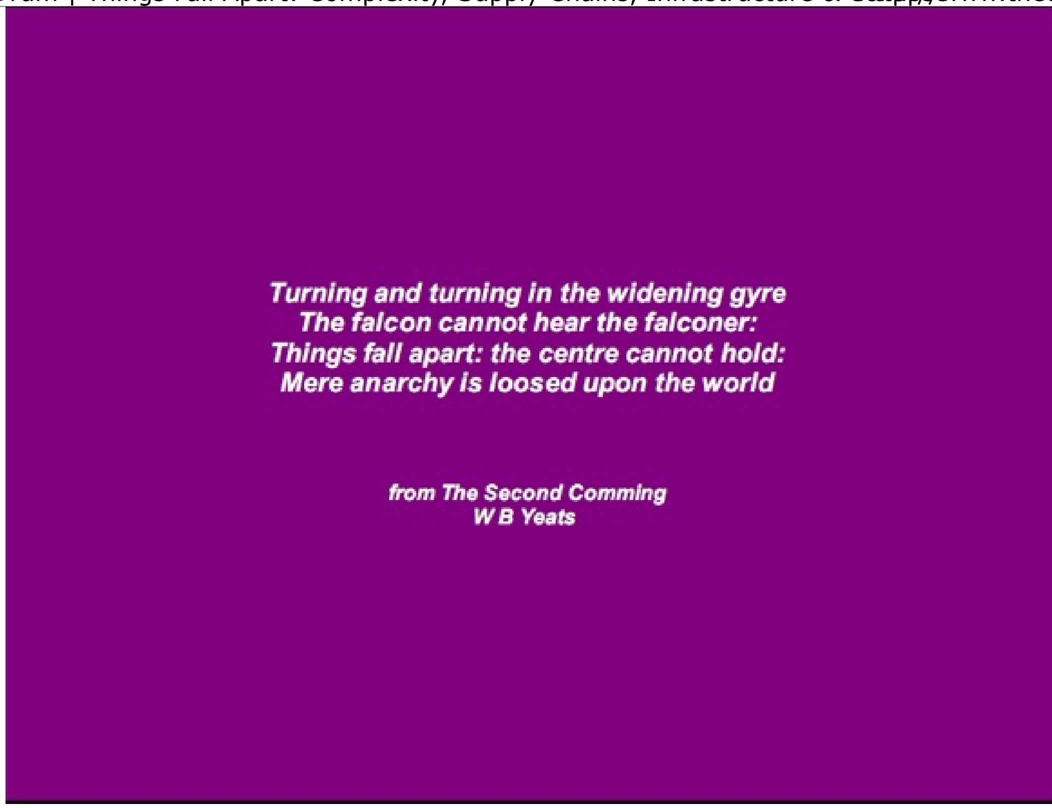
The Oil Drum
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Things Fall Apart: Complexity, Supply Chains, Infrastructure & Collapse

Posted by Rembrandt on August 4, 2009 - 10:18am
Topic: Economics/Finance
Tags: alcatraz conference, collapse, complexity, dynamics, feasta, infrastructure, supply chains [list all tags]

This is a presentation by Dr. David Korowicz from Feasta, given at the Oil Drum/ASPO Conference at Alcatraz, Italy in June 2009. It can be downloaded here: Things fall apart: Some thoughts on complexity, supply chains, infrastructure & collapse dynamics, PDF 23 slides, 1.3 MB, text of spoken presentation.

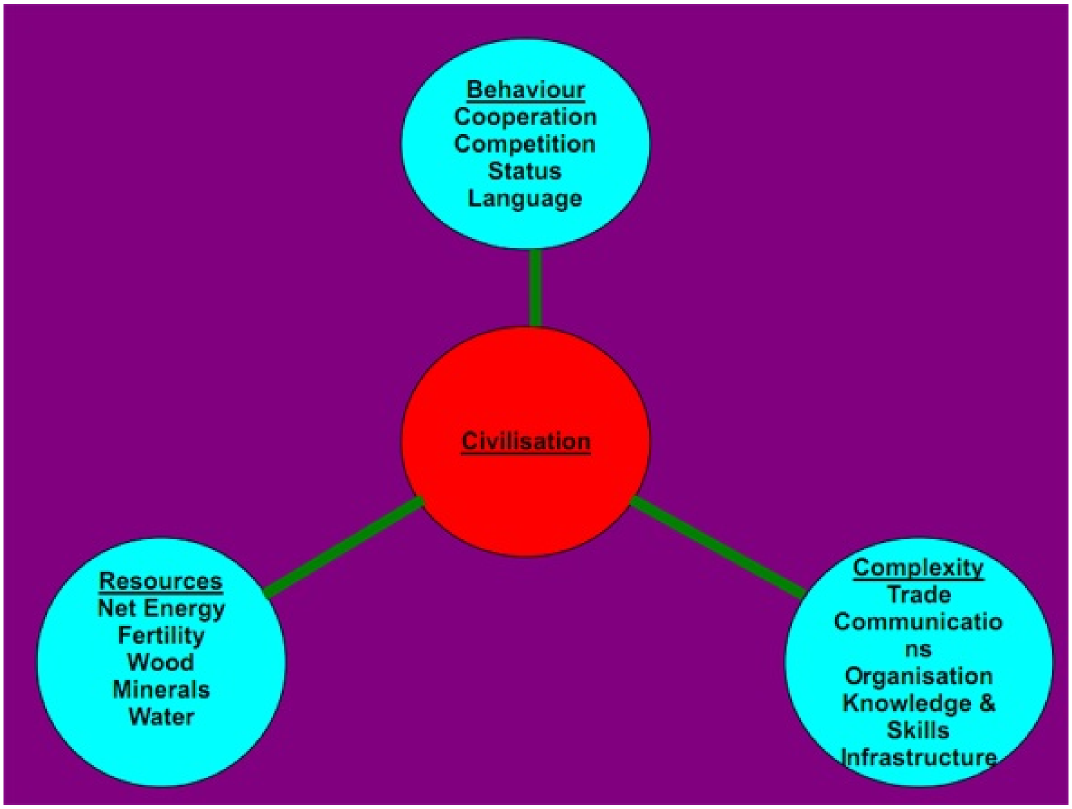


Slide 2: Poem

This poem by W.B. Yeats inspired my talk's title.

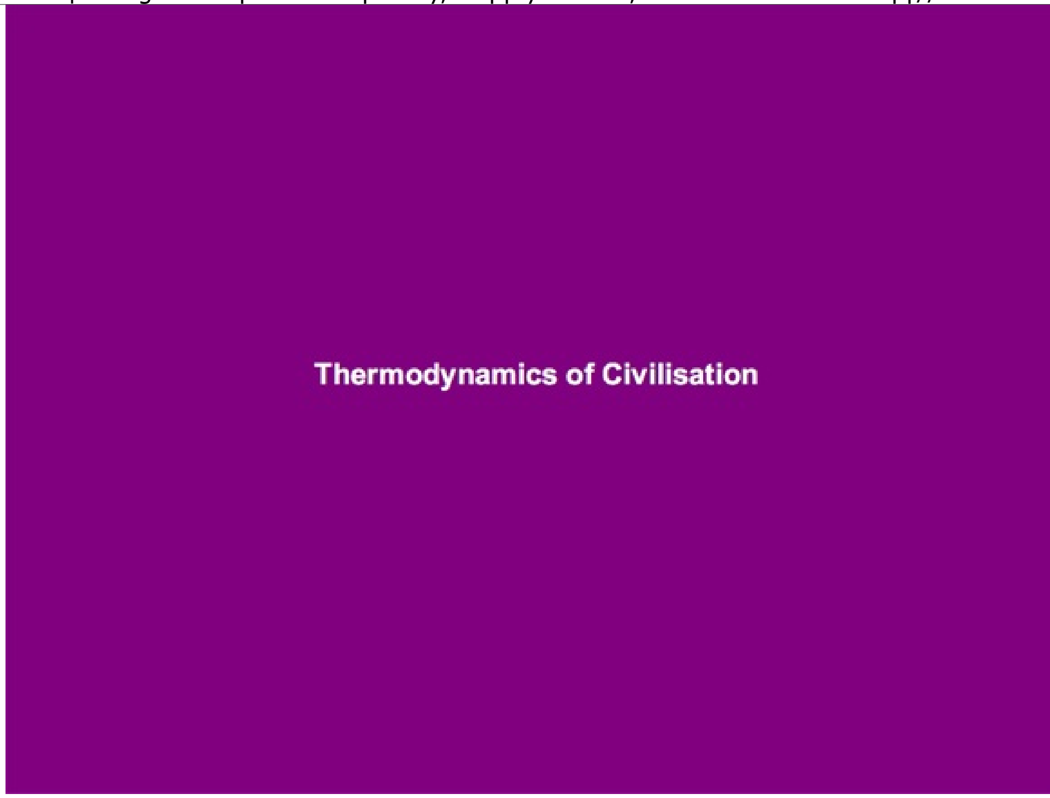
Slide 3: A 16,000 thousand year switch

Suppose I were to take your new born infant, and by some magic transport her back through 16,000 years to a cave in what is now Lascaux in south-western France. Let's swap your baby with a baby born to a Neolithic mother. There is no reason to believe that in time both children would not turn out to be well-adjusted, unremarkable members of their respective communities. Genetically they are the same. What is clearly different is the world in which they would have to make their way.



