to fall (Gordon, 2016). The curves began to flatten out. Then, as the 1980s were coming to a close there was a downturn overall[54]. The economies of the world suffered a number of

[54] The bursting of the Dot-Com bubble at the end of the millennium (see the Wikipedia article: https://en.wikipedia.org/wiki/Dot-com_bubble for background; accessed 11/14/2018) showed that what most economists thought was legitimate growth of the economy turned out to be an illusion, spurred by enthusiasm for a

economic shocks, usually attributed to normal business cycle declines but also to the effects of financial bubbles bursting and dragging down the rest of the economy. Economists were often taken by surprise, i.e. did not predict the timing or depth of recessions, for example. Post facto they looked for classical economics explanations for these episodes, every economist having a favored phenomenal cause. None of them thought to look at either the overall trends (the big picture) or the role of energy costs and net energy per capita because energy, in general, has been taken for granted in all economic theories. The physics of wealth production was not considered in any of these theories. As of this writing a number of economists and historians are still uncertain as to what the long-term reduction in growth rates and productivity mean, let alone what might be causing them. This is because they simply do not understand the role of energy in driving work processes and the production of low entropy products and services – wealth..

However, we can anticipate what that future might look like in Graph 8.3. This is based on a model that combines the effects of fossil fuel depletion, ensuing energy cost increases, and the amount of free energy that can be applied to producing wealth or assets.



Graph 8.3. Effects of "peak fossil fuel energy", decreasing EROI (increasing energy cost) and the production/accumulation of wealth into the future.

This model starts after the onset of the oil age and was based primarily on the dynamics of oil extraction. It does not take into account the seeming extension of the oil age through non-conventional drilling and bitumen mining. However, these will not change the overall shape of

"new economy" based on technology, the Internet, and the World Wide Web. After adjusting GDP for this anomaly the period from the mid-1970s through the 1990s showed overall slowing. As the first decade of the 21st century comes to a close there are strong arguments that, globally, the economy is beginning to contract.

the curves in the graph; they will only extend further in time the events depicted. Fossil fuels are still finite stocks so the situation depicted in figures 8.15 and 8.16 will still play out.

In Figure 8.1 the blue curve, labeled "Gross Energy" represents the extraction rate of oil, pushed to its maximum and constrained only by economic factors such as financing and technology. It rises logistically (early exponential with an inflection point – just below the Y in Energy – and then decelerates) reaching a peak. This was presumed to be the phenomenon of peak conventional oil that data indicated was taking place around 2012[55]. The red curve at the bottom of the graph represents the increasing energy cost of extraction and refining. As oil reserves became more expensive to get at, the costs of extraction increased. Thus the net energy available to do useful (economic) work (green curve) as a fraction of gross energy also declined. The graph indicates the net energy reached its peak before gross energy did. That is, net energy started to decline a number of years before 2012 and is also reflected in Graph 8.1.

The purple curve in the graph represents the use of free energy to do work and accumulate assets or total wealth. The wealth is measured in units of embodied energy in material goods of all kinds – that is we assume that all of the free energy was turned into assets; the gap between the net free energy curve and the accumulating asset curve represents the less-than-perfect efficiency. The colored zones are the real story here. The green area represents the period in which the availability of more free energy in the future would always seem to increase. Thus in the future one could expect to accumulate even more assets. This is the situation that supports the concept of economic growth for society. It is a time in which debt-financing makes some sense because the expectation that wealth will increase and debts can be paid back appears reasonable. But after the inflection point in the net free energy curve occurs the gap between asset accumulation and free energy starts to narrow. From that point on (the yellow zone) there is increasingly less energy to do work with and so the overall production of assets begins to tail off as well. More importantly, the ability to pay back loans becomes increasingly infeasible.

There continues to be some increasing accumulation of assets, owing mostly to the fact that many kinds of assets are long-lived. But the consequences of the peaking of oil extraction should be clear. The red zone represents an area where debt will increase without the hope of paying it back in the future. Debt, after all, is just a promise written on paper to pay back the amount borrowed (backed by current assets not future ones) and that promise assumes that the borrower will, in fact, own more assets in the future (liquidating some will provide the cash needed).

