The Foundation for the Economics of Sustainability
"Designing systems for a changing world"

Tipping Point

Near-Term Systemic Implications of a Peak in Global Oil Production
An Outline Review

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Feasta
& The Risk/Resilience Network

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The Foundation for the Economics of Sustainability
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Feasta (pronounced fasta) is taken from an old Irish poem which laments the decimation of the forests. It means “in the future” and Feasta sees itself as a collective thinking process about that future. It is a leading international think-tank exploring the interactions between human welfare, the structure and operation of human systems, and the ecosystem which supports both.

The Risk/Resilience Network

The Risk/Resilience Network is an initiative which was established in order to understand energy induced systemic risk, the scope for risk management, and general and emergency planning. It is a network where those persons and organisations with interest in the area can learn from each-other and engage with direct practical actions.

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Summary

The credit crisis exemplifies society's difficulties in the timely management of risks outside our experience or immediate concerns, even when such risks are well signposted. We have passed or are close to passing the peak of global oil production. Our civilisation is structurally unstable to an energy withdrawal. There is a high probability that our integrated and globalised civilisation is on the cusp of a fast and near-term collapse.

As individuals and as a social species we put up huge psychological defenses to protect the status quo. *We've heard this doom prophesied for decades, all is still well! What about technology? Rising energy prices will bring more oil! We need a Green New Deal! We still have time! We're busy with a financial crisis! This is depressing! If this were important, everybody would be talking about it!* Yet the evidence for such a scenario is as close to cast iron as any upon which policy is built: Oil production *must* peak; there *is* a growing probability that it has or will soon peak; energy flows and a functioning economy *are by necessity* highly correlated; our basic local needs *have* become dependent upon a hyper-complex, integrated, tightly-coupled global fabric of exchange; our primary infrastructure *is* dependent upon the operation of this fabric and global economies of scale; credit *is* the integral part of the fabric of our monetary, economic and trade systems; a credit market *must* collapse in a contracting economy, and so on.

We are living within dynamic processes. It matters little what technologies are in the pipeline, the potential of wind power in some choice location, or that the European Commission has a target; if a severe economic and structural collapse occurs before their enactment, then they may never be enacted.

Our primary question is what happens if there is a net decrease in energy flow through our civilisation? For it is absolutely dependent upon increasing flows of concentrated energy to evolve and grow, and to form and maintain its complex structures. The rules governing energy and its transformation, the laws of thermodynamics, are the inviolate framework through which all things happen- the evolution of the universe, the direction of time, life on earth, human development, the evolution of civilisation, and economic processes. This point is not rhetorical, access to increasing flows of concentrated energy, which can be transformed into work and dispersed energy, is the foundation upon which our civilisation stands. Yet we are at a point where these flows are, with high probability, about to begin decreasing. We should intuit that an energy withdrawal should have major systemic implications, for without energy flows nothing happens.

The key to understanding the implications of peak oil is to see it not just directly through its effect on transport, petrochemicals, or food say, but its systemic effects. A globalising, integrated and co-dependent economy has evolved with particular dynamics and embedded structures that have made our basic welfare dependent upon delocalised 'local' economies. It has locked us into hyper-complex economic and social processes that are increasing our vulnerability, but which we are unable to alter without risking a collapse in those same welfare supporting structures. And without increasing energy flows, those embedded structures, which include our expectations, institutions and infrastructure that evolved and adapted in the expectation of further economic

growth cannot be maintained.

In order to address these questions, the following paper considers the nature and evolution of this complex integrated globalised civilisation from which energy is being withdrawn. Some broad issues in thermodynamics, the energy-economy relationship, peak oil, and the limits of mitigation are reviewed. It is argued that assumptions about future oil production as held by some peak oil aware commentators are misleading. We draw on some concepts in systems dynamics and critical transitions to frame our discussion.

The economics of peak oil are explicated using three indicative models: *linear decline*; *oscillating decline*; and *systemic collapse*. While these models are not to be considered as mutually exclusive, a case is made that our civilisation is close to a critical transition, or collapse. A series of integrated collapse mechanisms are described and are argued to be necessary. The principal driving mechanisms are re-enforcing (positive) feedbacks:

- A decline in energy flows will reduce global economic production; reduced global production will undermine our ability to produce, trade, and use energy; which will further decrease economic production.

- Credit forms the basis of our monetary system, and is the unifying embedded structure of the global economy. In a growing economy debt and interest can be repaid, in a declining economy not even the principal can be paid back. In other words, reduced energy flows cannot maintain the economic production to service debt. Real debt outstanding in the world is not repayable, new credit will almost vanish.

- Our localized needs and welfare have become ever-more dependent upon hyper-integrated globalised supply-chains. One pillar of their system-wide functioning is monetary confidence and bank intermediation. Money in our economies is backed by debt and holds no intrinsic value; deflation and hyper-inflation risks will make monetary stability impossible to maintain. In addition, the banking system as a whole must become insolvent as their assets (loans) cannot be realised, they are also at risk from failing infrastructure.

- A failure of this pillar will collapse world trade. Our 'local' globalised economies will fracture for there is virtually nothing produced in developed countries that can be considered truly indigenous. The more complex the systems and inputs we rely upon, the more globalised they are, and the more we are at risk from a complete systemic collapse.

- Another pillar is the operation of critical infrastructure (IT-telecoms/ electricity generation/ financial system/ transport/ water & sewage) which has become increasingly co-dependent where a systemic failure in one may cause cascading failure in the others. This infrastructure depends upon continual re-supply; embodies short lifetime components; complex highly resource intensive and specialized supply-chains; and large economies of scale. They also depend upon the operation of the monetary and financial system. These dependencies are likely to induce rapid growth in the risk of systemic failure.

- The high dependence of food on fossil fuel inputs, the delocalisation of food sourcing, and lean just-in-time inventories could lead to quickly evolving food insecurity risks even in the most developed countries. At issue is not just food production, but the ability to link surpluses to deficits, collapsed purchasing power, and the ability to monetize transactions.

- Peak oil is likely to force peak energy in general. The ability to bring on new energy production and maintain existing energy infrastructure is likely to be severely compromised. We may see massive demand and supply collapses with limited ability to re-boot.

- The above mechanisms are non-linear, mutually re-enforcing, and not exclusive.

- We argue that one of the principal initial drivers of the collapse process will be growing visible action about peak oil. It is expected that investors will attempt to extract themselves from 'virtual assets' such as bond, equities, and cash and convert them into 'real' assets before the system collapses. But the nominal value of virtual assets vastly exceeds the real assets likely to be available. Confirmation of the peak oil idea (by official action), fear, and market decline will drive a positive feedback in financial markets.

- We outline the implications for climate change. A major collapse in greenhouse gas is expected, though may be impossible to quantitatively model. This may reduce the risks of severe climate change impacts. However the relative ability to cope with the impacts of climate change will be much reduced as we will be much poorer with much lower resilience.

This will evolve as a systemic crisis; as the integrated infrastructure of our civilisation breaks down. It will give rise to a multi-front predicament that will swamp governments' ability to manage. It is likely to lead to widespread disorientation, anxiety, severe welfare risks, and possible social breakdown. The report argues that a managed 'de-growth' is impossible.

We are at the cusp of rapid and severely disruptive changes. From now on the risk of entering a collapse must be considered significant and rising. The challenge is not about how we introduce energy infrastructure to maintain the viability of the systems we depend upon, rather it is how we deal with the consequences of not having the energy and other resources to maintain those same systems. Appeals towards localism, transition initiatives, organic food and renewable energy production, however laudable and necessary, are totally out of scale to what is approaching.

There is no solution, though there are some paths that are better and wiser than others. This is a societal issue, there is no 'other' to blame, but the responsibility belongs to us all. What we require is rapid emergency planning coupled with a plan for longer-term adaptation.

Contents

1. Introduction

The current financial crisis is contained within a framing narrative, most particularly that the crisis will end and global economic growth will return to its upward trend. Economists may argue about the extent and depth of the recession, but not on its inevitable passing. That is, economic growth is the natural order of things provided bad policy or recklessness do not derail it. Indeed throughout society our assumption of continued growth is implicit within our pensions, government finances, economic and monetary structures, climate and energy policy, research and development, expectations about the Smart Economy, the Health service, a Green New Deal, globalisation, and in the range of expectation we have about the rise of China, our own futures and those of our children. Through the experience of 200 years of globalising economic growth, we have come to embody its processes in how we live and understand the world.

The assumption of future growth implies the energy and material flows to support it are available. As individuals, energy in the form of food allows us to live. Our civilisation, and the economy which supports it, require flows of energy to function. The crucial difference is that once humans reach maturity their energy intake stabilizes, however our evolved economic structures are adaptive only to growing. And because economic growth is exponential, each year's growth of say 3% is bigger than the previous year's 3% growth. So even as energy use in the global economy may have become somewhat more efficient, it continues to rise.

There is growing concern, as expressed by Macquarie Bank, Goldman Sachs, consultants McKinsey, the International Energy Agency and the Saudi Oil minister Ali Naimi amongst others, that as the global economy begins to recover we will experience another rise in oil prices which will choke off further growth or in the words of Ali Naimi, constrained or declining oil production will "take the wheels of an already derailed global economy"[1,2]. These warnings chime with a recent survey report by the UK Energy Research Council (UKERC) which warned of a "significant risk" of a peak and subsequent decline in global oil production before 2020[3]. A growing number of analysts have been arguing that we have already passed the peak and that continuous declines are imminent[4]. Former head of exploration & production at Saudi Aramco, Sadad al-Huseini has said that we have already reached maximum sustainable production[5]. What are important are flows of oil, not the promises of fields or other substitutes yet to be developed; no more than the promise of water a thousand miles away is relevant to a man dying of thirst. While we will focus here on oil, we are probably close to peak natural gas, and peak energy in general[6,7]. Though as we shall see, peak oil is likely to force a peak on other concentrated energy carriers.

If peak oil is imminent or medium-term, we have neither the time nor the resources to substitute for oil, or invest in conservation and efficiency, a point re-iterated in the UKERC report. It is not merely that the net energy, material and financial resources we need to adapt will be in shorter supply, or that we are replacing high quality energy sources with lower quality ones. Nor is it that the productive base for deploying alternative energy infrastructure is small with limited ramp-up rates, or that it competes with food. Nor even that as the global credit crisis continues with further risks ahead, ramping up financing will remain difficult while many countries struggle with ballooning deficits and pressing immediate concerns. But, once the effects of decline become apparent, we will lose much of what we might call the *operational fabric* of our civilisation. The operational fabric comprises the given conditions at any time that support system wide functionality. This includes functioning markets, financing, monetary stability, operational supply-chains, transport, digital infrastructure, command & control, health service, institutions of trust, and sociopolitical stability. It is what we casually assume does and will exist, and which provides the structural foundation for any project we wish to develop. For example, near future degradation and collapse of the operational fabric may mean that we already have in place a significant fraction of the renewable energy infrastructure which will ever be in place globally.

It may at first seem counter-intuitive, how could a potential small yearly decline in energy flows through the global economy, which integrates our global civilisation, lead to a major collapse? Especially as we tend to assume that as a society we are resilient, adaptive, and innovative, especially in times of crisis. To understand this we need to understand our growing globalising economy has evolved a very particular and unique structural form which we and our institutions participate in, but cannot control. And this structural form is adaptive to economic growth. If an energy constraint means it cannot grow, it does not just get smaller, it starts to break up. What is more, we can pinpoint directly some of the major mechanism of collapse dynamics and some of the associated timing issues. The challenge is to see our civilisation outside the cultural narratives that grew out of and affirm its inevitability.

Peak oil is expected to be the first ecological constraint to impact significantly on the advanced infrastructure of the globalised economy. However it is only one part of an increasingly integrated web of constraints on fresh water, bio-diversity loss, soil and fertility loss, key mineral shortages, and climate change. In such a context it makes little sense to compartmentalize our focus as we see through the UN Framework Convention on Climate Change processes, for example. The interwoven nature of our predicament is clear, for example, in the green revolution of the 1960s which supposedly 'solved' the increasing pressure on food production from a growing population. Technology was marshaled to put food production onto a fossil fuel platform, which allowed further population overshoot and thus a more general growth in resource and sink demands. The result is that even more people are more vulnerable as their increased welfare demands are dependent upon a less diverse and more fragile resource base. As limits tighten, we are responding to stress on one key resource (say reducing greenhouse gas emissions or fuel constraints with biofuels) by displacing stresses on other key resources that are themselves already under strain (food, water). This demonstrates how little adaptive capacity we have left.

For at least four decades laws have been passed, targets set out, treaties signed, technologies developed, and the public cajoled to limit our collective demand on an array of major human ecosystem services and resources. Yet despite this, growing damage and unsustainable resource use has consistently far outweighed our limited successes. The hopeful optimism that continues to drive these processes has begun to resemble a ritualized maintenance of collective denial.

We are attempting to solve these problems within systems that are themselves driving the problem. Furthermore, we are effectively trapped or locked into these systems. We are embedded within economic and social systems whose operation we require for our immediate welfare. But those systems are too interconnected and too complex to comprehend, control and manage in any systemic way that would allow a controlled contraction while still maintaining our welfare. There is no possible path to sustainability or planned de-growth.

The argument we are making in this paper is that an energy withdrawal is likely to initiate a series of processes that will lead to a major collapse in our civilisation. When we talk of systemic collapse, we are referring to major abrupt changes that cause many integrated and co-dependent systems to re-enforce each-others failure. In our context, we see it as a relatively sudden loss of complexity, and a jump to a new stable state.