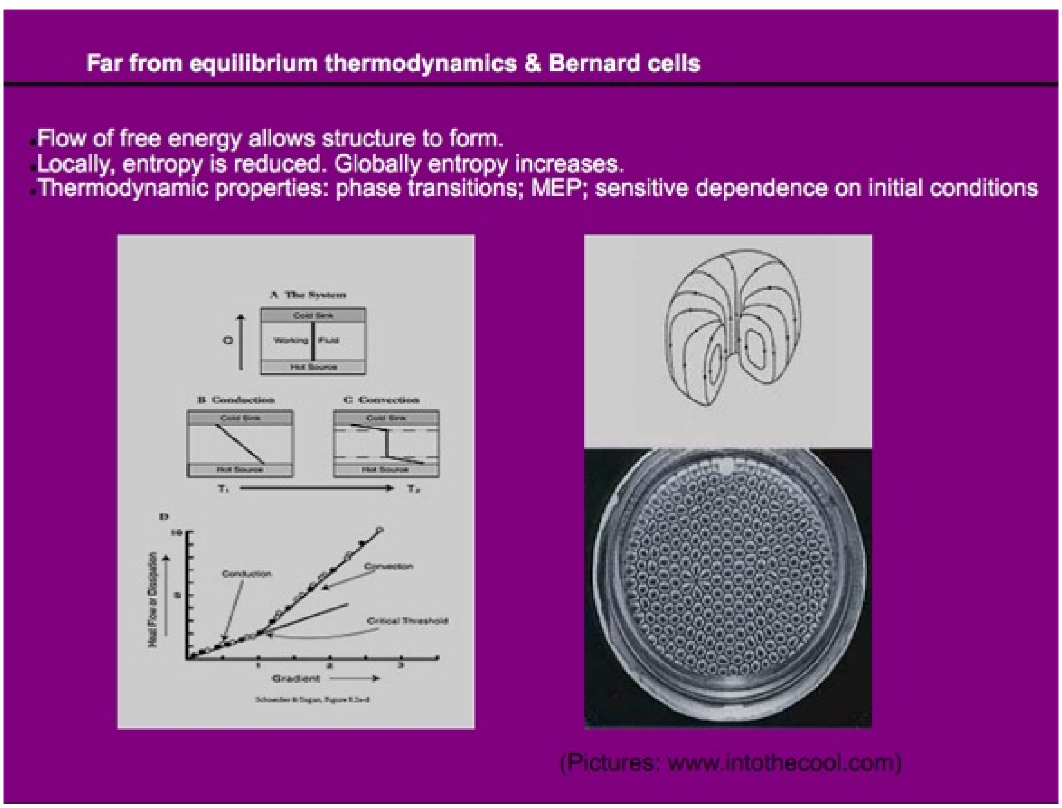
Slide 4: Triad/Civilisation

What shaped our modern world is our hunter gatherer minds, and the growth in complexity and size of human society and infrastructure facilitated by access to increasing energetic and material resources. We could say that civilisation is the emergent feature of these interactions.



Slide 5: Title page Thermodynamics of Civilisation

This lecture will focus on the complexity part, but the other elements are always close by.



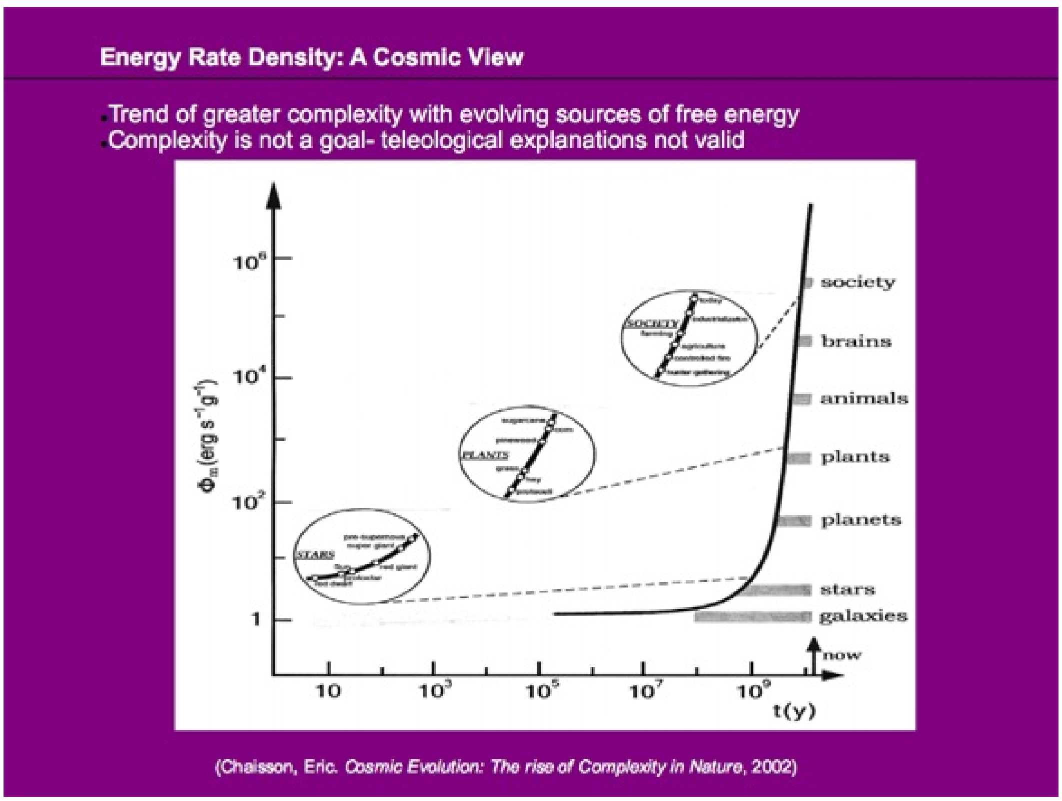
Slide 6: Far-from equilibrium thermodynamics

In the universe as a whole, entropy, or disorder is increasing. Yet life, our civilisation, the things and institutions we create are ordered. We create islands of low entropy out of the tendency to universal disorder.

To see this we can look at the simple example of a Bernard cell. The molecules in the liquid between the hot and cold plate are moving randomly in all directions. Any one part of the liquid is the same as any other part. As we increase the temperature gradient, we arrive at a point where suddenly there appears lots of convection cells. This phase transition corresponds to the emergence of lots of order and structure within the system.

While the cells themselves are low entropy, we see in the graph that the transition corresponds to a big increase in the rate at which heat is dissipated. Heat is the most disordered (high entropy) form of energy. The dissipation is into the environment outside the experiment. In general locally ordered structures enhance the flow of general disorder and so such structures are thermodynamically stable- as long as there is a continuous flow of free energy through the system. If we reduce the flow of free energy that allows us to maintain the gradient below the critical threshold, the order disappears.