The red zone is where debt bubbles of all sorts will develop. Unable to pay back current debt, for example, some countries will "restructure" their loans from some banking institution and, in effect, increase their long-term debt even more. The normal expectation is that by

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[55] No precise time window could be declared but the projection models based on historical extraction rate growth coupled with various projection techniques such as Hubbert's method (see the Wikipedia article: https://en.wikipedia.org/wiki/Hubbert_peak_theory for background and a view of the model) showed the peak to be somewhere in that time frame. The then nascent fracking of tight oil had not yet started showing up in the data.

becoming fiscally prudent and somehow attracting investors in the future, those countries will be able to pay back their debts one day. But as Graph 8.3 indicates, without some new source of energy to compensate for the decline of oil (and other fossil fuels) the loss of net free energy will cause a relatively sudden collapse of the economy's capacity to do useful work.

This model is not meant to provide an accurate or precise prediction of the future. All of the units of measure are relative to a presumed value of raw energy available. This is an attempt to explore the dynamical behavior of the boundary conditions of the economic system depending on oil as its main (over 80% at present) source of free energy. The rules apply to any fixed, finite supply of energy. So we expect the same behavior from an economy dependent on all of the fossil fuels. The inclusion of alternative energies (but see the section below, [An Exercise in] for an examination of this feasibility), assuming their EROIs are around 20:1 and do not decline over time, might change the maximum of the peak but unless they took over the whole supply of free energy, the shape of the curves would remain the same.

When one combines these curves with the per capita curves (recall due to growing populations) the prospects do appear dim. At the same time, the dynamics demonstrated in Graph 8.3 represent the worst-case scenario, that humanity will drill, drill, drill and pump, pump, pump at the maximum rate possible until it becomes uneconomic to do so. And that is because humanity is also committed to accumulate wealth at the fastest possible rate until it is no longer possible to do so. It assumes that humanity cares nothing for their grandchildren and just wants to consume and have it all now. It doesn't have to be that way.

8.6.1.2. A Short Note on So-Called "Decoupling"

Most modern economists will argue that there is a tendency for an economy to decouple from carbon naturally as that economy becomes increasingly a so-called service economy. Supposedly service work doesn't buy as much energy and so they are not significant users of primary energy in the way, say, manufacturers are. But this misses the fact that service companies are buying products that have embedded energy, i.e. energy that has already been used to produce them (think paper and computers). So energy was consumed to support the work of services[56]. It just doesn't show up in the books of the service company as such. Those books reflect direct costs of energy, electricity and gas, which are relatively minor. But they fail to take into account the embedded energy in the products and services they buy. In theory those energy costs are reflected in the prices they paid for those products and services, so these never really show up in so-called carbon footprint analyses as contributions to carbon emissions.

[56] Cloud computing server farms, in fact, are huge consumers of electricity, so much so that some of the larger ones have set up their operations next to major dams in order to have access to the amount they need. Since they are getting electricity from hydroelectric they are decoupled from carbon, technically. But hydro isn't everywhere available so server farms in the Midwest, for example, have to rely on coal or natural gas-fired generators (until really huge wind farms can provide).

The belief that the economy, by becoming more service oriented, is decoupling from energy usage is not borne out in fact. The use (and cost) of energy is just more diffuse among multiple other services and manufacturing. Off-shoring of production is also another way in which energy usage has been hidden from the ordinary bookkeeping. Energy, and in many cases the energy source is particularly "dirty," that is coal-powered electricity, is still very much being used. In fact, given that the total global CO_2 emissions have continued to increase in spite of the supposed decoupling, the world is using more fossil fuels in toto even while the free energy per capita is in decline.

8.6.1.3. The Control of Energy Flows

Consider what work gets done in the economy. How does a manufacturing subsystem decide to build another unit of product? The building of such a unit requires the availability of free energy. But why should the subsystem take in that free energy, do the work, and provide the unit to a purchaser?