The idea of collapse is not new, indeed its mythic spectre has probably always been a feature of civilisations[8]. In 1972, the famous *Limits to Growth* argued that economic growth could not continue indefinitely in a world of finite resources and limited sink capacity for our waste. It deployed simple scenarios and early examples of systems modeling to argue that a continuation of business-as-usual would lead to a limit to global economic growth, and thereafter a long slow decline[9]. Later, authors were more explicit about collapse. They cited ecological constraints as a cause, but also the interaction between the structural, functional, institutional, and behavioral conditions of society. Among the most important studies are *Overshoot* by William Catton, and *The Collapse of Complex Societies* by Joseph Tainter[10,11]. In recent years the genre has caught the attention of the reading public with the works of Jared Diamond, Richard Heinberg and others[12,13,14,15,16]. The web-based 'think-tank', *The Oil Drum* has often had lively and informed debates on these issues.[17]

To the public and to the media, anyone who proclaims "the end of the world is nigh" is likely to be seen as deluded or quite mad (that is not what is being claimed here). The dominant social narrative soon re-asserts itself with re-assuring nods towards our collective genius, technology, the shibboleths of our time, or the minor history of our collective wisdom. The intuitive retort that there must be 'a solution', or facile expressions of the need for 'hope' represent a failure to understand the imminent material reality of our own predicament.

This report outlines why we may be close to a global systemic collapse in our economy, and by extension, our civilisation. It is written as an overview accessible to non-specialists. Where arguments and debates do not alter the principal conclusions, they are alluded to but not picked over. We have deliberately not written a 'what to do' section, so that readers could concentrate on thinking about the nature of our predicament. All too often there is a rush to 'solutions' before the context is understood, with the result that the proposed solutions are totally mal-adaptive to the most likely scenarios.

It is the first publication of The Risk/Resilience Network, and the fact that there will be ongoing publications, initiatives, and events reflects our belief that better and wiser choices can be made.

2. Energy & Stability in the Global Economy

2.1 Energy and Economic Growth

All evolving systems, life, economies, and civilisations require flows of energy through them to maintain their structure and to allow growth. We see this not just in our ability to run cars, and keep lights and machines running, it is embodied in the things we use such as food, water, and mobile phone components. If we do not maintain flows of energy (directly or by maintenance and replacement) through systems we depend upon, they decay.

The self-organisation and biodiversity of life on earth is maintained by the flows of low entropy solar energy that irradiate our planet as it is transformed into high entropy heat radiating into space. Likewise our complex civilisation has formed from the transformation of the living bio-sphere and the fossil reserves of ancient solar energy into useful work, and the entropy of waste heat energy, greenhouse gasses, and pollution that are the necessary consequences of the fact that no process is perfectly efficient.

The first law of thermodynamics tells us that energy cannot be created or destroyed. But energy can be transformed. The second law of thermodynamics tells us that all processes are winding down from a more concentrated and organised state to a more disorganised one, or from low to higher entropy. We see this when our cup of hot coffee cools to the room's ambient temperature, and when humans and their artifacts decay to dust. The second law defines the direction in which processes happen. In transforming energy from a low entropy to a higher entropy state, work can be done, but this process is never 100% efficient. Some heat will always be wasted and be unavailable for work. This work is what has built and maintains life on earth and our civilisation. Exergy is the name given to the maximum amount of work that can be done by a system, which is a function of the energy concentration gradient between the source and its environment. In the process of transforming energy, entropy increases and exergy decreases.

So how is it that an island of locally concentrated and complex low entropy civilisation can form out of the universal tendency to disorder? The answer is by supplying more and more concentrated energy flows in to keep the local system further and further away from the disorder to which it tends. The evolution and emergence of complex structures maximizes the production of entropy in the universe (local system plus everywhere else) as a whole. Clearly if growing and maintaining complexity costs energy, then energy supply is the master platform upon which all forms of complexity depends[18].

The correlation between energy use and economic and social change should therefore come as no surprise. The major transitions in the evolution of human civilisation, from hunter-gatherers, through the agricultural, industrial, the green revolution to the information age have been predicated on revolutions in the quality and quantity of energy sources used.

We can see this through an example. According to the 1911 Census of England & Wales, the three largest occupational groups were domestic service, agriculture, and coal mining. By 2008, the three largest groups were sales personnel, middle managers, and teachers[19]. What we can first notice is one hundred years ago much of the work done in the economy was direct human labour. And much of that labour was associated directly with harnessing energy in the form of food or fossil fuels. Today, the largest groups have little to do with production, but are more focused upon the management of complexity directly; or indirectly through providing the knowledge base required of people living in a world of more specialised and diverse occupational roles.

What evolved in the intervening hundred years was that human effort in direct energy production was replaced by fossil fuels. The contribution of fossil fuels to the economy can be expressed as being energetically equivalent to a huge slave supplement to our economy. The energy content of a barrel of oil is equivalent to twelve years of adult labour at forty hours a week. Even at $100 /bl, oil is remarkably cheap compared with human labour. As fossil fuel use increased, human labour in agriculture and energy extraction fell, as did the real price of food and fuel. These price falls freed up discretionary income, making people richer. And the freed up workers could provide the more sophisticated skills required to build the discretionary consumer production which rested itself upon fossil fuels inputs, other resources, and innovation.

In energy terms a number of things happened. Firstly, we were accessing highly concentrated energy stores in growing quantities. Secondly, fossil fuels required little energy to extract and process. That is, the net energy remaining after the energy cost of obtaining the energy was very high. Thirdly, the fuels used were high quality, especially oil, which was concentrated and easy to transport at room temperature; or the fuels could be converted to provide very versatile electricity. Finally, our dependencies co-evolved with fossil fuel growth, so our road networks, supply-chains, settlement patterns and consumer behavior, for example, became adaptive to particular energy vectors and the assumption of their future availability.

The growth and complexity of our civilisation, of which growing Gross World Product (GWP) is a primary economic indicator, is fundamentally a thermodynamic system. As such our economies are subject to fundamental laws. Such fundamental relationships are distinct from the culturally and economically contingent observations found say, within economic discourse.

In neo-classical models of economic growth, energy is not considered a factor of production. It is assumed that energy is non-essential and will always substitute with capital. This assumption has been challenged by researchers who recognize that the laws of physics must apply to the economy, and that substitution cannot continue indefinitely in a finite world. Such studies support a very close energy-growth relationship. They see rising energy flows as a necessary condition for economic growth, which they have demonstrated historically and in theory[20,21,22]. It has been noted that there has been some decoupling of GWP from total primary energy supply since 1979 but much of this perceived de-coupling is removed when energy quality is accounted for [23].

It is sometimes suggested that energy intensity (energy/unit GDP) is stabilising, or declining a little in advanced economies, a sign to some that local de-coupling can occur. This confuses what are local effects with the functioning of an increasingly integrated global economy. Advanced knowledge and service economies may not do as much of the energy intensive raw materials production and manufacturing as before; but their economies are dependent upon the use of such energy intensive products manufactured elsewhere, and the prosperity of the manufacturers.

2.2 Recent Short-term Energy-Economy Correlation

The current financial crisis was initiated by a bubble in the credit markets, driven by cheap money, financial innovation, and the perennial desire of people to make money while the going was good. This much is true, but it is not a sufficient explanation. Since 2005 global oil production has been essentially flat. Even as oil prices rose, production remained stagnant. Jeff Rubin, former chief economist of CIBC notes that four of the five last recessions followed an oil price spike. When oil was at $135 per barrel, the US was spending the equivalent of $1Trillion per annum for oil, which is equivalent to 15% of US take-home pay for all taxpayers, nor does this percentage account for indirect rises associated with food (highly fossil-fuel dependent, and competitive with bio-fuels), and natural gas (price correlated). This hit discretionary consumption and put pressure on peoples' ability to service their loans. The second element was that higher oil prices meant more money flowed out of the hands of those who spent what they had into the hands of savers in rich oil producing countries. Even if those savings were re-cycled through Wall Street, they leaked out of general consumption.

Work by James Hamilton also demonstrates the recent economic impacts of oil price rises[24]. He shows that the recent oil price spike was 'indisputably a contributing factor' to the current recession. He argues that the rise in oil prices should properly be seen as a combination of flat oil production and pent-up demand, demand inelasticity, all magnified by speculation in the futures markets.

To summarise, the close relationship between economic growth and energy flows that we would expect from the laws of thermodynamics are confirmed in long run macro-economic correlations, and in the relationship between energy price spikes and recessions.

2.3 Peak Oil

Oil contributes to about 40% of global energy production, but over 90% of all transport fuel. It provided the physical linkages of good and people across the globalised economy. Peak oil is the point in time when global oil production has reached a maximum and thereafter it enters a period of terminal decline. Figure:1 shows an example of actual and modeled global oil production.

The phenomena of peaking, be it in oil, natural gas, minerals, or even fishing is an expression of the following dynamics. With a finite resource such as oil, we find in general that which is easiest to exploit is used first. As demand for oil increases, and knowledge and technology associated with exploration and exploitation progresses, production can be ramped up. New and cheap oil encourages new oil-based products, markets, and revenues, which in turn provide revenue for investments in production. For a while this is a self-re-enforcing process. Countervailing this trend is that the energetic, material and financial cost of finding and exploiting new production starts to rise. This is because as time goes on new fields become more costly to discover and exploit as they are found in smaller deposits, in deeper water, in more technically demanding geological conditions, and require more advanced processing.

Oil production from individual wells peak, and then decline. So must production from fields, countries, and the globe. Two-thirds of oil producing countries have already passed their local peak. For example, the United States peaked in 1970, and the United Kingdom in 1999 and decline has continued in both cases. It should be noted that both countries contain the worlds' best universities, most dynamic financial markets, most technologically able exploration and production companies, and stable pro-business political environments. Nevertheless, in neither case has decline been halted.

As large old fields producing cheap oil decline, more and more effort must be made to maintain production with the discovery and production from smaller and more expensive fields. In financial terms, adding each new barrel of production (the marginal barrel) becomes more expensive. Sadad al-Huseini said in 2007 that the technical floor (the basic cost of producing oil) was about $70 per barrel on the margin, and that this would rise by $12 per annum (assuming demand was maintained by economic growth) [25]. This rapid escalation in the marginal cost of producing oil is recent. In early 2002, the marginal barrel was $20.

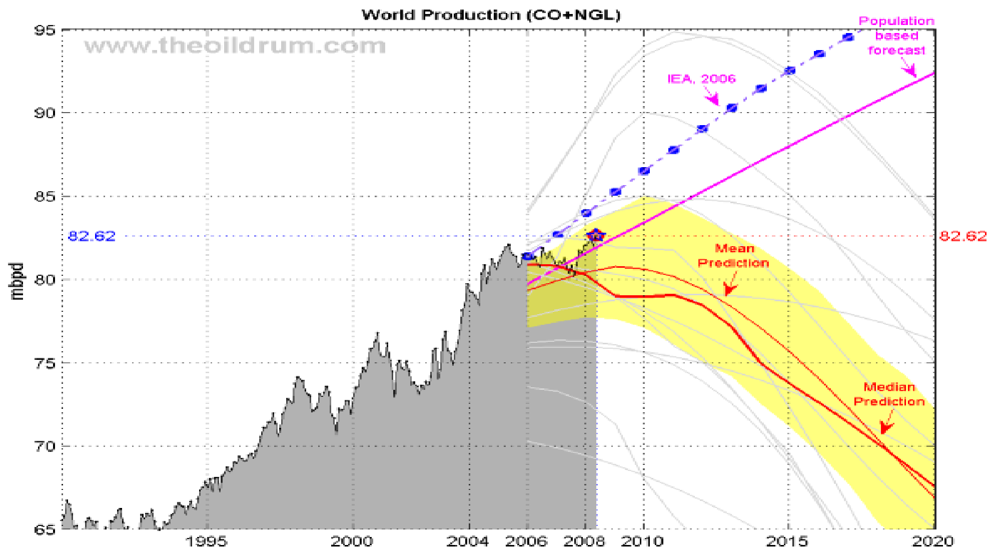


Figure: 1 World oil production against time. The grey area shows global oil production which has remained approximately flat since 2005. Also given are various modeled post-peak production estimates. Source: Sam Foucher at The Oil Drum[26].

It is sometimes argued that there are huge potential oil reserves in the Canadian tar sands, for example. The question is then at what rate can oil be made available from it, what is the net energy return, and can society afford the cost of extraction. And if less energy from oil were to make us very much poorer we could afford even less. Eventually, production would become unviable as economics could no longer afford the marginal cost of a barrel. In a similar vein, our seas contain huge reserves of gold but it is so dispersed that the energetic and financial cost of refining it would far outweigh any benefits (Irish territorial waters contain about 30 tons).

The question, where it has been considered, is around the timing of a production peak and the decline rate. A variety of assessment methodologies and secretive data ensure there is room for debate. Nor should we assume that cultural assumptions and the stakes involved play no part in estimates. We outline a general risk assessment framework for dealing with diverse estimates in the appendix. Projected decline rate estimates range from 2-3% per annum[27]. This gross rate is made up from the decline in old large fields, and the increase in production from new smaller fields, enhanced oil recovery, and new non-conventional production brought on stream. Clearly there are assumptions in this figure, about the future ability to bring on new production and to maintain existing production, and about the ability of society to pay for it. We shall come back to this issue in section 2.5.

2.4 Energy, Net Energy, & Society

It requires energy to get energy. *Energy Return on Investment* (EROI) is the ratio of useful energy obtained from a source relative to the direct and indirect energy used to obtain it. *Net Energy* is the energy you have left after the energy 'cost' of production.