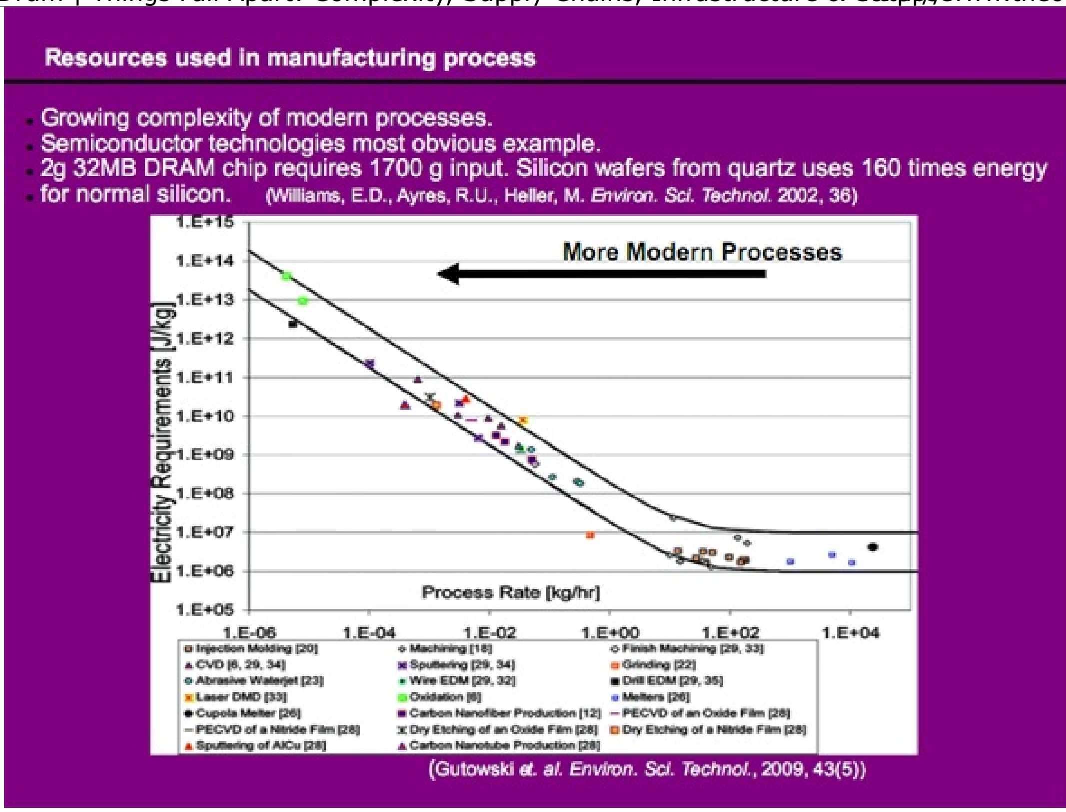
Our civilisation expresses these thermodynamic realities. Far-from-equilibrium thermodynamics gives us a way to view the consequences of what reducing the flow of free energy that is required to build and maintain our society might mean in practice.



Slide 7: Energy Rate Density

Eric Chaisson has, using simple thermodynamic relations, associated energy per unit time per unit mass with complexity. In this graph he has taken the overview of our 'cosmic history' as one of increasing complexity.

Complexity is not a goal of life, merely the result of increasing free energy stores being accessible. Complex humans share the universe with far far more less complex things.



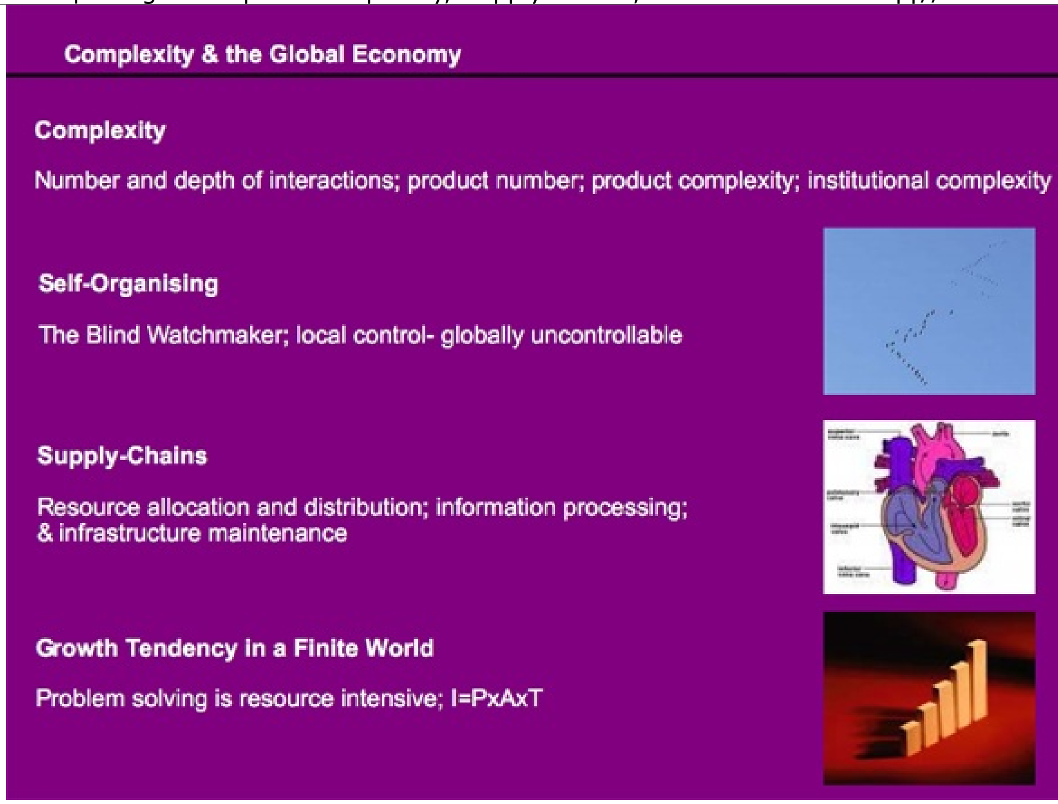
Slide 8: Resources used in Manufacturing Processes.

It is a cliché, though true, to say that life has become more complex. We can see this in the products we produce. This figure shows the energy used per unit mass graphed against process rate of various manufacturing processes. The processes range from manufacturing processes used half a century ago, up to modern semi-conductor and nanotechnology manufacture. What we see is that we are making much more energy intensive products, of much smaller size. The most modern commercial processes are forming distinctive structures on the scale of only tens of atoms.

Let us take advanced semiconductors as our standard barer of complexity. They form the basis of our telecommunications and information processes, being as the basis of mobile phones and their network infrastructure; computers and their network infrastructure; they run our power grids and car electronics, medical equipment and games consoles.

A 32 MB DRAM chip would now be considered archaic, but we see that its 2grams require 1700g of resources. One expects that contemporary Very Large Scale Integration (VLSI) chips require vastly more resources.

Again, all of this reflects the thermodynamic reality that the cost for higher complexity on smaller and smaller scales must be paid in increasing energetic and material resources.