In a market-based system the answer is that the purchaser, an economic agent, offers to acquire the product and give up something that represents an amount of free energy that they control, an amount that is equivalent to the free energy needed to build the next unit. The customer signals the value of the product by virtue of offering something considered to be valuable in the sense that it could be used to purchase other products of equal value. The production subsystem is responding to the demand signaled by the willingness of a customer agent, or, rather it is responding to an aggregate of such demands by a population of customers. It turns that aggregate of signals into a motive to produce more of the product. What is the nature of these signals that they cause the producer to do more work in the future?

A market economy is the equivalent of the cytoplasmic matrix of a cell or the circulatory/lymphatic system of a body, in which signals of demand and supply diffuse through the medium (cytosol, blood, and price). Producers respond to signals that indicate demand (higher prices paid) and consumers respond to signals of availability (lowering prices).

Work processes do what they do when what they do has some value to receiving processes (consumers). They can only know what that value is when the customers provide signals that correspond to their desires (needs) for the product. Once those signals are received, the work process has a motive to continue producing its product under the assumption that that product will be desired in the future and that there are more customers in the marketplace. Car manufacturers keep making cars because people keep buying cars. And, in a replacement population, with new customers coming into the market continuously, there will always be customers in the future so it makes sense to produce the next units in anticipation of those transactions. Thus the producers will further signal the suppliers of materials and energy that they need more of these resources currently.

Consumer agents decide that the possession of a particular product will enhance their existence (considering hedonistic aspects!) And assuming said agents had acquired the necessary accumulation of signal tokens (money), they will send said signals to the purveyor of the product, thus demonstrating a 'demand' for that product. Figure 8.14 shows a few of the kinds of signals that are communicated between producers and consumers to regulate the flow of energy. The black arrows represent specific information conveyance, things like purchase orders. The green arrows represent a more generalized kind of message, one in which the information content is determined by a simple metric – price – conveyed by flows of money. This one kind of signal is simple to implement and understand but depends on the agents' grasp of what the unit measure of the currency is "worth." That is each unit of currency should have a constant value as compared, for example to some standard. Historically, the currency was valued in terms of units of some convenient commodity, such as barley (valued as food, but especially its use in brewing beer!)

Any agent that holds currency is in a position to direct the future flows of energy by virtue of how they spend that currency. Spending is the signal that prompts directing energy flows into the work processes that produced the good or service.

There is a major flaw in the logic of market-based producing and consuming using money to provide the signals. Producers receiving money (a price paid) from a customer assume that there will be more customers wanting the same product or service, so they direct the money to the purchase of supplies, raw materials, labor, and etc. to produce more for future sales. However, consider the case of long-lasting products like cars and houses. People don't go out every other day and buy these things. Since they last a long time with some maintenance there would be no continuing signal once the market had been saturated. This actually happens, cyclically, all the time. There is only one thing that keeps, say car manufactures or home builders, in steady business and that is growth of the population[57]. New humans have to keep coming into the market at more or less a steady pace to keep the energy flowing through these work processes (firms). Some products can be engineered to break down – planned obsolescence – so that customers will have to keep coming back. But in markets where maintenance services are available (like the automobile market) this strategy doesn't work too well.

So there is a built-in grand positive feedback loop that reinforces the growth of the population just to keep new customers coming into the market. Indeed, countries like Japan, where reproduction rates have plummeted and the population is not increasing, are quite worried that markets will not be buoyed up by growth[58].

The plastic-based products and throw-away economy is essential to maintain the illusion of endless growth.

[57] Growth of a population in a given area can be due either to positive birth rates or immigration or generally a combination of both.

[58] They are also worried that with the demographic distribution continually moving toward an older population they will have fewer workers to supply labor!