If EROI is less than one, it is a sink. However human society could not have evolved had it relied upon energy sources with very low EROI. Our ancestors living in the simplest tribal societies required a large enough surplus to reproduce, look after children, keep warm, and fight off predators. Modern hunter-gatherers, such as the *!Kung* of the Kalahari desert, have been estimated to live off an EROI of 10:1[28]. Energy surplus is a combination of the energy density available and EROI. So that hunter-gatherers may have had a high EROI, but if they lived in an area with a low prey animal density, then their surplus energy might be relatively low. Early agricultural civilisation probably had a much lower EROI than hunter-gatherers, but they could increase the area density of the energy they harvested through use of intensive cultivation and irrigation. In doing so, they had the surplus energy available to support non-agriculturally productive people to engage in building, administration, soldiering, and simple manufacturing. Major energy revolutions initiated overall energy surpluses that could support the greater and greater complexity of the rest of society.

The modern age was built upon increasingly high energy surpluses. However, as we find oil in more and more difficult deposits, have to use lower energy content coal, or have to build longer gas pipelines over more difficult terrain, EROI is dropping. Calculating EROI is difficult, however it has been estimated that the EROI of US oil has fallen from 100:1 in the 1930's, to 30:1 in the in 1970, and to between 11:1-18:1 today, and that the EROI for global oil and gas production is 18:1 [29]. These values represent an average, however marginal oil production will be even lower, Oil Shale has an EROI of 1.5-4:1 for example. Of course the energy input for oil production comes not just from coal itself, but from other fossil fuels also. The interdependence of fuels (see also sec. 6..6) complicates analysis, but it also propagates declining EROI across individual fuels.

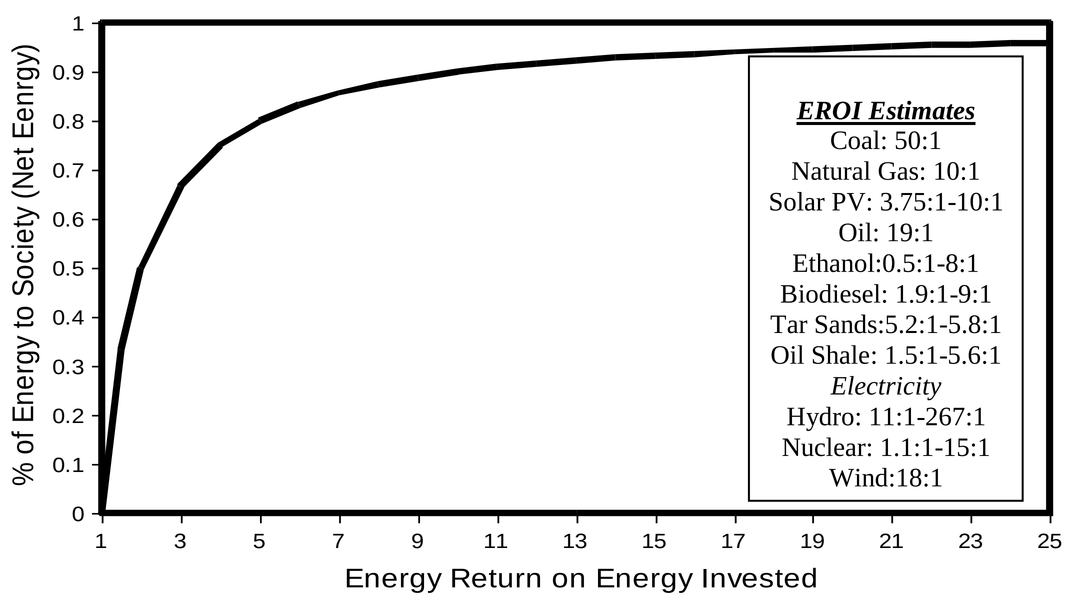


Fig 2: As EROI gets lower, the energy spent on getting energy rises, while that left to run 'the rest' of society declines. EROI estimates from Heinberg[30].

The importance of declining EROI is clearly demonstrated in figure:2. Let us assume that the energy supply to civilisation is constant, but EROI is decreasing. The total supply is divided between the percentage used to produce energy, and the percentage left over which runs society, and produces the goods and services used. For EROI above 10:1, over 90% of the energy is left to run society. It can clearly be seen that as the EROI drops further, the ratio begins to change very fast, especially after about 3:1. As conventional oil declines it is argued, we will use more unconventional oils from biofuels, tar sands etc. For example (assuming no interdependence), 100 Joules of conventional oil with an EROI of 11:1, costs 9 J to produce, leaving 91 J to run the rest of society. If we replaced it with 100J of bio-ethanol, with an EROI of 4:1, production would require 25J and society would only get 75J.

So we see we are facing the problem not just of declining production, but also lowering of EROI, with the net result of an even faster decline in energy surplus to society.

2.5 The Decline Curve Assumption

Models like that shown in figure:1 are often used in discussing and informing about peak oil. And with them an assumption has become ingrained in popular and academic writing on the subject. This assumption is that the production modeled on the downward slope of curve is what will be available to the global economy. Under such assumptions people might conclude that we still have approximately as much oil available for use as we have used heretofore, but it will gradually become scarcer, declining at say 2% per annum.

We might add two important modifications to this. Firstly, in acknowledging that the energetic cost of finding oil in smaller and more inaccessible fields is rising (a lowering EROI), the net energy (E_{Net} in fig:3) available to society will fall at a faster rate than the actual production curve (E_{Gross}). Secondly, the countries with the biggest growth rates of oil use are oil producers who will have preferential access to their own falling reserves. This is because they earn large foreign reserves from oil sales supporting consumption, have subsidized local energy prices, and for example, are increasingly reliant on the use of very energy intensive desalination to deal with evolving water constraints. This means that oil available on the global market will fall faster than the decline in global production.

The modeled assumptions for the declining production, even accounting for declining net energy and producer consumption assumes a stable economy and infrastructure. In most of the modeling, the production curve is derived from proven reserves or proven plus probable. Proven reserves imply current price and technology; proven plus probable reserves make assumptions about the growth in technology and increasing wealth (that might allow us to pay higher prices more comfortably). This means that at a minimum, the future production curve assumes current technology and prices.

That is, even as oil production falls, societies can still afford to deploy the technical resources to extract and refine oil, society can afford the price of bringing on new fields, and the financing and price stability is available for investment. It assumes there is no strong feedback between declining production-the economy-and oil production.

However the *decline curve assumption* is likely to be deeply misleading (as we shall see in Chapter 6): declines in oil production undermine the ability of society to produce, trade, and use oil (and other energy carriers) in a re-enforcing feedback loop. Energy flows through the economy are likely to be unpredictable, erratic, and prone to sudden and severe collapse. The implication is that much of the oil (and other energy carriers) that are assumed to be available to the global economy will remain in the ground as the real purchasing power, energy infrastructure, economic and financial systems will not be available to extract and use it.

2.6 The Energy Gap

In this section we will assume the decline curve assumption. The aim here is to indicate how realistic is the hope that we might fill the gap that will open up between declining oil production and the oil required for growth with alternative energy and efficiency measures.

In the most straightforward way we are expecting a gap to open up between the oil production required to keep the global economy growing, which has averaged about 1.6% per annum over the preceeding decades, and the net energy available after the energy costs of extraction has been removed from gross production. We will mention here some of the reasons why we cannot fill this gap under current conditions, though we refer elsewhere for more thorough discussion[31,32]. In later chapters an even more important set of reasons why this gap cannot be filled is discussed,

The actual energy gap is the sum of the gross production drop plus the growth addition (which the IEA estimated it might be 1.2% p.a.) plus the energy cost of extraction. Decline rates when quoted tend to refer to the gross production, let us conservatively say 2% p.a. (*Note:* among peak oil analysts gross declines are decline rates of currently producing fields, and net decline rates are the gross declines plus additions from new production. For energy systems analysts gross production is what is produced-net production according to peak oil analysts-and net production is what is accounted for by declining EROI. In this case, we take the latter's definition). We will assume that cost of energy extraction is zero. So we could by way of example imagine the energy gap growing at 3.2% per annum. Total liquid fuels production is 86 million b/d (of which 73mb/d is crude, 7.94 mb/d is Natural Gas Liquids, and the rest comprises extra heavy oil, Canadian oil sands, deep-water oil and biofuels) [33] so the gap is 2.75 million b/d.

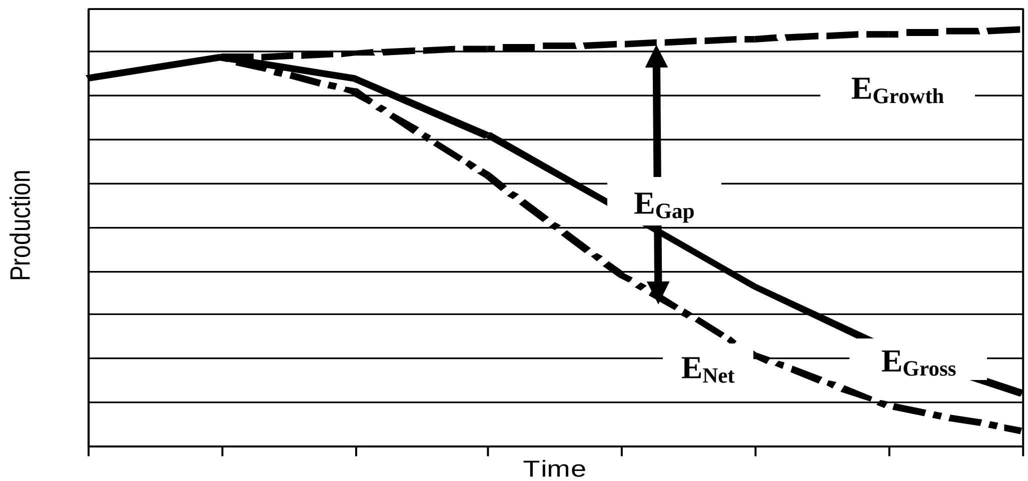


Figure:3 A toy model of oil production versus time. The energy gap is the additional energy required to keep the economy growing as net oil production declines.

How easily could we fill this gap, so that the economy keeps growing? As first glance we might substitute bio-ethanol and bio-diesal as our transport fleet would need little modification. In addition, we already have an established agricultural infrastructure in place. Current biofuel production is 1.45 mb/d. However the energy content of a barrel of biofuels is much less than the energy content of a barrel of oil which it is replacing, so in energy terms current biofuel production is about 1mb/d. To produce at this level has taken years of growth and subsidies, we would need to expand the industry by 275% in the first year alone, when even at the industries height it had a maximum growth rate of less than 30%. We have not considered that we are replacing high EROI oil with low EROI biofuels, but one result would be that as oil and other energy prices rose, biofuels price would rise even faster because it embodies so much fossil fuel energy in its production. So clearly there is an issue of scale, timing and energy return.

Another major constraint against substituting oil with biofuels is its effects upon food production. Biofuels compete with the land, water, and energy used to produce food. We can get a sense of what such a drop might mean by considering that the Food and Agricultural Organisation (FAO) food price index rose 140% between Feb 2002-Feb2008, with both the World Bank[34] and Goldman Sachs[35] attributing the main part of that rise to biofuels. The so-called ‘Tortilla Riots’ in Mexico and a coup in Haiti in 2007 were two of the more dramatic outcomes. Expanding biofuel production when global food production is already under stress will drive not just hunger and instability in poorer countries, but entrench economic instability in rich ones. We shall consider food again in the chapter six.

The future according to some will be electrification of transport. If we are not going to eat into our already at risk current electricity production capacity, or build back-up power for intermittant renewables, we might try running electric cars from wind turbines. Again we come to the issue of scale and ramp-up. Global installed wind capacity at the end of 2009 was 157GW, and near record increase of 31% on the year before[36]. If we assume 30% capacity, this is in energy terms less than 25% of the 2.75mb/d gap. Nor have we accounted for the tiny number of electric cars produced, their limited ramp-up rates, and fears over the lithium supplies (peak Li) required for batteries. Nor have we suggested what economic forces might drive this massive development when the world is in recession, the cars expensive, and the auto makers are in crisis.

Coal-to-liquids(CTL) technology has been available in some form for over fifty years, and there is still plenty of coal available. Here we emphasise again that it is not enough to establish that a substitution is hypothetically possible. We need to know the rate at which coal production and particularly the CTL production infrastructure can be ramped up relative to the oil production decline. In addition we need to know how affordable the liquids are, and it's EROI. Currently, there is only a trickle of CTL produced globally.

It is well known that we could use far less energy yet receive the same benefit if we were more efficient. Some measures cost us nothing and bring a direct benefit, turning off unused appliances for example. However, for many other measures there are upfront costs with longer-term payback. This ranges from low cost low-energy lightbulbs, to insulation, to expensive combined heat and power plants. All of these require energy and resources, and an ability of customers to pay the upfront costs or obtain credit. When we (as individuals or governments) are poorer with less access to credit, as in the current recession or one caused by high energy prices, there is less money to pay for such things and our investment decisions tend to become more short-term. In such a manner we can be locked into low efficiency living.

If we were to enact such efficiency measures there is a high likelyhood that the energy use would be transferred elsewhere in the economy, this is the well-known rebound effect[37]. That is, the money I save from efficiency measures is spent on goods and services elsewhere in the economy, leading to a further demand on energy. However, the rebound effect is limited when there are actual constraints on accessing more energy elsewhere in the economy.

If there is so much easily accessible 'fat' in our energy usage, one might expect very high energy prices to preferentially drive it out. This might be partially true, but the impact is highly asymmetric. We can look at this through the perspective of the energy price rises in 2007/8. For a rich but energy inefficent person or business where direct energy expenditure was a small part of their costs life could continue as before. For a poor person or company where energy was already a high part of costs it was considerably more difficult. Among those who were most hit were important highly optomised industries such as haulage and fishing. There were also wide-spread warnings about fuel poverty.