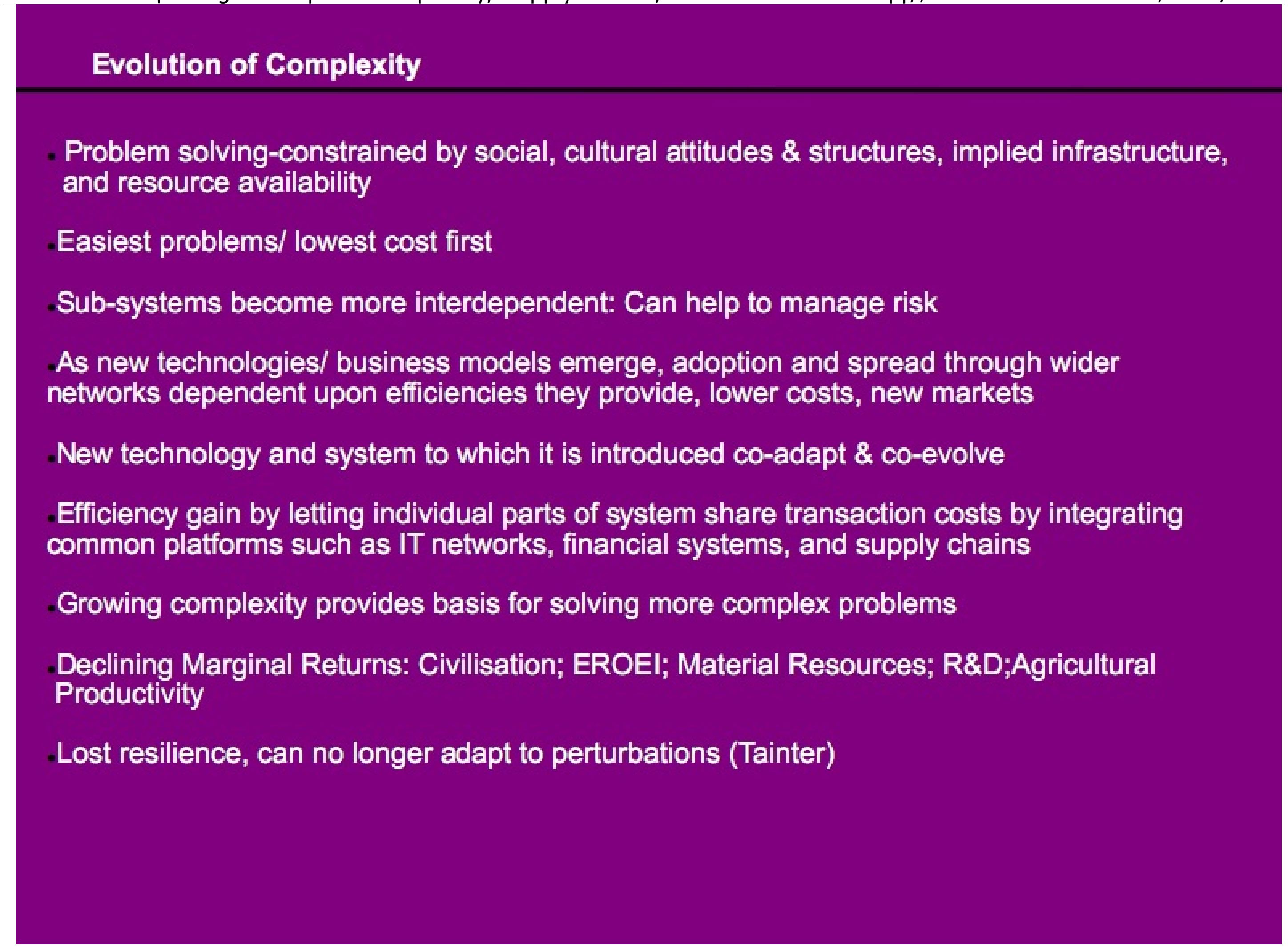
Slide 9: Complexity & the Global Economy

We can see complexity in the number and depth of interactions, numbers of products, the complexity of products, the number of institutions, and the number of specialised roles and their knowledge base.

The remarkable thing about our 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, thousands, millions, even hundreds of millions of people acting in a coherent manner. There was no master organiser, nor could there be, given the complexity of the process. From each of us playing our own small part, through the market and price system, the global economy emerges. The global economy, like the formation of birds in flight, is self-organised.

The number of products, their complexity; and the increased infrastructure required to manage elements of the increasingly complex world in which we live all require more complex supply-chains that are required to transform raw materials into products and services that criss-cross the globe. It is said that a car has about 15,000 components. If each of those components has on average 150 components (1%), and each of those 1.5 components, that makes over 3 million interactions- and we have not included staff, plants, production lines, IT and financial systems.
And as things and infrastructure wear out, that's the laws of thermodynamics working again, these supply-chains are required not just to grow the global economy but to maintain it.

In a world of growing population with increased consumption demands, the tendency to complexify will remain a huge driver as new problems and challenges arise. Well it would, were it not for the ecological limits to growth.



Slide 10: Evolution of complexity

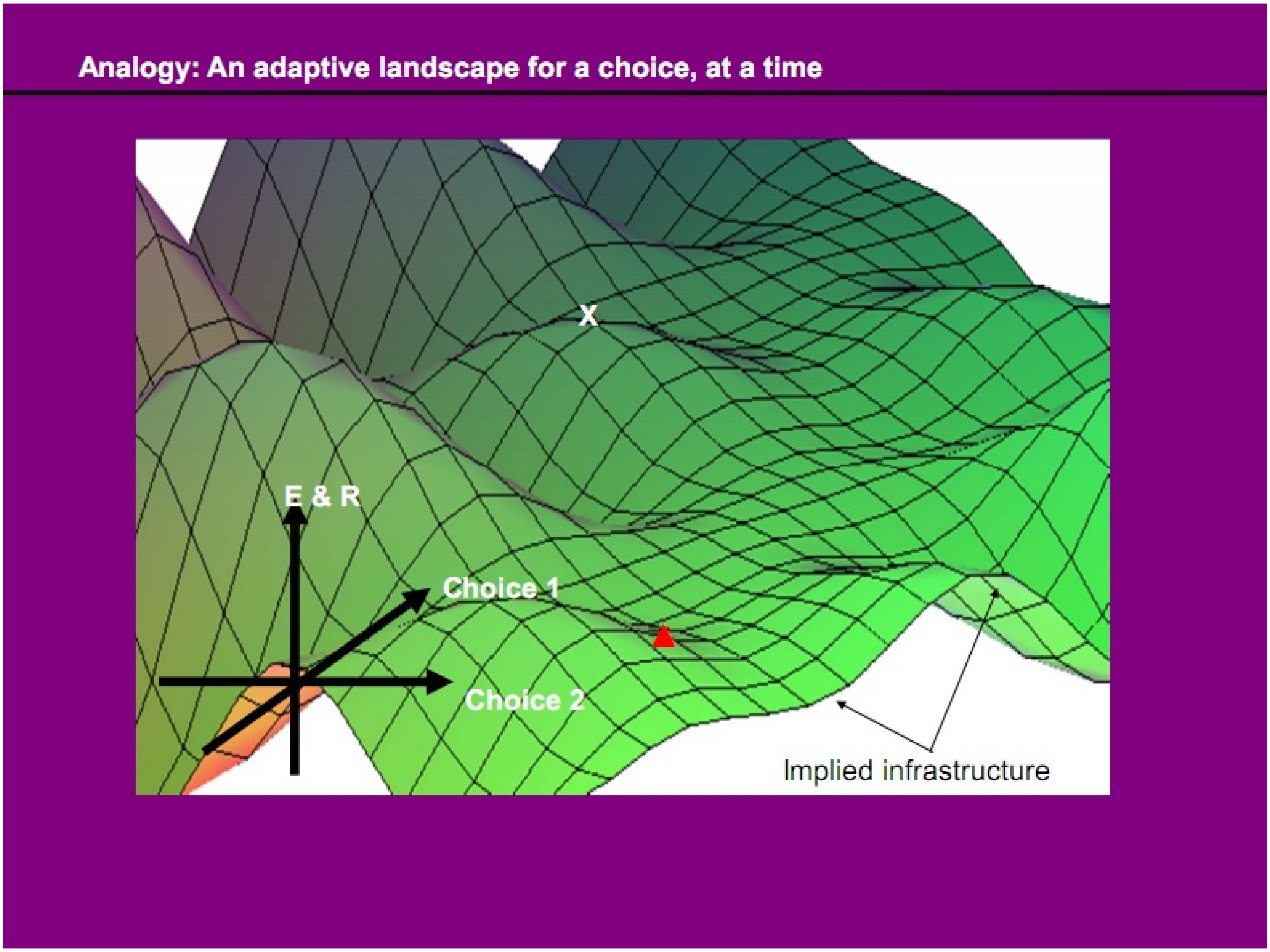
As Joseph Tainter has so well demonstrated, societies are problem solving organisations, developing the easiest solutions first. That could be simple, e.g. the need to make bread; or it could be complex, e.g. putting in a renewable energy infrastructure.

As new solutions are introduced they co-adapt and co-evolve with what is already in place. Where they provide some new good or service we like, or provide some new efficiency they spread more quickly through our society.

However we see declining marginal returns in our investments in complexity. This can be seen across the board, for energy, metals, agricultural productivity etc.

It is something that society finds hard to understand. The more complex human, institutional, and infrastructural resources we throw at a problem, the more confirmed we are in our potency as problem solvers. But consider the cutting edge of physics in 1897, the discovery of the electron by J.J. Thompson. It was performed on a laboratory bench, and would have required the services of a master glass blower and a couple of other crafts people. Now consider the Large Hadron Collider, the cutting edge of modern physics which requires over 20 km of tunnels under the French-Swiss border; 72 twenty ton magnets, and thousands of highly trained direct staff- to find (possibly) another particle, the Higgs boson.