Overall, the flow of monetary value (money) is counter to the flow of energy, both embodied energy in products, or free energy flowing into work processes in order to produce lower entropy products and provide services (again, shown in Figure 8.14). Originally this is exactly what the role of currency was, to signal the producer members of the economy how they should manage their resources and efforts. Today, however, there has been a massive distortion in the signaling value of money. The over use of debt has increased the amount of apparent money being routed and thus confounding the actual information value of monetary flows. Money itself has become a commodity and less a measure of true physical (utility) value of the units.

8.6.1.4. Entropy Reduction in the System at the Expense of Entropy Increases Outside the System

Cells, bodies, societies, and ecosystems do work to decrease or maintain low entropy internally. They do this by extracting material resources from the environment and high potential energy. As living systems minimize entropy internally, they contribute to increasing the entropy of the environment in which they are embedded. Overall, the total entropy of the Universe increases even while pockets of low entropy persist – on planets like Earth. This is only possible because of the continual energy influx from the sun to the Ecos. That energy allows the Ecos as a whole to maintain or even reduce its entropic state even while it is degrading the high value visible light photons into low value ones, infrared.

Starting from the extraction of material resources and the capture and conversion of energy sources, the role of the economy is to reduce the entropy of bits and pieces of the system, ultimately in support of maintaining human life. Material resources are generally already in a low entropic form. For example the metal content in usable ores is already somewhat concentrated due to the work that the geothermal processes in the Earth's mantle. The degree of concentration is sufficient to make the ore valuable since the amount of additional work to purify the metal is energetically feasible. The pure metal is further valuable because it can be used to produce more complex products. The same is true of petrochemicals and fuels such as gasoline. At each stage in the economic process value is added to the bits and pieces as they become more directly useful to consumers (users).

Ironically, the reduction of entropy within the system, the HSS, is accomplished by increasing the entropy of the environment.

Solar energy – rate of energy flow that restores the natural resources of the biosphere is not sufficient to keep balance. Extraction of the mineral resources far exceeds the rate of replenishment (that is why we face peak oil). Recycling is essential – in the same manner that ecosystems involve recycling of biochemicals (nutrients and minerals).

The current structure/function of the HSS economy is such that the system is increasing the entropy of the Ecos much faster than the latter can use solar or geothermal energy to repair its pre-human state far from equilibrium.

8.6.2. Energy Capture, Conversion, and Delivery to Consumers

Over eighty percent of primary energy used by the global economy comes from fossil fuels. The extractive industries include coal mining, taking various forms such as deep crustal mines, and quarrying after "mountain top removal", oil and gas drilling of wells to find pockets of these raw fuels which are then pumped to the surface. As mentioned above, fossil fuels are a finite reserve that humanity has been drawing down at increasing rates. It will become increasingly expensive, in both financial and energy terms, to extract as time goes on because the industry has to go deeper into the earth, go out to expensive to drill areas like deep water wells on the Continental Shelf[59], and require increasingly sophisticated (thus expensive) technology in order to keep the production rates up.

Coal requires a minimum of further processing other than grinding into small chunks optimal for burning. Similarly, natural gas (methane) requires minimal processing, perhaps filtering out other gasses like CO_2. Oil, on the other hand, requires considerable processing, the refining of oil-derived products that contain much denser energy per weight (or volume) unit such as gasoline and diesel.

Refining of oil produces a number of power delivery fuels and other useful products. These fuels are rated according to their energy density (e.g. Joules or BTUs per unit weight). Jet fuel, for example, is richer in hydrogen molecules which make it burn at higher temperatures than gasoline. It is the temperature of combustion that produces the power or useful energy per unit time. Coal burns at a much lower temperature than jet fuel, but sufficient to boil water and, through the expansion of steam, drive mechanical devices, particularly steam turbines which, in turn, drive electrical generators.

Electricity is one of the most efficient forms of energy for both transportation to points of use and in terms of the mechanical conversion. However, there are limitations to the use of electricity especially in the transportation sector. A big hurdle in this regard is the state of battery technology. There have been some impressive developments in increasing the power density of the storage device, the duration of charges, and the lifetimes. All electric ground transportation is under development and its uses could help reduce the emissions of carbon dioxide, especially in areas like the Pacific Northwest of the US where most electricity comes from hydroelectric sources. The same may be true in areas that can produce significant contributions to the electric grid from wind turbines. But in areas where the electricity is coming from coal, or even gas-fired power plants electric vehicles have a substantial carbon footprint even though they are not directly burning fossil fuels.