3. The Dynamics of Complex Civilisation

3.1 Civilisation, the Economy, & Complexity

This paper is concerned with humanity's impact on its environmental resource base, and the effect the resource base has on human welfare. What mediates between these is our complex civilisation[38].

The idea of civilisation has inspired intellectuals and propagandists for millenia, and it is not particularly helpful to enter the debate here. We shall define it broadly, and in a way that serves our purposes in the current context. Civilisation is firstly *a system*, a singular object that connects all its constituant elements together. The constituants are people, institutions, companies, and the products and services of human artifice. The connections are people, supply-chains and transport networks, telecommunications and information networks, financial and monetary systems, culture and forms of language. It has dimensions of space, in the momentary transmission of goods, images, money, and people across the globe. And it has dimensions of time as stored in libraries, education and institutional knowledge, the patterns of fields and city streets, ideas of who we are and why we do as we do. It also places, through its history and evolved structures, constraints on its future evolution.

Our particular *globalised civilisation* is one that has grown to connect almost every person on the planet. One is in some way part of it if you have heard of Barak Obama, seen a moving image, used money, or have or desire something made in a factory. There are very few people on the planet who are unconnected, most are more or less integrated. We can also look at this as our level of *system dependency*. Imagine if suddenly across the globe; all the advanced infrastructure of civilisation-banking, IT, communications systems, and supply-chains suddenly stopped working. For developed countries relying upon just-in-time delivery of food, digital money; and complex information systems, starvation and social breakdown could evolve rapidly. In developing countries the situation would not be much better. Only for the most remote tribes on the planet it would make little or no difference. Occasionally we get a glimpse of the issue as during the fuel depot blockades in the UK in 2000, when supermarkets emptied and the Home Secretary Jack Straw accused the blockaders of "threatening the lives of others and trying to put the whole of our economy and society at risk"[39]. More recently, the collapse of Lehman Brothers helped precipitate a brief freeze in the financing of world trade as banks became afraid of perceived counter-party risks to Letters of Credit[40]. The more we become part of the system the more we share its benefits and the more system dependent we become.

It is a cliché, though true, to say that civilisation has become more complex. We can understand complexity as involving the number of connections between people and institutions; the intensity of hierarchical networks, the number of products available, the extent and number of the supply-chain functions required to produce these products; the number of specialized occupations; the amount of effort that is required to manage and operate systems; the amount of information available, and the energy flows through the system. Here is a vivid description of one aspect of complexity by Eric Beinhocker who compares the number of distinct culturally produced artifacts produced by the Yanomamo tribe on the Orinoco River, and modern New Yorkers. The Yanomamo have a few hundred, the New Yorkers have in the order of tens of billions, and this wealth is a measure of complexity:

"To summarize 2.5 million years of economic history in brief: for a very, very long time not much happened; then all of a sudden all hell broke loose. It took 99.4% of economic history to reach the wealth levels of the Yanomamo, 0.59% to double that level by 1750, and then just 0.01% for global wealth to reach the level of the modern world"[41].

Or we can look at it from the point of view of the supply-chains that are required to transform raw materials into products and services that criss-cross the globe. It is said that a modern car manufacturer has about 15,000 inputs to the manufacturing process. If each of those components was made by a supplier who put together on average 1500 components (10%), and each of those was put together by a supplier who put together 150 components, that makes over 3 billion interactions- and we have not included staff, plant, production lines, IT and financial systems. Nor are we at the end of the story here. For the car manufacturer would not exist were there not customers who could afford to buy a new car, which depends upon their economic outputs which are themselves dependent upon vast complex supply chains, and so on. Nor could these vast networks of exchange exist without transport, finance, and communications networks. And those networks would not be economically viable unless they were benefiting from the economies of scale shared with many other products and services. In this way we can start to see how intimately connected we are with one another across the planet, and why we see the global economy as a singular system.

The remarkable thing about such a complex economy is that it works. Each day I buy bread. The person who sold me that bread need not know from whom the wheat was bought, who manufactured the mixer, or who provided export credit insurance for the bulk wheat shipment. The person who delivered the bread to the shop did not need to know who refined his diesel, who invented the polymer for his gasket, or if I personally have money to pay for bread. The steel company did not know that a small manufacturer of bread mixers would use its product, nor cared where its investment came from. The process required to simply give me tasty and affordable bread, required, depending on the system boundaries, millions, even hundreds of millions of people acting in a coherent manner.

Yet in all this there was no organizer. The complexity of understanding, designing, and managing such a system is far beyond human and computer assisted abilities. We say such systems are self-organised, just like the formation of birds in flight, and the patterns of walkers down a city street. Self-organisation can be a feature of all complex adaptive systems, as opposed to ‘just’ complex systems such as a watch. Birds do not ‘agree’ together that arrow shapes make good sense aerodynamically, and then work out who flies where. Each bird simply adapts to its local environment and path of least effort, with some innate sense of hierarchy for the lead bird, and what emerges is a macro-structure without intentional design (readers will notice the same non-teleological explanations within evolutionary biology).

Our globalised civilisation has evolved and operates as a complex adaptive system. From each person, company or institution, with common and distinctive histories, playing their own part in their own niche, and interacting together through cultural and structural channels, the global system emerges.

What ties our globalised civilisation together is the global economy. It is to our civilisation what blood and the central nervous system is to our body. The economy allows the exchange of goods and services across the globe. And the more system dependent we are, the more we rely upon the global economy.

If one side of the global economy is goods and services, the other side is money. Money has no intrinsic value, it is a piece of paper or charged capacitors in an integrated circuit. It represents not wealth, but a claim on wealth (money is not the house or food we can buy with it). Across the globe we exchange something intrinsically valuable for something intrinsically useless. This only works if we all play the game, governments mandate legal tender, and monetary stability and trust is maintained. The hyper-inflation in Weimar Germany and in today's Zimbabwe shows what happens when trust is lost.

One of the great virtues of the global economy is that factories may fail and links in a supply chain can break down, but the economy can quickly adapt to fulfilling that need elsewhere or finding a substitute. This is a measure of the adaptive capacity within the globalised economy, and is a natural feature of such a de-localised and networked complex adaptive system. But it is true only within a certain context. There are common platforms or ‘hub infrastructure’ that maintain the operation of the global economy and the operational fabric, without which they would collapse. Principal amoung them are the the monetary and financial system, accessible energy flows, and the integrated infrastructures of information technology, electricity generation, and transport.

We can make an analogy here with another complex adaptive system, the human body. Hub infrastructure for the human body would include blood circulation (heart), the signalling and information (central nervous system), and the respiratory system. If any of these fail, we die. However our body can self-repair cuts and light trauma, and can survive quite major local damage (limb loss). If the local damage is significant enough (or death by a thousand cuts), the body can fail. So collapse (death) can result from hub failure or significant general system damage. We tend to find that final collapse is driven by the interactions of these elements (death caused by heart or respiratory failure caused by trauma).

This current integrated complexity was not always so. We have adapted so well to its changes, and its changes have been in general so stable, that we are often oblivious to its ties. Imagine if all the integrated circuits introduced within the last 10 or even five years should stop working. Financial systems, the grid, and supply-chains would fail. Our just-in-time food systems would soon leave the cupboard bare, and our inability to carry out financial transactions would ensure it remained so, real starvation could appear in the most advanced (system dependent) economies. The question poses itself, how can something introduced only in the last five or ten years cause such chaos if removed, afterall we were fine just ten years ago? Even just consider the consequences of losing the mobile phone network. Our most basic functioning has become, almost by stealth, more and more entwined with rapid turnover technologies, the complex supply-chains that carry our needs and labours across the planet, and the financial and monetary systems that hold them all together.

3.2 The Evolution of the Global Economy

For most people living before the late medieval period, sustenance and welfare depended upon one's own efforts and those of one's close community. In such a context, abundant harvests could co-exist with nearby famine[42]. From a general welfare point of view there was a production and a distribution problem.

The central problem of distribution was firstly that money was a small part of the local economy, as most communities were largely self-sufficient. Secondly, there were very rudimentary transport links, and actual communication between towns may have been infrequent and haphazard. This meant that there was neither a proper signaling mechanism to indicate shortages, a tradable store of value, nor a trade and transport system to facilitate the resource redistribution. Rural villages could find themselves vulnerable to harvest failure (from flooding say), which was the bedrock asset of community welfare, and therefore they had to bear all the risk locally. The risk could be partially managed by storage and storage technology, but the ability to store for a rainy day also meant that there needed to be surplus production. But investing in increasing production tends to require surpluses, traded inputs and knowledge from elsewhere.

One of the great advantages of a growing interconnectedness between regions, and more trade with money was that localised risks could be shared over the whole network of regions. Surpluses could be sold to where prices were highest in the network, and the money received in return would hold its value better than the stored grain prone to rot or rodents. Distributing surpluses across the network was also the most efficient use of resources. What economists now call comparative advantage meant that more specialised roles could be performed in the network than in a similar number of isolated regions or towns with greater efficiency. This meant new products and services could be developed, especially ones that relied on diverse sub-components. This promoted further efficiency, increased wealth, surpluses, capital and a growing knowledge and technical base. Now increased investment in future wealth could be more ambitious in building the size of the network (through assimilation, integration and conquest) and its levels of integration (bridges, markets, and guilds).

There are push-pull drivers of growth; in human behavior; in population growth; in the need to maintain existing infrastructure and wealth against entropic decay; in the need to employ those displaced by technology; in the response to new problems arising; and in the need to service debt that forms the basis of our economic system. The process of economic growth and complexity has been self-re-enforcing. The growth in the size of the networks of exchange, the level of complexity, the economic efficiencies all provide a basis for further growth. Growing complexity provides the basis for developing even more complex integration. In aggregate, as the operational fabric evolves in complexity it provides the basis to build more complex solutions.

We are problem solvers, arising from our basic needs, status anxiety, and our responses to the new challenges a dynamic environment presents. That could be simple such as getting a bus or making bread; or it could be complex, putting in a renewable energy infrastructure say. We tend to exploit the easiest and least costly solutions first. We pick the lowest hanging fruit, or the easiest extractable oil first. As problems are solved new ones tend to require more complex solutions. Our ability to solve problems is limited by the range of possible solutions available to us, *the solution space*. The extent of the solution space is limited by knowledge and culture; the operational fabric at a time; and the available energetic, material, and economic resources available to us. It is also shaped by the interactions with the myriad other interacting agents such as people and institutions, and because all may be increasingly complex, they may re-enforce growing complexity as they co-evolve together.

As new technologies and business models (solutions or sets of solutions) emerge they co-adapt and co-evolve with what is already present. Their adoption and spread through wider networks will be dependent upon the efficiencies they provide in terms of lower costs and new market opportunities. One of the principal ways of gaining overall efficiency is by letting individual parts of the system share the costs of transactions by sharing common platforms (information networks, supply chains, financial systems), and integrating more. Thus there is a re-enforcing trend of benefits for those who build the platform and the users of the platform, which grows as the number of users grow. In time the scale of the system becomes a barrier to a diversity of alternative systems as the upfront cost and the embedded economies of scale become a greater barrier to new entrants, this being truer for more complex hub infrastructure. Here we are not necessarily associating lack of system diversity with corporate monopolies. There is quite vigorous competition between mobile phone service providers-but they share common platforms and co-integrate with electricity networks and the monetary system, for example.

This however can lay the basis for systemic vulnerability. That is, if our IT platform failed so too would our financial, knowledge and energy systems. Conversely if our financial system collapsed, it would not take long for our IT and supply-chains to collapse. The UK based Institute of Civil Engineers acknowledges that the complex relationships between co-dependent critical infrastructure is not understood[43]. Our operational systems are not isolated from the wider economy either. Because of the expense of infrastructure and the continual need for replacement of components, a large number of economically connected people and economies of scale are necessary to provide their operational viability. What has helped make such systems viable is that they are being cross-subsidized throughout the whole economy. The resource required to build and maintain critical complex infrastructure demands that we buy games consoles, send superfluous text messages, and watch YouTube.

The growth of civilisation has costs, and as it grows, costs rise. The biggest driver of environmental destruction is the growth process itself. Rising soil and aquifer depletion, collapsed fisheries, deforestation, greenhouse gas emissions, and polluted groundwater are just some of the consequences of the requirement for continuous flows for the maintenance and growth in GDP. There are also the costs of complexity itself. As systems become more complex there are growing costs associated with managing and operating the systems and the investment in educating people who will work in more specialised roles.

Joseph Tainter has argued that declining marginal returns on growing complexity provide the context in which previous civilisations have collapsed[44]. The benefits of rising complexity are finally outweighed by the rising costs. But problems still arise, and a society no longer can respond to those problems in the traditional way-increasingly complex solutions. It becomes locked into established processes and infrastructures but is less able to recover from shocks or adapt to change, it loses resilience.

3.3 Evolution of Science & Technology

The assumption that science and technology will automatically respond to meet the challenges we face has become an article of faith. It is related to our conceptions of 'progress', and its power and potential may be asserted with authority by anyone. In discussions of sustainability, science and technology is often invoked as the *deus ex machina* destined to fill the looming gaps between our demands and the earth's ability to supply them. In this sense it may act as a collective charm wielded to chase away the anxiety induced by glimpses of our civilisation's precariousness. The following section attempts to locate science and technology within the evolutionary and material conditions of our economy. We also wish to illuminate a little more why high technology infrastructure is vulnerable.