We see a similar story in drug discovery. Alexander Flemming discovered penicillin in the 1920's for a cost in the order of tens of thousands of euros, with a huge return to human welfare. Now we spend hundreds of millions on making minor improvements to drugs that have minimal benefits for humanity.



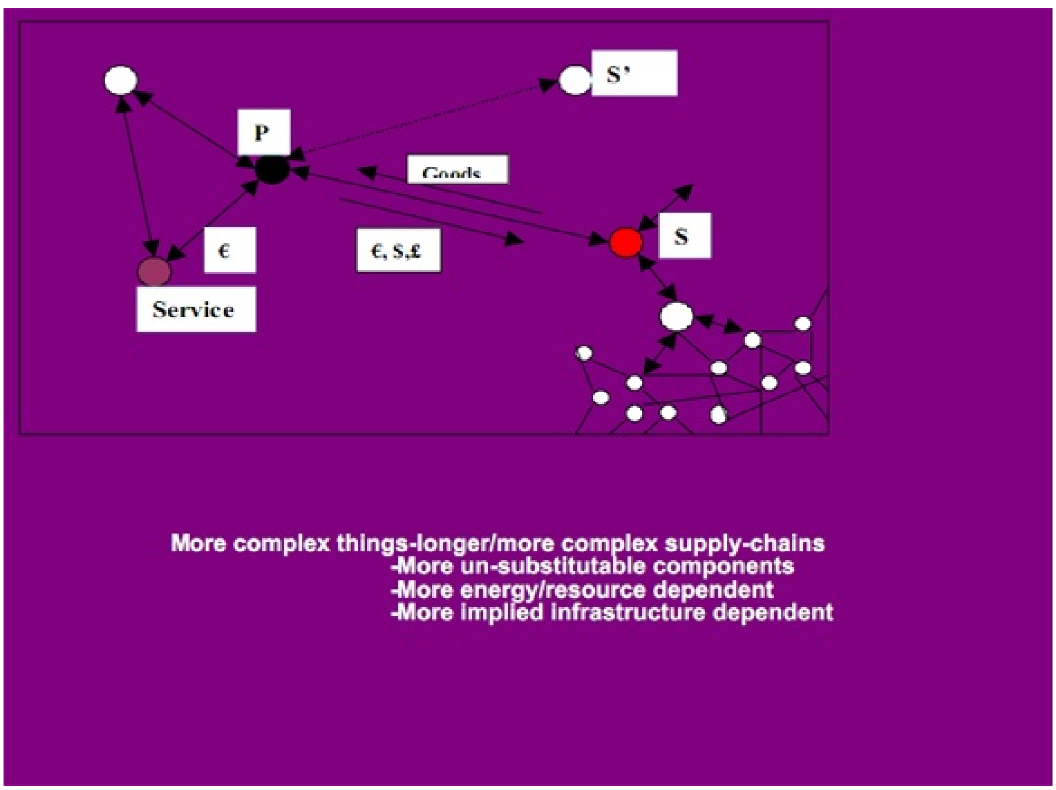
Slide 11: Analogy: An adaptive landscape...

We can look at an analogy of these processes. This figure shows us at a moment, represented by the red triangle, faced with choices in the x-y plane. The problem, say putting in renewable energy infrastructure, has an energy & resource cost represented by the height of the mountain, represented by the cross here.

What we tend to concentrate upon is this cost. However we must also consider the ground beneath our feet-this is the implied infrastructure which includes all those things we take for granted but are essential to the project's completion. These might include the availability of a financial market; that supply-chains work; that contracts can be enforced; that transport systems work, really the list is endless. In total, our implied infrastructure is the accumulation of all the complex organisation and infrastructure up to this point in time, throughout global society, without which, the project cannot succeed.

While most concentrate upon the trip to the summit, the real problem is that the ground is about to crumble beneath our feet.

Slide 12: Supply-Chains and infrastructure title page



Slide 13: Supply-Chains

Let's zoom in on a little piece of a supply-chain and see the essential components. One of the defining features is that we can change suppliers for economic or other reasons, we can substitute S for S'. This means we can loose suppliers in a supply-chain, and the market system allows us to find new ones easily. This can allow us to manage risk. Indeed the system is so efficient that many companies hold virtually no stock and can partake of the efficiencies provided by just-in-time delivery.

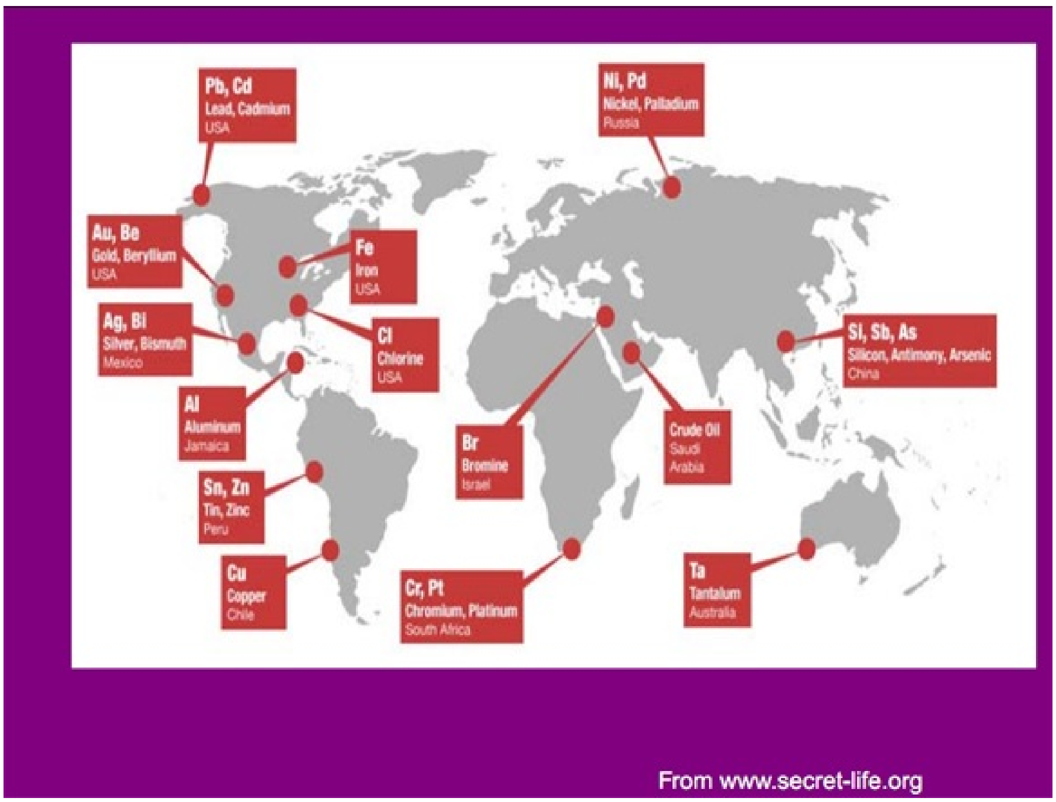
If we zoom out and look over the whole supply-chain networks we see that some nodes are essential to the functioning of the whole. Virtually all financial transactions are mediated by banks. If there were a systemic collapse in the banking system, the supply-chain would collapse also as there is no direct substitute available. We saw such a shudder in the system in late 2008 after Lehman Brothers collapsed. Banks would not issue the letters of credit required for international trade as they did not trust counter-party banks. One reason for the 90% drop in the Baltic Dry Shipping Index was due to a temporary freezing of such financing. In the parlance of network theory, the banking system is a hub.

On the basis of our previous discussion, and intuitively it makes sense I think to say:

More complex things have longer and deeper supply-chains.

They have more substitutable components- i.e. there are very few alternative suppliers of advanced integrated circuits, compared to the number of suppliers of say, plastic moulding, or cardbord boxes.