[59] Many will remember the Deepwater Horizon tragedy in which a well "blow-out" led to one of the worst oil spill accidents in history. See the Wikipedia article: https://en.wikipedia.org/wiki/Deepwater_Horizon_oil_spill for background. Accessed 11/12/2018.

As mentioned above, the hope of many is for alternative energy capture to take over from burning fossil fuels.

8.6.2.1. An Exercise in Evaluating Solar Photovoltaic Capture and Conversion

One of the alternative energy sources being considered to replace fossil fuels is the capture of solar radiation (light) through the photo-voltaic mechanism to produce electricity. We mentioned earlier the thought experiment in which sufficient energy needed to be collected to both supply society with electricity for consumption and provide for the on-going replacement and repair of solar collection subsystems.

In this section we provide an analysis framework for considering if the goal of producing a self-replicating energy source is feasible. This analysis is meant to supply guidelines for the collection of data to test that feasibility. It is an example of where a top-down deep systems analysis would lead as we look for solutions to societal problems.

Figure 8.17 provides a schematic model of a photovoltaic solar system. This system includes not only the solar panels needed to supply electricity to society for their consumption, but also a set of panels that supply the manufacturing plant (of the panels and associated equipment)[60]. The manufacturing process shown in the figure should also include construction and repair activities on the manufacturing facilities themselves. In other words, we have to supply energy to the acts of constructing the facilities and energy to the maintenance of said facilities. It would be possible to adopt a wider boundary condition by including the manufacturing of vehicles (i.e. in the blue deployment ovals) which would, presumably, be electric, and even some amortized cost of building and maintaining roads for delivering panels, etc. However, this model should suffice to point out the difficulty in deriving a "solution" to the power supply problem. A more realistic requirement for a system like this would be that it is autopoietic[61], that is it needs to be completely self-regenerating, self-maintaining as well as producing the free energy for societal consumption.

[60] We are ignoring a lot of infrastructure requirements such as power converters (from DC to AC), and the electric grid itself. The point of this exercise is to demonstrate the general methodology, not to produce a definitive answer.

[61] See the Wikipedia article: https://en.wikipedia.org/wiki/Autopoiesis for background. Accessed 5/14/2020. Also the concept of autopoiesis will resurface in the next chapter in Part 3 in the context of aa complex, adaptive, and evolvable system.