Science & Technology Suffer from Declining Marginal Returns

In 1897 J.J. Thompson discovered the electron, then the cutting edge of physics, all on a laboratory bench. The understanding of this particle laid the foundation for the digital infrastructure upon which much of the world relies. Today it requires a 27km underground tunnel, 1,600 27 ton superconducting magnets cooled to less than 2 degrees above absolute zero, and the direct involvement of over 10,000 scientists and engineers to find (possibly) today's cutting-edge particle, the Higgs boson. In the 1920’s Alexander Fleming discovered penicillin, with a huge benefit to human welfare, for a cost of about €20,000. Today it costs hundreds of millions to develop minor variations on existing drugs that do little for human welfare.

Science and technology are an exercise in problem solving. As generalised knowledge is established early on in the history of a discipline, the work that remains to be done becomes increasingly specialised. The problems become more difficult to solve, are more costly, and progress in smaller increments. Increasing investments in research yield declining marginal return[45]. We see this in the growing size of research groups, levels of specialisation, and the knowledge burden[46].

The conclusion is that further research and development is likely to be more resource intensive, yet on average give smaller returns to society. For a society trying to undergo an energy transformation, this means that more and more of possibly declining energy available to society must be devoted to research and development, but with less likelihood of significant breakthroughs.

The Most Advanced Technology is the Most Resource Intensive

Because new technologies tend to be solutions to more complex problems, are built using high technology components, and have relied upon the continually upgrading operational fabric; they tend to be more resource intensive. We can see this in the evolution of key manufacturing processes over the last century where one analysis shows a six order of magnitude increase in the energy and resource intensiveness per unit mass of processed materials. This was driven by the desire for smaller and more precise devices and products[47]. A 2 gram 32 MB DRAM chip would now be considered archaic, but it required 1700g of resources to fabricate, one expects that contemporary Very Large Scale Integration (VLSI) chips require vastly more resources[48]. While popular focus tends to be on the direct energy used by final goods, it is the embodied energy and material resources that is staggering[49].

Yet the high-tec products we use (computers say), require the networks, telecoms infrastructure, software, and the computer use of others to realise their value. Which in turn depends upon an even vaster infrastructure. So in a way, asking about the resource requirements of your computer is akin to asking about the resource requirements for your finger, it make sense only if you assume the rest of the body is well resourced.

Finally, we note for completeness that rising energetic and material costs from growing complexity (more specifically energy flows per unit mass) is just what we would expect from thermodynamic principals.

The Most Advanced Technology Has the Most Complex Supply-Chain Dependencies

The more complex a product and production process the more tightly integrated it is into the global economy. There are far more direct and indirect links in the supply-chains upon which they are dependent. Its production process is also dependent upon the inputs of more specialized suppliers with fewer substitutes. Let us consider the integrated circuit as our standard-barer of technological complexity. Intel, who supply 90% of the processors in personal computers relies upon high-tech research-led companies providing sophisticated optical and metrology systems, control electronics, and a vast array of specialty chemicals. Those companies rely upon further sophisticated inputs with few substitutes. High-tech is less geographically mobile, relies upon very specialised staff and institutional knowledge, and generally will have a very large sunk cost in the operations and plant. Thus we can say that the more technologically advanced a process the greater risk it faces from supply-chain breakdown, just like the old rhyme:

For want of a nail the shoe was lost.
For want of a shoe the horse was lost.
For want of a horse the rider was lost.
For want of a rider the battle was lost.
For want of a battle the kingdom was lost.
And all for the want of a horseshoe nail.

Because of the complexity of chip manufacture no company has the knowledge to build an integrated circuit (IC) 'from the ground up', that is, by starting with the raw elemenents to build all the production and operation systems, and process inputs. Many companies have co-adapted and co-evolved together, so that the knowledge of fabrication and the tools of fabrication, and the tools of those tools is really an IC-ecosystem knowledge, which itself is co-dependent on the global economy.

4. Collapse Dynamics

4.1 The Dynamical State of Globalised Civilisation

The period since the end of the last ice age provided the large-scale stability in which human civilisation emerged. Climatic stability provided the opportunity for diverse human settlements to 'bed' down over generations. This formed the basis upon which knowledge, cultures, institutions, and infrastructures could build complexity and capability over generations without, by-and-large having it shattered by extreme drought or flooding outside their capacity to adapt.

Within this macro-climatic stability, is the medium-term stability that we refered to above, the period of globalising economic growth over the last century and a half. We tend to see the growth of this economy in terms of change. We can observe it through increasing energy and resource flows, population, material wealth, and as a general proxy, GWP. We could view this from another angle. We could say that the globalizing growth economy for the last one hundred and fifty years has been remarkably stable. It could have grown linearly by any percentage rate, declined exponentially, oscillated periodically, or swung chaotically, for example, what we see is a tendency to compound growth of a few percent per annum. And at this growth rate the system could evolve, unsurprisingly, at a rate we could adapt to.

This does not mean that there are not unpredictable fluctuations in the economy. However, the fluctuations are around a small additional percentage on the previous years gross output. By magnitude we are roughly referring to $|^{\Delta GWP}/_{GWP}|$. Angus Maddison has estimated that GWP grew 0.32% per annum between 1500 and 1820; 0.94%(1820-1870); 2.12% (1870-1913); 1.82% (1913-1950); 4.9% (1950-1973); 3.17% (1973-2003), and 2.25% (1820-2003)[50]. Even through two world wars and the Great Depression in the most economically developed countries (1913-1950) growth remained positive and in a relatively narrow band. Figure:4 shows growth rates of the global economy in frequency bands over the last four decades, again the narrow band indicates system stability. Of course small differences in aggregate exponential growth can have major effects over time, but here we are concentrating upon the stability issue only.

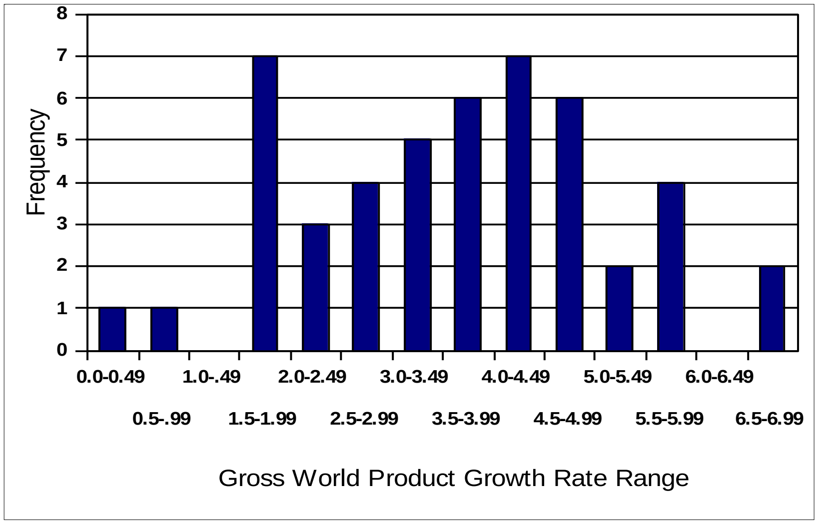


Figure: 4 Real GWP percentage change year on year 1961-2008. Source: Based upon World Bank data.

Governments and populations are highly sensitive to even minor negative changes in growth. The constraints felt by governments and society in general from only a very small change in GDP growth should emphasize to us that our systems have adapted to this narrow range of stability, and the impact of moving outside it can provoke major stresses.

4.2 Tipping Points in Complex Systems

Despite the diversity of complex systems, from markets to ecosystems to crowd behavior- there are remarkable similarities. For most of the time such systems are stable. However, many complex systems have critical thresholds, called tipping points, when the system shifts abruptly from one state to another. This has been studied in many systems including market crashes, abrupt climate change, fisheries collapse, and asthma attacks. Despite the complexity and number of parameters within such systems, the meta-state of the system may often be dependent on just one or two key state variables[51].

Recent research has indicated that as systems approach a tipping point they begin to share common behavioral features, irrespective of the particular type of system[52]. This unity between the dynamics of disparate systems gives us a formalism through which to describe the dynamical state of globalised civilisation, via its proxy measure of GWP, and its major state variable, energy flow.

We are particularly interested in the class of transitions called catastrophic bifurcations where once the tipping point has been passed, a series of positive feedbacks drive the system to a contrasting state. Such ideas have become popularised in discussions of climate change. For example, as the climate warms it drives up emissions of methane from the artic tundra, which drives further climate change, which leads to further exponential growth in emissions. This could trigger other tipping points such as a die-off in the amazon, itself driving further emissions. Such positive feedbacks could mean that whatever humanity does would no longer matter as its impact would be swamped by the acceleration of much larger scale processes.

Figure:5 shows how the system state responds to a change in conditions. The state of a system could represent the size of a fish population, or the level of biodiversity in a forest, while the conditions could represent nutrient loading or temperature (both effectively energy vectors). The continuous line represents a stable equilibrium, the dotted line an unstable one. In a stable equilibrium, the state of the system can be maintained once the condition is maintained. In figure a) and b) we see two different responses of a stable system under changing conditions. In the first, a given change in conditions has a proportional effect on the system state, in the latter, the state is highly sensitive to a change in conditions. In c) and d) the system is said to be close to a catastrophic bifurcation. In both of these cases there is an unstable region, where there is a range of system states that cannot be maintained. If a system state is in an unstable regime, it is dynamically driven to another available stable state. If one is close to a tipping point at a catastrophic bifurcation the slightest change in the condition can cause a collapse to a new state as in c), or a small perturbation can drive the system over the boundary as in d).

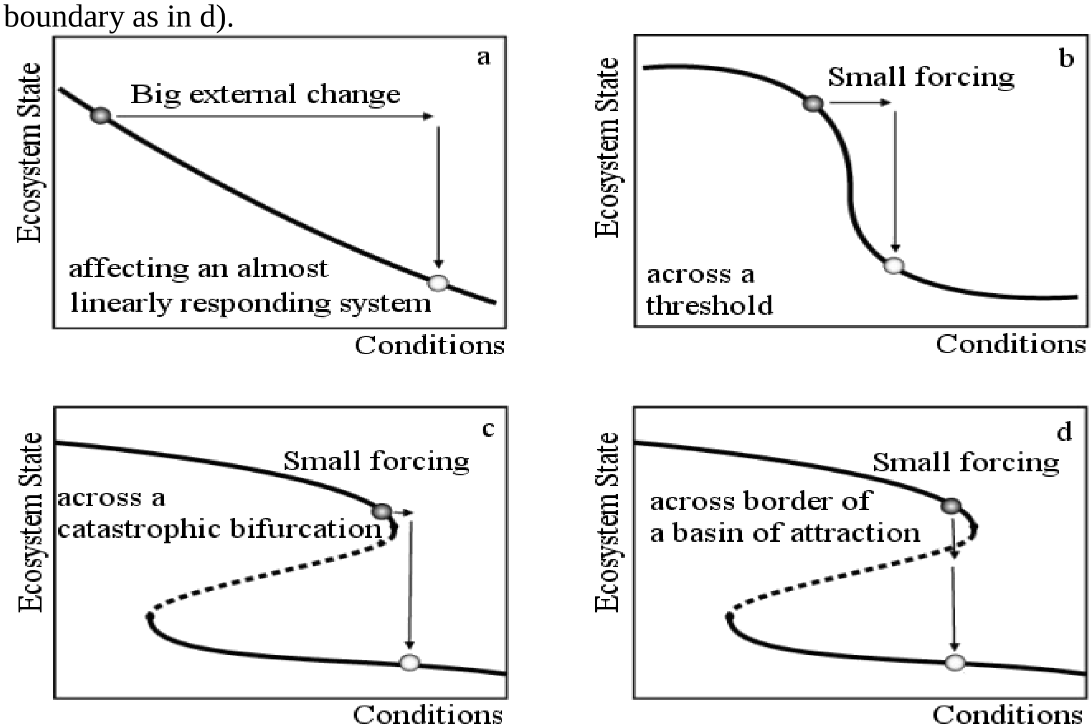


Figure:5 The state of a system responds to a change in conditions. The continuous line represents a stable equilibria. In a) a change in conditions drives an approximately linear response in the systems state, unlike b) where a threshold is crossed and the relationship becomes very sensitive. The fold bifurcation (c,d) has three equliibra for the same condition, but one represented by the dotted line is unstable. That means that there is a range of system states which are dynamically unstable to any condition[53].

5. Three Peak Energy-Economy Models

5.1 Introduction

While discussions of peak oil have begun to enter the policy arena, and while it is generally acknowledged that it would have a major effect upon the economy, the discussion is often fragmented and lacking in a broad system synthesis. In general, discussion tends to focus on the direct uses of oil, and sometimes its effect on a country's balance of payments. Where economic impact studies of peak oil have been done, they are based upon the direct decline curve assumption such as the 4see model by Arup for the UK Peak Oil Task Force Report[54]. Nel and Cooper have used the decline curve assumption and accounted for EROI and peak coal and gas to look at the economic implications[55]. The latter authors show a smooth decline in GDP but acknowledge that their modeling assumptions include that the financial markets must remain functional, State legitimacy remains intact; and international law prevails.

In most cases there is an intuitive assumption or mental model of what the effects of peaking oil production will mean economically and socially. In order to clarify our discussion, and introduce some working concepts, we will look at three models.

These should not be considered in isolation. In a very broad and general fashion we might consider that the *linear decline* model is valid for small energy constraints that have a very small effect on the overall magnitude of real GWP and level of complexity. This merges into an *oscillating decline* phase which causes larger perturbations in GWP/Complexity level. Finally, tipping points are crossed that rapidly cause a severe *collapse* in GWP/Complexity.