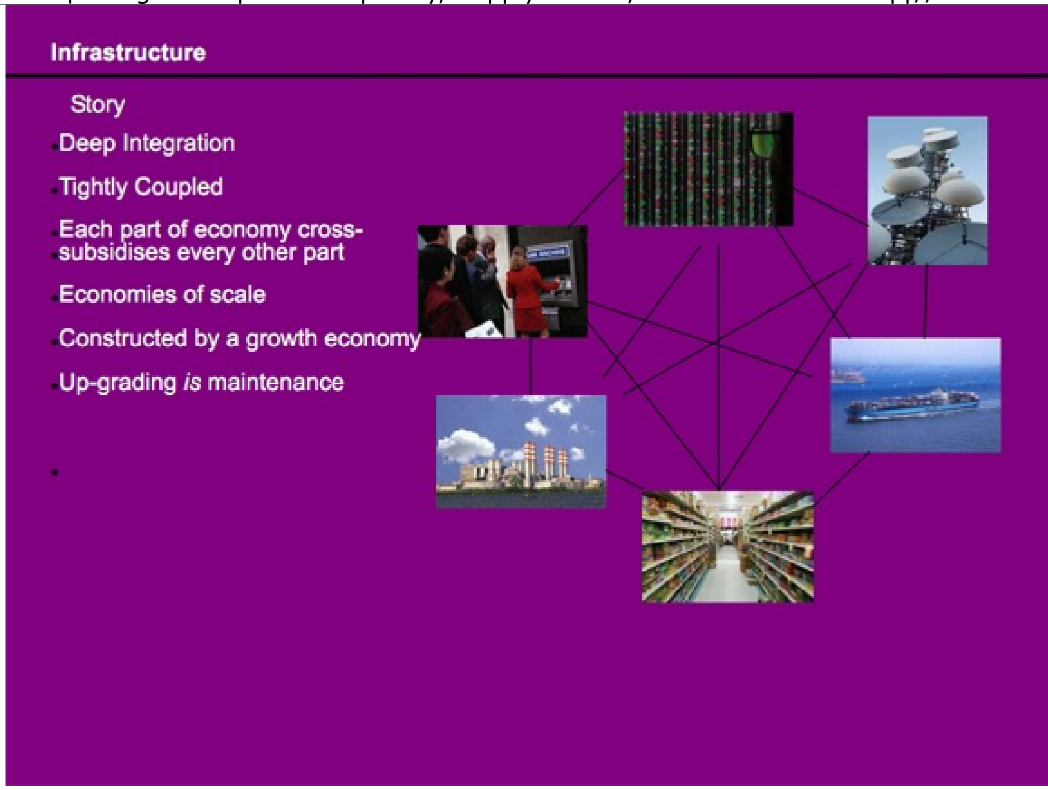
They are more resource and implied infrastructure dependent.



Slide 14: Map of the origins of base materials required for a mobile phone.

This is a nice map showing the origin of the base materials required for the manufacture of a mobile phone. For each element this is only the beginning of a long journey that will directly involve thousands of enterprises before the phone ever appears in your hand.

The implied infrastructure would be the networks of international trade and finance that facilitates this; and the availability of complex mining technologies.



Slide 15: Infrastructure

What has evolved is that we have put these most complex components and infrastructures at the heart of our most critical systems.

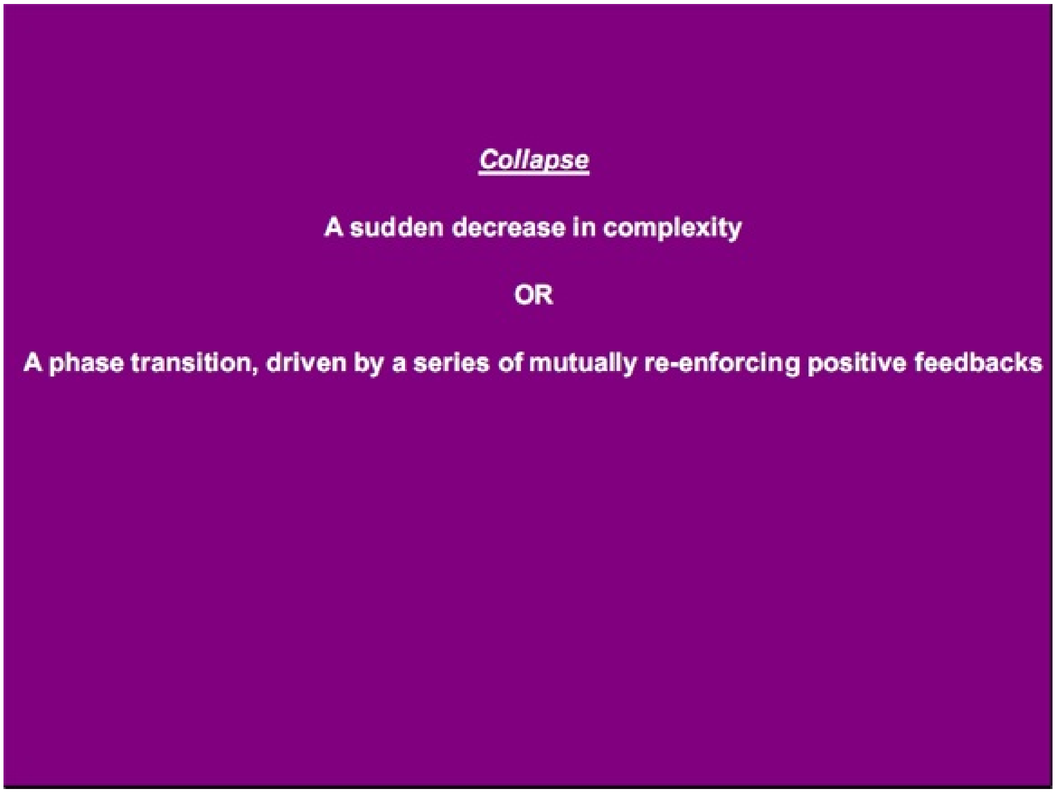
To see this process we imagine that suddenly all our IT systems, introduced over the last 15 years, stopped working. The result would not be to return us to where we were just before their introduction. Many people would become uncontactable, records would disappear, business and commerce would be in crisis. Our banking system, airline transport, stock markets would fail. The electric grid would go down. For most, work would become difficult or impossible. The little cash we had would be spent, but could not be replaced as banking systems would fail. We could not buy food and there would be reduced food within the economy. The ability of state to manage the crisis would be greatly impaired. Within days we could see major social unrest. How is it that a series of developments only 15 years old, could if suddenly removed cause such chaos, after all we were fine without it? Well we have seen some of the answers in how complex systems evolve.

The continuous functioning of our supply-chains (particularly in the case of food where just-in-time delivery and globalised sourcing means modern cities could be days away from a food crisis); financial and banking system; telecommunications; energy systems, and transport have become increasingly integrated and co-dependent. A serious failure in one could cause a cascading failure in the others.

What has helped make such systems viable is that they are being cross-subsidised throughout the whole economy. The resource required to build and maintain such complex infrastructure require that we buy games consoles, send superfluous text messages, listen to iPods, and watch YouTube.

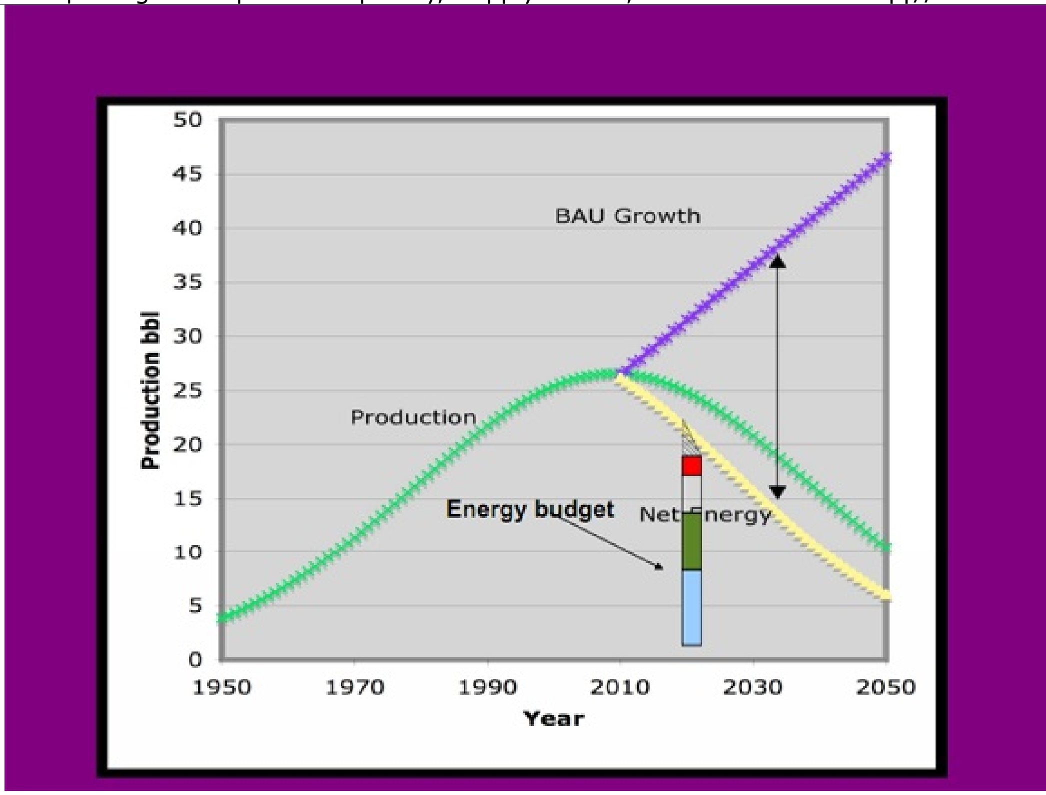
The short lifetime and rapid turnover of mobile phones, computers, servers, and network infrastructure are often presented as an upgrade to new technologies and services. This may be so, however a level of throughput is required to keep the system functional. Internally, because more complex structures will tend to fail more rapidly than less complex ones (for thermodynamic reasons, though built-in obsolescence may also play a part). Externally, because of the economies of scale require that such complex and resource intensive components must be produced continuously in quantity.