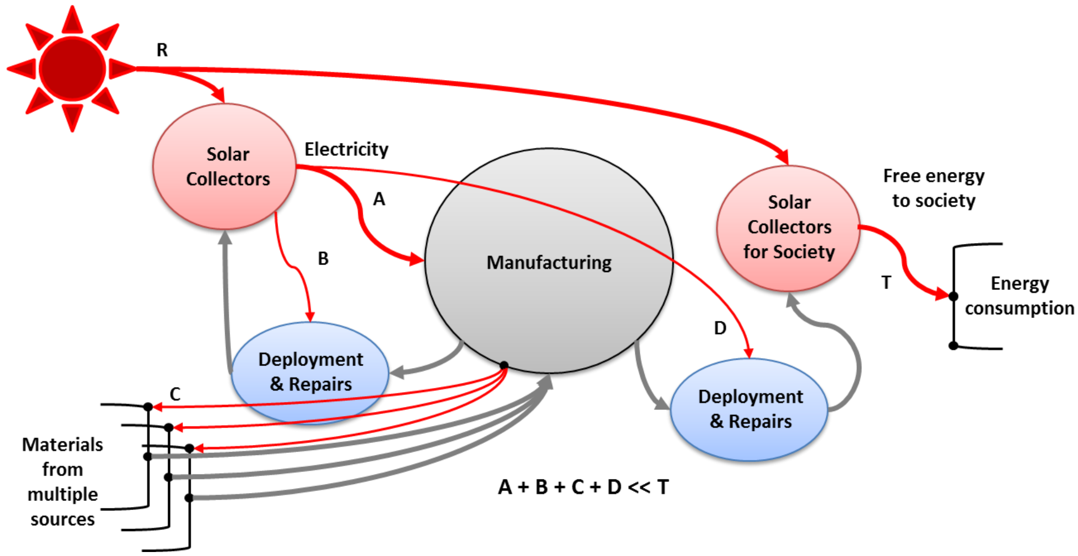

Fig. 8.17. A solar energy capture and conversion system includes the capacity to power the replacement of solar panels (including deployment and repairs). This means providing energy from solar capture to the manufacturing process but also should include the construction of the manufacturing capability as well as its repair.

Figure 8.17 does include the supply of power to various material extraction resources, the materials that are needed in the construction of solar panels and accouterments, which must be accomplished by electrical power. The letters, A, B, C, and D represent the power supplied to all of the processes that produce solar panels, deploy and maintain them. The letter ‘T’, standing for Total free energy to society it the payoff. But the necessary condition for this scheme to work is shown as the sum of A, B, C, and D must be considerably less than the total energy supply to society.

This is another version of the EROI problem that we have discussed with fossil fuels. Even though solar energy won’t be depleted by collection, the ultimate economic viability of this technology depends on whether T/(A+B+C+D) > 20, or 30 (Hall & Klitgaard, 2012). The EROI of solar must be capable of supplying enough energy to society to support social uses such as household consumption and transportation as well as replacement of the solar energy infrastructure. As of this writing there has been neither a convincing model simulation, nor a comprehensive experiment that would demonstrate this feasibility.

For the foreseeable future it appears that the majority of society’s power will come from fossil fuels. This may be increasingly supplied by natural gas (many electric power plants are converting to natural gas as this is being written). But that still involves burning carbon-based fuels and pumping CO_2 into the atmosphere. As long as humanity insists on power (and convenience) this will continue to be the case.

8.6.2.2. Other Alternatives

The same logic regarding the EROI of solar applies to all other alternative energy system proposals, wind, tidal, etc.

Famously during the G.W. Bush administration the idea arose that perhaps corn-derived ethanol might supplement the gasoline supply. In part the thought was that corn-based ethanol would be carbon-neutral, that is, corn plants would absorb CO_2 from the atmosphere to grow and so, when the ethanol was burned, it would not add net carbon to the atmosphere! Congress in the US acted and passed a law requiring up to 10% corn-based ethanol to gasoline. It didn't hurt that Midwest corn farmers would recognize a healthy new market for their products.

Subsequent analysis of the EROI of corn-based ethanol has shown that it is far too low to provide a positive economic advantage (Hall & Klitgaard, 2012, page 336). Furthermore, taking some of the activities that are needed to subsidize corn ethanol, the carbon footprint may also be net negative.

The lessons from solar and corn ethanol in terms of systemic effects should be instructive. But political choices are often made for other than scientific reality reasons.

Wind energy appears to have a better economic advantage (ibid). A major caveat, however, is that wind turbines, to achieve very high efficiencies, require using rare-earth metals that are quite expensive and in limited supply (hence the name "rare-earth"). The same kind of analysis of solar energy self-sustainability shown above should be applied to wind as well, taking these issues into account.

Overall the jury is still out on the overall feasibility of alternative energy source technologies. Since they are all producers of electricity we also have to consider the various costs of converting most of our work processes to be driven by electric motors (and heaters). Since electric work is done more efficiently than heat engines powered by fire, this would be a good thing. But how fast it can be accomplished, and at what energetic cost, is still a very open question.