Finally, we note that what we are trying to do is clarify peak energy-civilisation dynamics and identify the major structural drivers in the process. The real world is more unknowable than can ever be engaged with here.

5.2 Linear Decline

Intuitively we tend to assume that most phenomena respond proportionately to some causation. This is mostly true. A change in price proportionately changes demand; an increase in population proportionately increases food demand; and increase in cars leads to a proportional increase in emissions.

Most commonly, there are two associated assumptions relating to the energy-economy relationship post-peak. The first is the Decline Curve Assumption. Thus oil production is withdrawn from the economy at between 2 and 3% p.a. The second element is that there is an approximately linear relationship between the oil production decline and economic decline. The combination of these assumptions is that the global economy declines in the form of the slope of the downward projection curve.

Thus we see oil price rises as oil becomes scarcer. Less energy constrains economic activity. Bit by bit we become poorer, there is less and less discretionary consumption. The rising prices force more localized production and consumption, and there is growing de-globalisation. Jobs lost in the areas serving today's discretionary needs are over time deployed in food and agriculture, and producing with more direct human effort and skill many of the essentials of life.

In such a case a longish period of adaptation is assumed in which gradually declining oil production and resulting oil price increases cause recession, hardship and cause some shocks, but also initiate a major move into renewable energy, efficiency investments, and societal adaptation. New energy production that was once too expensive becomes viable. The general operability of familiar systems and institutions is assumed, or they change slowly.

Even where the linear decline model valid, it would be difficult to adapt. Consider a country’s budget in energy terms, with some amount for health, business operations, agriculture, operations, education say; and investment. As the total energy available declined, less and less energy would be available in each sector. Because we discount the future (we favour short-term benefits), and the discount rate rises in economic stress, the ability to maintain investment in renewable energy would become increasingly difficult. In essence, it would be a choice between keeping some functionality in a crumbling health service, and stalling rising employment a little; or accepting job losses and a health crisis in return for a small energy return per annum in the future.

5.3 Oscillating Decline

In this model, constrained or declining oil production leads to an escalation in oil (plus other energy and food) prices. But economies cannot pay this price for a number of reasons. Firstly, it adds to energy and food price inflation, which are the most non-discretionary purchases. This means discretionary spending declines, from which follows job losses, business closures, and reduced purchasing power. The decline in economic activity leads to a fall in energy demand and a fall in its price. Secondly, for a country that is a net importer of energy, the money sent abroad to pay for energy is lost to the economy unless we export goods of equivalent value. This will drive deflation, cut production, and reduce energy demand and prices. Thirdly, it would increase the trade deficits of a country already struggling with growing indebtedness, and add to the cost of new debt and debt servicing.

Falling and volatile energy prices mean new production is harder to bring on stream, while the marginal cost of new energy rises and credit financing becomes more difficult. It would also mean that the cost of maintaining existing energy infrastructure (gas pipelines, refineries etc) would be higher, so laying the foundations for further reductions in production capability.

In such an energy constrained environment, one would also expect a rise in geo-political risks to supply. Bi-lateral arrangements between countries to secure oil (or food) become more likely, so reducing oil on the open market. It would also increase the inherent vulnerability to highly asymmetric price/supply shocks from state/non-state military action, extreme weather events, or other so-called black swan events.

When oil prices fall below what can be supplied above the marginal cost of production and delivery, and oil price is what can be afforded in the context of decreased purchasing power in the economy, the energy for growth is again available. Of course local and national differences (for example energy import dependence, export of key production such as food) could be expected to have shifted how regions have fared in the recession and in their general ability to pick up again. Growth then might be assumed to kick off again, focusing maybe on more 'sustainable' production and consumption.

However, as growth returns, the purchasing power of the economy will not be able to return to where it was before. Natural decline limits to oil production, lack of investment and entropic decay of infrastructure will reduce the supply-demand price point further. Again higher oil, food and energy prices would then drive another recession.

In the oscillating decline model: economic activity increases→energy prices rise→a recession occurs→energy prices fall→economic activity picks up again but to a lower bound set by declining oil production. In this model the economy oscillates to a lower and lower level of activity. From our discussion about the origins of the current recession, we see this process has already begun.

5.4 Systemic Collapse

This model draws on ideas from the general dynamics of complex systems and networks, and tends to see our civilisation as a single complex adaptive system by virtue of its connectedness and integration. Indeed the concept of globalization is about integration with a common singular network.

We associate systemic collapse of civilisation with a catastrophic bifurcation. The State of civilisation at a time is by necessity dependent upon the State of the globalised economy. The State of the global economy is dependent on the infrastructure that integrates the operational fabric. The state of the globalised economy may be parameterized by GWP, which implies a level of complexity. And GWP (and complexity) is absolutely dependent upon energy flows.

To argue that civilisation is on the cusp of a collapse, we need to be able to show that there are tipping points that, once passed, drive the system rapidly towards another contrasting state through a process of positive feedback; that may in turn drive other feedback processes. We need to also demonstrate that it is a catastrophic bifurcation in which the state of the globalised economy is driven through an unstable regime where the strength of the feedback processes is greater than any stabilizing process. It acknowledges that there may be an early period of oscillating decline, but that once major structural components (international finance, techno-sphere) drop or ‘freeze’ out, irreversible collapse must occur.

In the new post-collapse equilibrium state we would expect a collapse in material wealth and productivity, enforced localization/ de-globalisation, and collapse in the complexity as compared with before, an expression of the reduced energy flows.

The collapses in the Roman Empire occurred over centuries; collapse of the Greenland Viking settlements in decades. We suggest a hypothesis here that the speed of collapse is a function of the level of integration, coupling, and the key operational speeds of the systems that support the stability of the pre-collapse state. For us that includes the behavioral change in financial markets, food flow rates, and replacement lifetime of key components in infrastructure. In discussing the feedback processes in the next chapter we will see processes are indeed fast.

6 . Principal Feedback Mechanisms Driving Collapse

6.1 Introduction

We currently live within an integrated complex globalised economy. We have framed the process in which this occurs as a catastrophic bifurcation, driven by a series of re-enforcing positive feedbacks (sec: 4.2). The final point will be a de-globalised (localised) economy of much reduced complexity.

We begin with the state of globalised civilisation that we argued in sec: 4.1 has been in a relatively stable dynamical state for the last century and a half or so. In its broadest outline we might say that declining energy flows reduce economic activity which further reduce energy flows. A series of increasingly severe processes are set in train which start to cause cascading collapse in major hub infrastructures and the operational fabric of the global economy. These processes have different time-scales, some could evolve over years, some could be relatively abrupt but because of coupling between them, the faster process are likely to lead the overall collapse rate.

6.2 Monetary System & Debt

6.2.1 Credit in the Economy

Credit in its various guises is the unifying embedded structure in the global economy. Credit underpins our monetary system, investment financing, government deficit financing, trade deficits, Letters of Credit, the bond market, corporate and personal debt. Credit and the promise of future economic growth support our stock market, production, employment and much else besides. It is the primary institutional infrastructure of the global economy.

The money flowing through our economy has been created through the issuance of debt[56]. Money enters the economy when banks create money in return for the promise to repay that debt with interest at some time in the future. All positive balances in our accounts, except for a very small percentage reserve, are lent out to others at interest. Debt and money are the mirror of each other. If we all paid back the money we owed, there would be no money left in circulation, and leave the interest on the debt unpaid.

Money supply is the balance between loans being taken out, and loans and interest being repaid. At any time, the money supply is insufficient to repay the total amount of debt outstanding with interest. In order to pay back loans in aggregate, more loans must be taken out for consumption and investment than the repayment of old loans. Thus in order for debt to be repaid, money supply must increase year-on-year. This can be done either by increasing GDP and/or inflation. Our monetary system depends on continually increasing debt outstanding and GDP for its stability.

Bank reserves represent much less than 10% of money owed to depositors by banks, which means they have not the money to repay their debts to their depositors. This implies a strong level of collective trust: when we lose trust, bank-runs can ensue, potentially collapsing the banking system. If we lose the banking system, the society wide implications for welfare can be severe. In general, shocks of this kind can be transmitted and absorbed by governments, central banks, society at large, and international institutions. This too implies a level of trust- in the adaptive capacity of globalised networks to contain the damage and prevent contagion. Local shocks can in general be contained, but because of the level of integration and tight coupling some shocks can rapidly rattle the world as the current crisis attests. At the core trust in monetary system is largely assumed throughout the globalised world. But with the loss of that trust, the systems ability to absorb the shock is lost, for the system depends upon that trust. Further, that trust depends upon continued economic growth, because only by growth can the devastation of hyper-inflation, deflation, and monetary collapse be avoided.

The economist Paul Seabright sees trust as a central underpinning of the global monetary system, and thus the trade networks upon which we rely[57]. Trust between unrelated humans outside our own tribal networks cannot be taken for granted (would you trade with a random stranger across the globe and send real money or goods without the reassurance of some guarantee of honest completion or ability to punish a defaulter?). Because trade is in general, to all our benefit, we have developed institutions of trust and deterrence ('good standing', legal systems, the IMF, banking regulations, insurance against fraud, and the World Trade Organisation etc) to re-enforce cooperation and deter freeloaders. Trust builds compliance, which confers benefits, which then builds trust. But the reverse is also true, a breakdown in trust cause can defections from compliance further reducing trust.

6.2.2 *Credit & Monetary Collapse*

Increasing debt, and thus money supply, without a corresponding increase in GDP, leads to a devaluation of moneys purchasing power which is inflation. But increasing GDP requires increasing energy and material flows. With an energy contraction, the economy must contract. In a growing economy debt can be paid off on average, as the growing 'pie' allows the payment of the principal plus interest. In a permanently contracting economy, the shrinking pie cannot cover even the repayment of the principal. Another way of putting it is that reducing energy flows cannot maintain the economic production required to service debt. All the money in the world could not repay debt outstanding, mass default or hyper-inflation are the only ways out. Credit, the life-blood of economies must dry up.

This means that we are moving into a period of extreme monetary uncertainty, framed by the global economic crisis' intersection with energy constraints and its consequences. We would expect a continuation or initiation of deflationary trends within economies. That is, money supply decreases, that in turn causes prices to drop relative to goods and services produced. This is firstly, because increasing spare production capacity and fears of future business failures and job losses reduces demand for new loans. Lower production and margins in the economy increases the relative debt burden which puts further pressure on consumer, corporate, and government borrowing. Even though people and companies may continue to service their loans, growing bad debts may force banks to write off their capital, the basis of their ability to make new loans under the fractional reserve banking system. Perceptions of future risk will reduce consumption and increase interest rates, further stalling economic activity. This deflationary process is self-re-enforcing. Under normal recessionary conditions governments might step in to maintain demand and liquidity through deficit spending or quantitative easing. But underlying such initiatives is the assumption that growth will return facilitating the repayment of sovereign loans and mopping up of excess liquidity.

At this moment, increasing concern is being expressed over the risks of sovereign, commercial property, and credit card defaults. If we assume that as time goes on the implications of an energy withdrawal become clearer to some potential creditors, one might expect rising interest rates, loans having shorter terms, and eventually the absolute refusal to finance most loans. Why lend more to someone who will not be able to repay the loans they already have outstanding? Eventually, it will be clear that almost all debt outstanding cannot be repaid, except in hugely devalued money.

If a small percentage of people in an economy cannot service their debts, their secured assets may be taken. This is necessary to maintain the banking systems viability. Likewise, a nations standing within the bond market is dependent upon it striving to repay its debts. But there must come a point when a critical mass of defaulters rises to such a level that there is no longer the political will to enforce the confiscation of assets, or there is active defiance against debt collectors. Further, when a nation realises the bond market will no longer facilitate borrowing because growth cannot be maintained, the market and social cost of defaulting drops, while the benefit of doing so rises. This social cost, in general falls the further in the queue you are after the initial defaulter.

Increasing fears of banking collapse is likely to lead to panics by depositors trying to retrieve their money, but as we have seen, the money is not there. Traditionally the job of the Central Bank is to stand behind a bank with emergency cash. But such models are not designed to manage a system-wide insolvency crisis on this scale.

We can ask what this means for the monetary system. We remember that we only exchange something of intrinsic value for money if we assume that money can be exchanged elsewhere for something of intrinsic value in time and space. The two monetary conditions for this are stable exchange rates and low inflation. Both of these embody our trust in counter-party currencies and our perceptions of future risks. The other co-dependent pillar of the monetary system is bank intermediation. But the banking system of necessity must become insolvent as their assets (loans) vaporize and their capital disappears. However, unlike today there can be no bail-out except in hugely devalued money. We can list some of the risks to monetary stability:

- As money supply shrinks, unemployment rockets, and government finances fall apart, there will be the temptation to assuage short-term public anger by printing money to pay wages. This could drive inflation and hyper-inflation.
- A severe collapse in production and supply chains could lead to an overhang of money in an economy as against goods and services, driving inflation.
- Fears of inflation, and fears over expectations of future availability of important goods, could drive inflation (by increasing the velocity of money).
- A collapse of the banking system and/or a failure of banking infrastructure (see sec. 6.4)) may mean that money and records are not available to enable transactions. Since some 97% of money is digital, and the global ability to print quality notes per unit time is small, there is a possibility of an almost complete absence of tradable money.
- If production collapses in potential trading partners, banking intermediation risks, increased risks of civil unrest, and a loss of trust; one may not want to hold that countries currency as there is a large risk of not being able to exchange it for intrinsically useful assets. For similar reasons, they may not want to hold our currency. This becomes a mutually re-enforcing feedback driving out monetary confidence globally.