In this sense we are upgrading just to sustain the basic functionality of the systems upon which we have grown increasingly reliant.



Slide 16 Collapse

Here are a couple of definitions of collapse. It's what we'll talk about now. It is I hope clear from what we have said that complexity and energy flows are inextricably linked, and that a draw-down in such flows are most likely to lead to abrupt changes rather than continuous changes in complexity.



Slide 17: Energy decline & energy budgeted

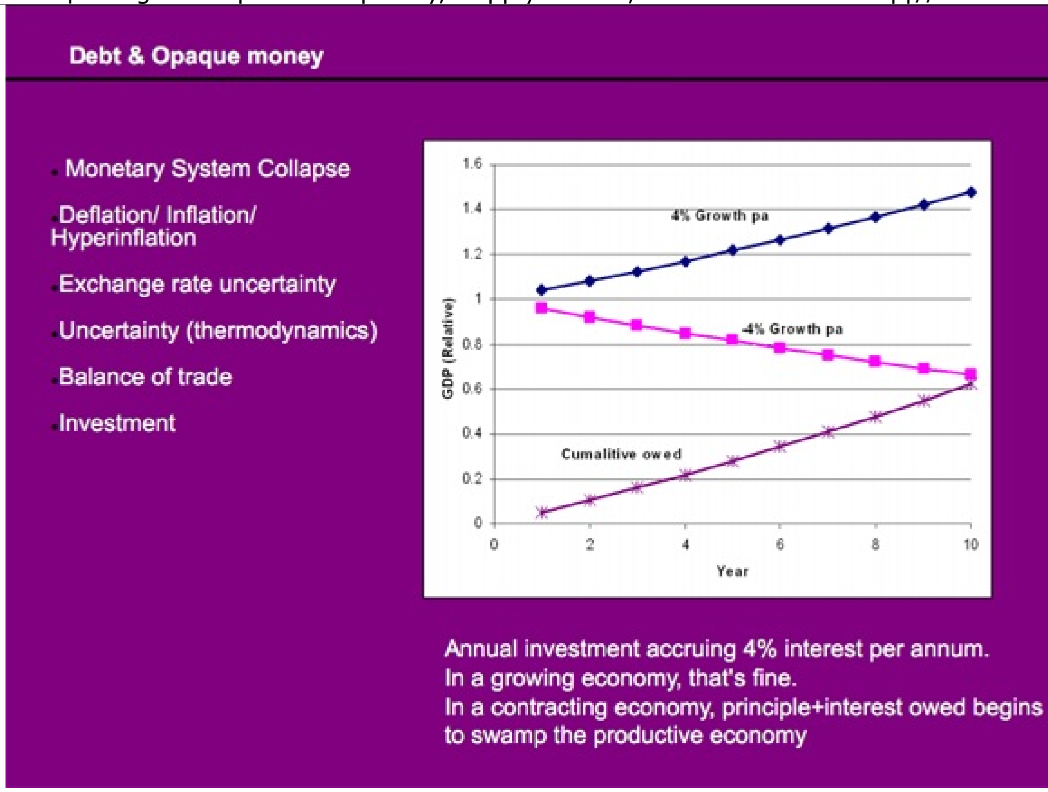
Here is a familiar Gaussian plot of oil production, we have also an account for declining EROEI, giving us the net energy available to society. Ignore the actual figures, this is just for illustrative purposes.

As we'll see in a moment talking about a money budget in such circumstances is likely to be very problematic, but we could talk of an energy budget for a country. Each of those sections represent energy spent on health-care, general administration, running businesses, schools, and investment, for example.

Well the first thing is as net energy declined, each sector would be under increasing pressure to maintain basic operations. Investing in conventional or renewable energy, which requires a large up-front energy payment for a small annual return over many years would be increasingly difficult. Firstly because there would be less investable energy. Secondly, our social discount rate is likely to increase, that is society is likely to become more short-term. When offered the choice between saving basic employment or health services now verses a slow long term energy payback, it is more likely to choose the former, especially as the stakes rise.

Both of these represent positive feedbacks on declining net energy, and thus on decreasing complexity.

However the above scenario seems far too optimistic, we are unlikely to have such well defined net energy available. There are other positive feedback that will make the decline process far more uncertain as we will now see.



Slide 18 Debt & Opaque money

If energy flows into the economy decline, growth cannot continue, this reflects thermodynamic realities and embedded dynamic constraints.

Debt is a call on future wealth. We can borrow because the principle plus interest has a better chance of being paid back in a growing economy. In a contracting economy paying back the principle will take a growing share of the total economy, never mind the interest.

The sovereign, corporate, and personal debt already accumulated, and governments' attempts to run deficit financing to bring us out of recession are likely to fail as rising energy and food prices choke off growth, and lower discretionary income make servicing debt more and more difficult. Eventually, lenders will realise they are throwing good money after bad, or rather bad after worse.

If countries cannot borrow, they cannot run deficits. If you need to import energy, food, or components for vital infrastructure or services, you will need to export something of similar value. This will mean companies integrated into parts of supply-chains may have to drop out.

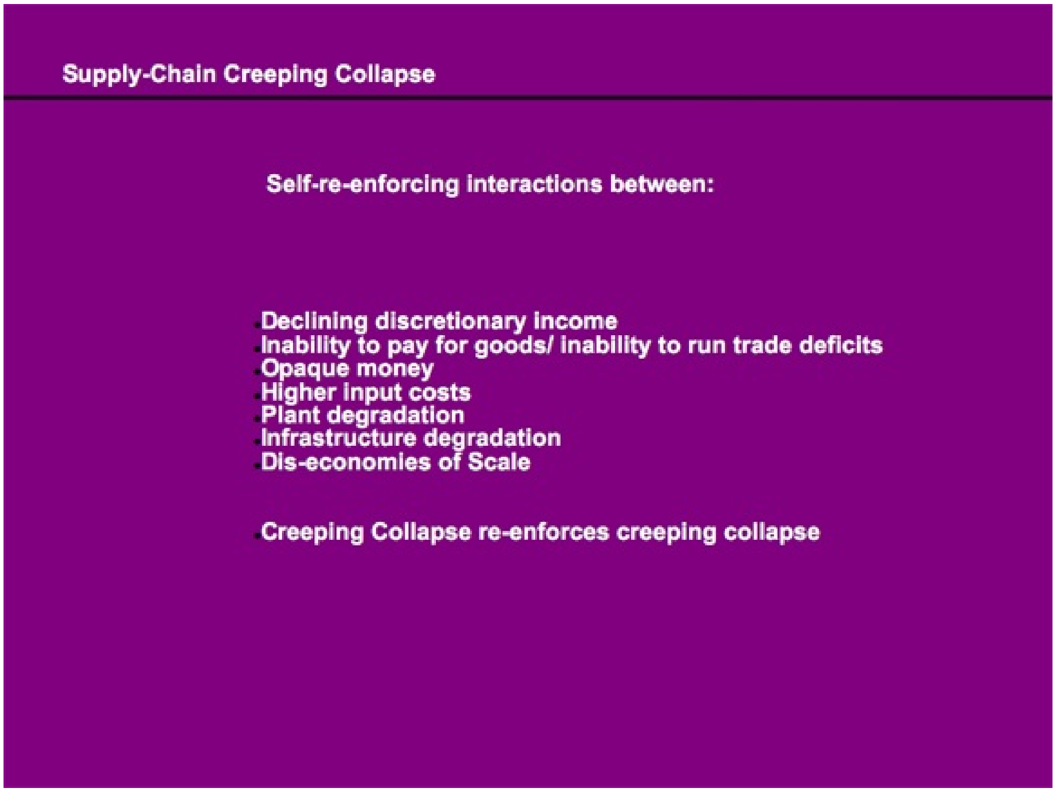
Investment will become close to impossible, even energy investments will occur in a much more risky environment.