8.6.3. Energy Consumption: Work Processes, Efficiencies, and Waste

For most of the 18th, 19th, and 20th centuries energy has been taken for granted. Wind and water drove the nascent industries of the 18th century. Wood charcoal and then coal was the source of power for the 19th and early 20th centuries. Then oil and natural gas began to take center stage. In all of these cases, energy seemed abundant and easily obtained. The idea that we should be overly concerned about efficiency did not start to take hold until the age of air travel when the means of conveyance needed to carry its own fuel source and be light enough to get airborne. Engineers were generally concerned with efficiency but it was not the pressing issue for an economic system most concerned with profit-making. Especially one in which sellers could increase their prices as they felt necessary if they could not reduce costs.

That is, until the availability and cost of fuels began to become more visible as a factor in all work processes. The oil shocks of the 1970s (1973 and 1979) due to an OPEC embargo brought the western world's attention to the fundamental role of energy[62]. In the early 2000s the price of oil climbed rapidly, peaking at $147+ in 2008 before declining again[63]. It never fell back to its price levels prior to that event. It is believed that the price shock helped trigger the Great Recession, which followed closely on the heels of the shock[64].

The cost of energy as a major factor in the economy finally became apparent in the years that followed. However, most economists did not really know how to interpret the meaning of the phenomenon. There were so many concurrent factors that were better understood by economists so that they tended to focus on them as causing the recession, like the drunk who lost his keys at night and went looking for them under the street light because he could see better there. One example was the mortgage debt bubble created by lenders providing sub-prime loans to people who had no prospects of paying them off. A financial bubble was something that economists had seen many times and their association with recession triggers were well recognized. However, correlation is not causation. Were the bubble bursts causes or effects? Debt financing, as discussed previously, completely obfuscates the relationships.

There are starting to be some recognition among some economists that the relationship between wealth production and energy, as well as the negative effects of decreasing EROI, are primary forces in explaining economic phenomena (Hall & Klitgaard, 2012). But the full extent of the relationship has yet to become completely understood. Most economists are not as schooled in systems science as they probably should be.

8.7. Conclusion

The reality of the nature of an economic system is substantially different from the observations of Adam Smith and other 18th century political-economists. Using knowledge of modern physics (thermodynamics is central) and guided by systems principles, the picture of what an economy is and how it actually works, as considered in this chapter, turn out to be very different from that developed by neoclassical economics academia. We can see, now, that an economic system is not closed in any sense. It requires the continuous input of medium entropy materials (ores, wood, etc.) and high quality energy to further reduce the entropy of materials and increase their usefulness in maintaining the "metabolism" of society.

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[62] See the Wikipedia article: https://en.wikipedia.org/wiki/1973_oil_crisis for background. Accessed 11/16/2018.

[63] See the Wikipedia article: https://en.wikipedia.org/wiki/2000s_energy_crisis for background. Accessed 11/16/2018.

[64] Oil prices did tumble back to pre-spike levels in a rebound effect. However, that was a short-lived condition and oil prices have gradually climbed back up. At the time of this writing a barrel of West Texas crude is running around $50. It is estimated that oil produced from Canadian tar sands (bitumen) needs to capture around $70 per barrel in order to just break even.

The current HSS economic system does not really conform to the natural economic systems of the Ecos. It is based on fallacies such as continuous growth and maximizing profits which are actually counterproductive with respect to the maintenance of a viable system, one that is stable, resilient to changes, and sustainable in the long run.

The systems science archetype model of an economy offers a foundational approach to the conceptualization of what an HSS economy ought to look like. The deep analysis of our current economic systems (across the spectrum of ideological models) based on systems principles shows that we are far off the mark when it comes to having an economy that is life-supporting in the same way that ecosystems, physiologies, and metabolisms are. There are some aspects which attempt to emulate the archetype, e.g. using money flows to signal energy channeling. But human hubris along with a zeal to invent too often muck up the systemic workings of these mechanisms. One can only hope that as we develop a more systemic knowledgebase of economics along with a better grasp of human neuropsychology (and how to tame it) we will start to fashion an economic system that truly supports all humans' bodies as their physiologies support their living cellular metabolisms. Then, the HSS might actually become a fit component of the Ecos.

8.8. References

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