Money, and exchange rates we might say, are becoming opaque. Difficult to value in space, which supports trade; and time, which supports investment and saving; which together scupper economic life.

Bank intermediation, credit, and confidence in money holding value is the foundation of the complex trade-networks upon which we rely. The financial situation described will expose what heretofore has not been a problem; the mismatch between our dependencies upon globalised integrated supply-chains, local and regional monetary systems, and nationalised economic policy. A complete collapse in world-trade is an extreme but not unlikely consequence.

The failure of production within the economy will mean that almost all income is absorbed by food and energy, but there will be little income to pay for it. Importing energy, food, and inputs for the production process into a country will only be possible by exporting something of equal value because running trade deficits is based upon credit. Monetary opaqueness may mean that barter, hard currency (gold, oil, grain, wood) may be used to settle accounts.

With the collapse of production within a country comes the collapse of exports too, from which follows a further inability to import energy or materials to increase production. As explained modern economies produce almost nothing indigenously, increasing dramatically the probability of supply-chain breakdowns causing key inputs in the production processes to disappear, further stalling production. Thus countries are likely to remain trapped with limited economic activity.

And because our supply-chains are so complex and globalised, we may not be able to import important even if we had something to exchange. For our supplier may have lost some critical inputs into its supply-chain, or lost its operational, social, or informational capacity locally. This means that local supply-chain failures quickly become globalised.

6.3 Financial System Dynamics

Money only has value because it can be exchanged for a real asset such as food, clothing, or a train journey. As long as we share the confidence in monetary stability we can save, trade and invest.[6] Like bonds and shares, it is a *virtual asset*, as it represents only a claim on something physically useful[58]. However, the current valuation of virtual assets towers over real productive assets on which their value is supposed to be based. A bond is valuable because we expect to be paid back with interest some years hence; paying twenty times earnings for shares in a company is a measure of confidence in the future growth of that company. The output of real productive assets must collapse because of energy and resource constraints and the failing operational fabric. The implication is that virtual wealth including pension funds, insurance collateral, and debt will become worthless.

The acknowledgment by market participants that peak oil is upon us, coupled with an understanding of the consequences is likely to permanently crash the global financial system. That is, the behavior of the market is based on fundamental physical constraints, such as rising loan defaults induced by the current economic crisis further constrained by energy and food price inflation-and its interactions with the hopes and fears of market participants, particularly their faith in the overall stability and continued growth of the system. The transition from few market participants accepting the idea, and large-scale acceptance can be very rapid, though the onset of the fast transition can be difficult to predict. In other words: growing government, corporate, and public acceptance of peak oil, will initiate a fear-driven conversion of a mountain of paper virtual assets into a mole-hill of resilient real assets which will help precipitate an irretrievable collapse of the financial and economic system. Such a transition can be expected to be fear-driven and mutually re-enforcing. This is part of the reflexivity of markets, in George Soros's phrase; or an example of a positive feedback, in the language of dynamical systems. In this context we can understand reported pressure placed upon the International Energy Agency by the United States to overstate future production in its World Energy Outlook 2009[59].

The end-point will be a collapse in bond and equity values. This is a result of various re-enforcing processes, including loss of confidence in debt repayment, monetary confidence, supply-chain disruption, evolving dis-economies of scale, and massive potential losses in discretionary consumption.

The end result for market participants would be a rush to extract virtual assets (money, bonds, shares, derivative instruments) to convert them into productive, non-discretionary assets (resilient energy assets, land, farm tools, gold). However, there is a vast imbalance in their respective size. In all total paper assets are probably valued at over $300Tr, supported on a Gross World Product of about $55Tr, which itself must collapse. For a comparator, the total clean -tech market capitalisation is about $1 Tr. In order to get an indication of the ability of the clean-tech sector to absorb investment, we note a record global investment in renewable power of $140 billion in 2008. The vast mismatch is clear, even assuming there were willing sellers of renewable assets or land. Green-field renewable infrastructure investments (building wind turbines, solar PV cells, DC cabling) are likely to have limited ramp-up rates, which if on the scale of investment increases between 2007 and 2008 would be of the order of 16%. This means pension funds, sovereign funds, insurance funds, and other major holders of such assets will loose everything, with little hope of asset conversion. Maintaining value in cash is likely to be ineffective because of deflation blocking conversion, or extreme inflation eroding the valuation of cash holdings.

It should be clear from the body of the text that one could expect much of the greentech sector to collapse due to failing operational fabric, so the rush will be to secure actual turbines/solar PV panels, or to produce them before systems begin to fail.

This means that there is a very small conversion window and that only a tiny fraction of investors will get out of virtual assets, to secure the small amount of real resilient assets

6.4 Critical Infrastructure

Economies of scale are the familiar benefits of a globalising world. They mean that not only can goods or services be produced more cheaply, meaning greater sales volumes; but also a freed up discretionary income that can be spent on other goods and services.

In the energy-economic environment so far discussed, this process goes into reverse. The rising prices of goods (because of the energy and resource cost, supply-chain and money risk reasons) and reduced discretionary income reduces the number of goods sold, reducing broader economies of scale, feeding back into the rising cost of goods, reducing further the number of sales. This dynamic is expected to be most forceful for the most advanced technologies.

For example, as fewer users can afford to replace mobile phones or computers, or use them less, the cost of the personal hardware and maintaining the network rises per user. Rising costs mean less discretionary use. But because common IT platforms require a large number of users, and economies of scale support the most discretionary use (say Facebook, texting, and Playstation) and the more important uses (business operations, banking, electric grid emergency services), the cost for businesses and critical services begins to escalate.

The components of infrastructure have been designed with the assumption that inputs to maintain, repair and upgrade would be on-stream. In addition component lifetime is often short (3-5 years for laptops and mobile phones). Furthermore most faults cannot be repaired locally without complex ready packaged components.

We remember that the most complex infrastructure has the most complex supply-chains and is more likely to have more inputs with fewer substitutes. Thus there is greater risk of critical infrastructure operational failure for want of a critical element. The complex sourcing and production over the globe means each nation’s particular economic, monetary, and social predicament becomes tied to our own, and ours to theirs.

To the above risks we must add the local economic and monetary risks, and on our ability to import energy. This interacting nest of conditions means that we could see cascading failures in the grid, Health service, IT systems, telecommunications, and water/sewage systems. This leave us with the risk of a near complete systemic failure in the operational fabric upon which our welfare depends.

Failing infrastructure feeds back into reduced economic activity and energy use, further re-enforcing failing infrastructure.

6.5 Food

Global food production is already straining against a rising demand and the stresses of soil degradation, water constraints, over-fishing, and the burgeoning effects of climate change[60]. It is estimated that between seven and ten calories of fossil fuel energy go into every one calorie of food energy we consume. For example, it has been estimated that without nitrogen fertilizer, produced from natural gas, no more than 48% of today's population could be fed at the inadequate per capital level of 1900[61]. Today it is true to say that no country is self-sufficient in food production.

The fragility of global food production will be exposed by a decline in oil and other energy production. It is not just the more direct energy using inputs that would be affected such as fertilisers, pesticides, seeds, and diesel spares for machinery, and transport. The failing operational fabric may mean there is no electricity for refrigeration, for example.

It should be clear even from the above overview that a major financial collapse could not just cut actual food production, but could result in food left rotting in the fields, an inability to link surplus production with those in need, and an inability to enact monetized food transactions.

Our critical reliance upon complex just-in-time supply-chain networks mean that there is little buffering to protect us from supply shocks. In the event of a shock, and without any planning, it is likely that unrelieved hunger could spread rapidly. Even for a country that could be food independent, and even a potential net exporter, it may years to transition as old systems fail and new ones put in place (rationing systems, education, re-location of farm laborers, horse breeding, nutrient re-cycling systems, seasonal re-adjustment of production, tool production, storage and preservation skills and products). In the interim, the risks are severe.

6.6 Energy Production

We have focussed upon peak oil, though we have mentioned concern about peak gas and even coal. Here we wish to outline the principal issues around how a decline in oil production would effect the use of other energy carriers. The central point to be aware of is that the production and delivery of all fuels not only maintains the operational fabric of the globe, but is also part of, and dependent upon it.

The use of different energy vectors are tightly coupled. Oil is predominantly a transport fuel, however its demand is tied to production in the wider economy, which is dependant upon natural gas and coal via electricity production. The reverse is also true, a forced reduction in oil use would induce a system-wide reduction in electricity and heating use. They are also coupled within the energy production process itself, oil is used to transport coal and re-supply the infrastructure of natural gas and coal. The water required in much of the energy process and in electricity production is obtained by diverse fuels. At a wider level, all energy carriers interact to maintain the operational fabric, if it fails, continued production, processing and distribution of all energy carriers may be imperilled. Reduced production in one energy carrier can cause a reduction in the others in a re-enforcing feedback.

A fall in income for energy producers would reduce their ability to bring on new production or maintain existing energy infrastructure. Because the exploration and development of all fossil fuels, renewable technologies, along with nuclear power are on an upward path of higher energy and financial costs and operational complexity they are particularly dependent on high real prices being maintained, and continual inputs of high complexity inputs.

For example, much future natural gas supplies (and coal) are expected to be produced from remote regions such as Siberia, requiring huge up fromt investments of fixed pipelines, which require long-term confidence in purchaser solvency and monetary stability. Other sources, in Qatar for example, will require a ramp-up of liqufication/ gassification plants and specialised ships. Again this requires huge upfront costs; and open supply-chain inputs to provide a complex infrastructure that in many cases is at the limits of current technology.

The likely inability of the global economy to re-boot will mean that potential supply may overhand demand for years. All the while, the loss of the operational fabric may mean potential future production becomes lost to the entropic decay of energy infrastructure, and the dis-economies of scale in running large facilities with low volumes of production.

Usually when we talk of energy security we are in particular referring to the fuel. However the failure of the operational fabric might mean that fuel is available but we cannont pay for it; the electric grid collapses; or repairs to the natural gas pipeline network cannot be maintained. Monetary collapse may mean all energy carriers are not traded except under barter type arrangements.

7. Contexts & Implications

7.1 The De-Growth Delusion

Over the decades as the evidence mounted that infinite growth was not possible in a finite world, the question was asked if we could live sustainably by reducing growth. It has been noted since Epicuris and the Buddah, and buttressed by modern studies that beyond a certain level of wealth, marginal increases do not make us more content. Why not live with less and share our surplus with the destitute? In general we don't do this, not by a long shot. Status anxiety, the sunk cost effect, personal/kin/tribal preferences and more ensure that the issue is far more complex in actuality.

More recently a number of authors addressed the issue of peak oil and recognised that economies must contract as oil availability declines[62,63]. Would it not be wiser to do a planned *de-growth* or *powerdown* so as to avoid the worst economic shocks and ease the transition by moving in the direction in which the wind is blowing anyway?

These studies and arguments generally leave the energy-economy relationship unspecified, or assume the decline curve assumption. They have made suggestions including changing the debt based money system; pricing environmental externalities; reducing the working day; consuming less, controling population, increasing the lifetime of goods. In the context of the current financial crisis they often include some control on financial speculation.

So let us ask the question, could we do a managed de-growth and what might it imply? In the dynamical systems perspective could we find a stable or semi-stable path to a steady-state economy with much lower energy and resource flow throughput? The following reasons, in no particular order, suggest it is a vain hope:

We Can Turn on a Pin
We are close to, and may have passed the peak of global oil production, we are in denial with no preparation, we have little time, torturous decision making structures, multiple competing interests, and live in a hyper-complex environment. We are locked into many welfare supporting structures. We are about to be hit by a full spectrum systemic crisis (in food security, mass unemployment, monetary system, global financial system, health, education, industry, security, public works, IT and communications…..). As this is far beyond what any government or civil society has ever anticipated and planned for, how can we be ready for it in the next year, maybe two?

Missing the Train
Once collapse begins we will lose the tools and infrastructure we would need to manage

the collapse.

The Myth of Potency
We may look at our complex civilisation and say *'We did this, and if we did this, we surely can do almost anything!*' However we did not do this intentionally, with a plan that was executed, it is a self-organised system. The complexity is beyond our comprehension or ability to manage.

Control
Governments do not control their own economies, neither does civil society. The corporate or financial sectors do not control the economies within which they operate. That they can destroy the economy should not be taken as evidence that they can control it (this author cannot drive a car, though he is quite confident he could crash one).

Lock-in
We are trapped in the current system. It has locked us into hyper-complex economic and social processes that are increasing our vulnerability, but which we are unable to alter without risking a collapse in those same welfare supporting structures. For example, our current just-in-time food system and agricultural practices are hugely risky. As the current economic crisis tightens we are driving further efficiencies and economies of scale, particularly in food production, as deflation drives costs down. This helps maintain social peace, and supports debt servicing, which supports our battered banks, whose health must be preserved, or the bond market might not show up to a government auction. Which all makes it very hard to do major surgery on our food production. There are countless examples of lock-in.

Uncertainty and Dynamical Chaos
Collapse breaks up the familiar stability of the processes we take for granted, and which provide the frameworks to make judgements about the consequences of actions. The release of stored energy within the complexity of the global economy by collapse, will make the prediction required for large scale control impossible to maintain.

Competing interests
Nationally and internationally we all hold different assets and liabilities (some carry deficits, some carry surpluses, some oil, some land, some have armies, and some think it's all a conspiracy). From a game theoretic view, there is no stable solution that would give a fair distribution of risks and reward for everyone. Initiating a managed withdrawal, and instituting a new one, irrespective of complexity, would probably trigger a stampede.

Financial Feedback
We saw that one of our positive feedback processes was driven by market recognition of the problem. The more we do to prepare the more we confirm the hypothesis, which itself drives the collapse.

Stop Consuming/ Green Consuming
If we consume less of the trivial, we may reduce energy flows, but this will lead to rising

unemployment and reduced discretionary income. We have also noted that the trivial cross-subsidises the critical. So as the critical begins to decay, it will hamper our ability to manage the transition. We could mandate the redeployment of workers into new ‘green’ businesses (an upfront cost-where are the credit lines?), with limited ramp-up rates. This would of course cost more energy, just as energy supplies are declining.

Monetary Magic
It is relatively easy to concieve and introduce a local non-debt based money system. It is quite another to unweave the current system from the operational fabric, while keeping the operational fabric viable continuously so that people can be fed, employment maintained, the trade system operational etc.; never mind doing it in a way that lets creditors, debtors, pension funds, and petro-dollars find a happy accomodation.

Complementary currencies may be introduced, which may provide some support. It must be born in mind that the great models of such currencies particularly those introduced during the Great Depression, were built upon local economies that already had a significant local base of indigenous non-discretionary production. In our locally hollowed out economies, whose value and skill base is dependent upon globalised trade, little production is available to be traded whatever currencies are used.

7.2 Implications for Climate Change

The IPCC uses a number of scenarios based upon what they consider to be future growth trends to project future emissions of greenhouse gasses. These scenario families, A1, A2, B1 for example, all assume access to fossil fuels would not be a limiting factor on future emissions. A number of studies have recognised that the implications of peak oil, gas, and even coal on future emissions of greenhouse gas could alter the IPCC assumptions.

Kjell Aleklett has described the UN's future scenarios as “pure fantasy”[64]. However, researchers have pointed out that even with peak oil, gas and coal emissions could still rise beyond what is regarded as safe. Kharecha and Hansen argue that without corrective measures atmospheric CO_2 concentrations could still raise to 600ppm, while the safe level is 350ppm, this rise was mainly due to coal[65]. Brecha also included oil, gas and coal, but modeled their availability in a more careful manner. He concluded that world energy production would peak between 2030 and 2050, with CO_2 concentrations stabilizing between 480 and 580ppm[66]. Nel and Cooper, referred to earlier generated production profiles for the three fossil fuels, and find a peak occurring about 2025, and maximum concentrations of CO_2 are 550ppm.

This report takes serious issue with all these studies. Principally, it is because they rely upon the decline curve assumption. They all effectively assume no or little coupling between declining energy flows through the global economy and the general operability of the economy. Included within this assumption is that there is no or weak coupling between different forms of fossil fuels. What the decline curve assumption gives to researchers are data sets of future emissions to put into climate models, but the decline curve assumption we have argued is wrong. It may be impossible to generate emissions data sets from a collapsing global economy.

Irrespective of any decisions by governments, greenhouse gas emissions from fossil fuel burning and cement manufacture are likely to undergo a significant collapse, as production and the operational fabric falls apart. In addition, the most carbon intensive sources of oil such as the tar sands are likely to become unviable as demand collapses and purchasing power of customers drop way below the marginal cost of production, and energy infrastructure is lost to entropic decay.

Land based emissions may see various countervailing trends. A collapse in world trade may see emissions from fertilizers drop, and much reduced pressure on forests for the material resources for the global economy. However, the growth in demand for bio-fuels and food would increase greatly, however the ability to ramp up this trade would be compromised by the failing operational fabric. What is more likely is a localised destruction of forests, and the tilling of pasture as people reacted to their own immediate shortages.

However, even with a collapse in emissions, lags in the climate system will ensure temperatures will continue to rise. Nor are we sure how close we are to crossing strong feedbacks in the climate system that could continue to drive total greenhouse gas emissions upward even while anthropogenic emissions dropped. One way or another we are likely to experience the growing effects of climate change on our lives.

Few if any studies of the economic impact of climate change assume we will be very much poorer in the future. The physical effects of climate change in the form of flooding or food production are expected to amplify the effects of an energy induced systemic collapse. Being much poorer will mean that the relative costs of adaption or recovery from climate induced shocks and stresses will escalate beyond our ability to pay. There may not be the resources to repair homes and infrastructure damaged by flooding, say, or re-settling residents. Furthermore the support of insurance markets (dependent upon the financial markets) will not be there to help us manage those risks.

Many of the policy instruments being discussed to tackle climate change are likely to fall apart even if instituted. Carbon caps and prices, the adaption fund, and technology transfer are all likely to flounder as economies, and markets collapse and the most short-term concerns are given even more prominence than today.

7.3 From the Financial to the Civilisational Crisis

The processes described in this report have only touched on the current financial and economic stresses across the world. If the optimism of some commentators that the recession has bottomed-out is confirmed, then we can expect growth in energy demand to begin soon. Following on from that we can expect a return to rising energy and food prices and a resumption of an even more severe recession.

What seems more likely is that the risk of soverign defaults will rise, as will growing volatility in the currency markets, and growing stress in government finances. Even without energy constraints we could see further drops in energy demand and prices as economies fall deeper into recession.

Growing credit constraints, declining productivity and further stress on public finances in many developed countries will hamper our ability to invest in renewable energy and other mitigating measures. Energy companies will find it harder to finance new production and maintain existing infrastructure as costs rise, prices and exchange rates remain volatile, and credit is expensive.

Meanwhile discussion and actions regarding peak oil are likely to move participants along the cuve of the final frenzy, which may begin to drive up the price of certain land and other real assets, and constrict credit further. There may be a rush to renewable energy infrastructure but its expansion will be limited by the state of the global economy and its limited ramp-up rates.

Either the economy begins to grow again, or economies with deflation or stagflation may find that their already low energy demand is hit further declines in production and higher energy/ food prices.

All of this provides the uncertain backdrop to the main theme, that the defining dynamic of our civilisation is the withdrawal of energy from a complex and integrated system adapted only to growing. And when we look back at the history of this time, the anxious fretting about euro-zone defaults, Chinese bubbles, and US deficits may well be seen as the thinnest of froth on a vast bubble bursting.

8. Conclusion

This report has laid out why we may be entering a near-term period of profound and abrupt change. The temptation might be to ignore it, or to carry it awhile until some august personage assures and persuades us that such concerns are quite without foundation and that the experts are indeed in control. Or we might wonder why we should stand out from our social group, initiate some actions, and risk the ridicule of those whose opinion we value. There is an abundance of psychological literature exploring the diverse ways in which we as individuals and groups maintain cohesion and keep the frightening and uncomfortable at bay[67]. Yet in acknowledging our fears and anxieties we are being true to ourselves. Fear evolved to warn us that action must be taken, and for many, action is the means by which we surmount our fears.

There is much we can do. Not to prevent or defer a collapse, rather to prepare to some degree ourselves and communities for some of its impacts. For example, despite the limitations of lock-in, planning for food insecurity is something in which everyone, from children to governments, has a role to play. Other jobs, from monetary system collapse and reserve communication systems planning are more specialised, but in which we all have an interest in understanding. And the reality is that this is the most important, meaningful, and potentially liberating work that we have ever had to do, and it must be done right now. Our current employment status is immaterial, employed or unemployed, we can begin from where we are.

Part of the preparation is in the acknowledgement of our predicament, that we recognise it when we see it. That as systems fail, we spend our efforts on positive change and adaption, rather than finding scapegoats or letting anger and loss drive the cannibalisation of our social fabric. Putting a wise step forward increases the chance that the next step will be wise; putting the foolish foot forward increases the chance that the next step will be foolish, or even initiates an evolving spiral of social breakdown. By acknowledging the potential stresses and the demons in our nature, we can begin to protect ourselves from our own worst enemy.

What does seem clear is that those who, through fear or avarice, try and insulate themselves from the impacts by disproportionate hoarding or land grabs for example, will imperil not only their community's security and wellbeing, but their own. This will be a time when we really will need the cooperation and support of others, and where the idea of autonomous security through wealth and the market system will be revealed as a transient illusion.

What is important is wisdom and speed. Our current political and social processes have not evolved to take quick and decisive action, in developed democracies, they have evolved to manage competing interests for the spoils of growth, and the maintenance of general stability. Constructive action must be taken at the limits of the possible, and this will require individual courage and the support of those who recognise the precarious *status quo*.

Finally, this is a personal story. It will no doubt be a difficult time, and horrific for some. We are likely to see a major increase in mortality. But it will also be a time when many people will find a liberation in new social and personal roles; in the new friends and connections they make; in the skills and pastimes acquired; in their ability to contribute to other's welfare; in their freedom from the subtle corrosion of positional consumption; and in the pleasures gained from contributing to the most crucial of shared endeavours.

Appendix

I. Peak When? Risk Managment & Diverse Estimates.

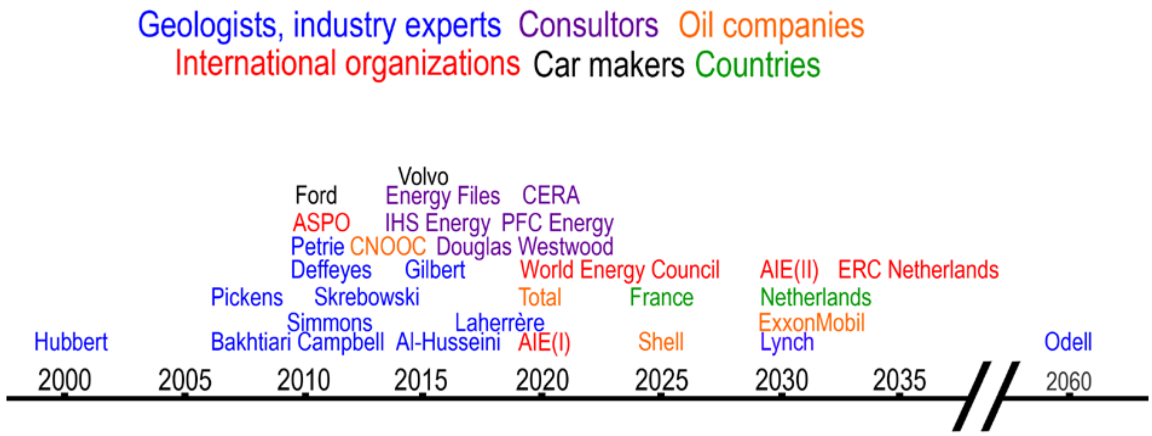
The issue of timing of peak oil is naturally uncertain. A variety of assessment methodologies and secretive data ensure there is room for debate. Nor should we assume that cultural assumptions and the stakes involved play no part in estimates. Some argue we have already passed a global peak, other voices such as Cambridge Energy Research Associates (CERA) say production will rise to 2030 then plateau. How than to we make sound policy judgments, and not just support the analysts that support our intuitions or prejudices?

A more appropriate conceptual model is risk management, which can mandate responses even allowing for differences in points of view. Risk management is in this case the application of conceptual and analytic tools to manage current capital expenditure (economic, human, natural) to maximise future benefit and minimise costs. Risk itself can be decomposed into Hazard, Exposure, and Vulnerability. Hazards are not disasters or calamities in themselves (a hurricane on a desert island does not trigger a disaster if there is no property or population), it is a probability distribution of an event happening. Exposure is a measure of that which is exposed to the hazard such as people and property. Vulnerability is defined as the condition resulting from physical, social, economic, and environmental factors which increases the susceptibility of a community to a hazard. Risk is then the expectation value of losses that would be caused by a hazard:

Risk= function (hazard, exposure, vulnerability) = function (hazard, exposure, 1/ resilience)

Resilience is a measure of our ability to adapt to, and recover from exposure to a hazard, and is thus the positive mirror of vulnerability. Opportunity can be put in a similar structure (positive risks)

We can give an example applied to peak oil. Figure:A shows a collection of different estimates regarding the timing of peak oil put together by the Association for the Study of Peak



Oil (ASPO), the data is rather dated, here we wish to demonstrate the method.

Figure: A1 A series of estimates for the peaking of global oil production compiled by ASPO from various sources from http://www.peakoil.net/files/DossierASPO8_0.pdf.

Rather than pick our favorite estimates (and few people have the knowledge to compare and contrast between them), we can write a probability distribution combining all the above estimates by assuming all are equally likely to be right, and that there is a 95% probability that one of them is right. This is shown below in figure:B. This is our hazard in the risk management model. Our exposure is vast as we have argued in this paper. The combination is the risk which is very high, and growing each year.

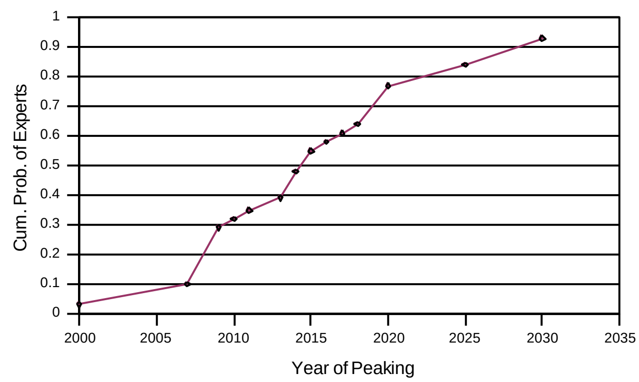


Figure: A2 The cumulative probability, based upon all expert opinion, that we will have passed a peak in global oil production at any year. Derived from figure:A1.

The argument is therefore because there is a huge risk, it must be managed. It is not an either/or question. Not to manage it becomes not a failure of one's choice of expert, but a failure to risk manage, and is thus negligent. Our framing policy is then (because we cannot change the exposure or hazard meaningfully) to develop resilience, or reduce vulnerability.

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