Our debt based fiat money system is effectively primed for deflation. The pool of money in the economy is maintained by new borrowing as old debt is repaid. A drop off in new debt issuance, and a reluctance to spend (a reduction in the velocity of money), will mean reduced economic activity on top of the energy constraints. Some governments will no doubt discover the short-term benefits of printing money, only to further loose confidence in their currency.

Valuing a currency will become fraught with difficulties, the dollar will no doubt crash, but against what?

We could say that money becomes opaque. We lose confidence in its valuation in space, that's trade; and time, that's investment.

Finally, sticking with our thermodynamic theme, we might remember that entropy and information bare a close relationship, a history going back to Claude Shannon in the 1950's. The collapse of structures and institutions represents a loss of information about how our world works. The increase in uncertainty will be fundamentally stochastic rather than epistemic.



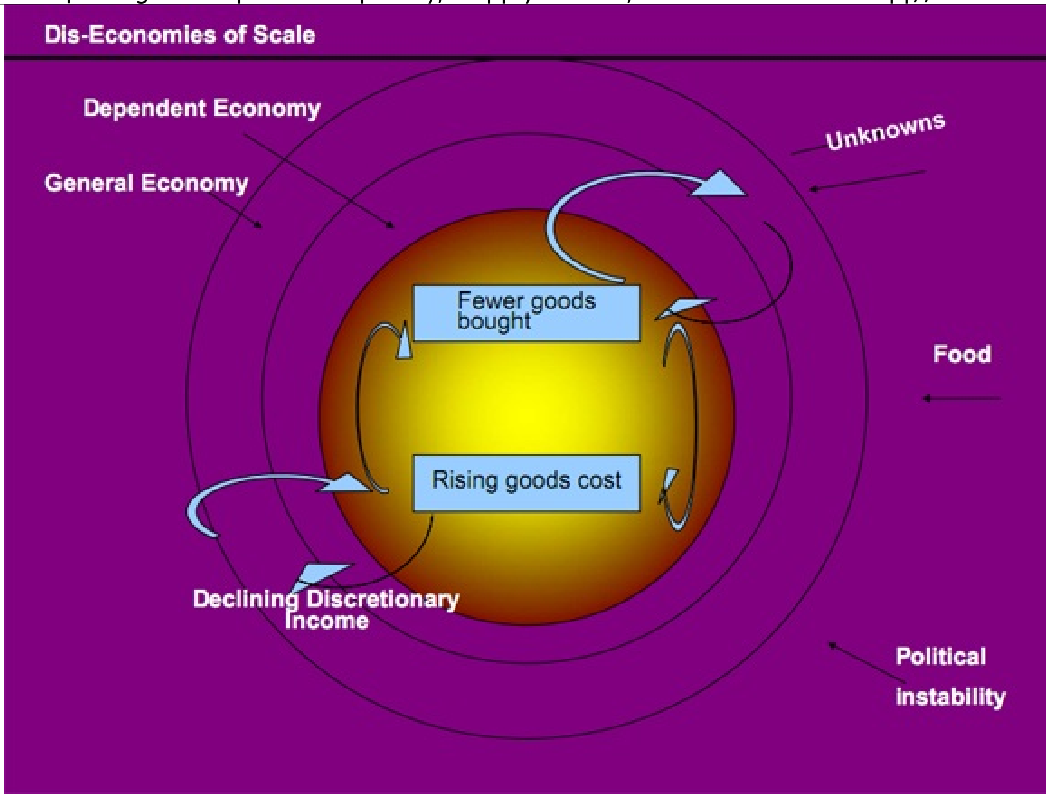
Slide 19: Supply-chain creeping collapses

What I mean by creeping collapse is the loss of individual companies and failing elements of supply-chains. This is in contrast to the failure of a hub, such as the global banking system.

In this list we see some of the constraints we mentioned before, plus some new ones. What is important is that they are interacting together and often re-enforcing each other.

The combined effect will be to reduce more and more the number of companies in the supply-chain, and make the exchanges (physical, monetary etc.) more and more difficult.

By reducing the number of substitutes in the chain, whole chains will grind to a halt for want of critical inputs, further reducing the viability of other members of the chain. In a way just like that old rhyme that encapsulates 'for want of a nail, the war was lost'.



Slide 20: Dis-economies of scale

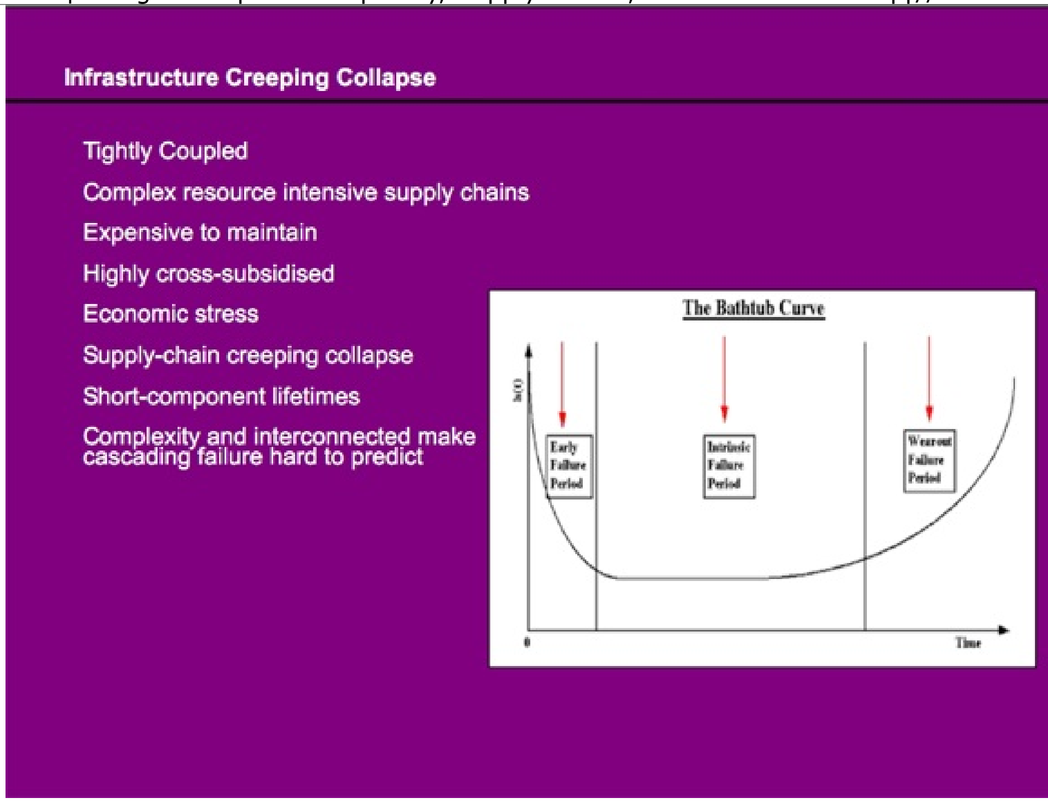
Economies of scale are the familiar benefits of a globalising world. They mean that not only can goods or services be produced cheaper, meaning greater sales volumes; but also a freed up discretionary income that can be spent on other goods and services.

In the energy/ economic environment I have been discussing, this process goes into reverse. The rising prices of goods (because of the energy cost, supply-chain and money risk reasons), and reduced discretionary income reduces the number of goods sold. This further increases the price at which the good must be sold, further reducing sales.

The rising cost of critical goods reduces discretionary income in the wider economy, reducing broader economies of scale, feeding back into the rising cost of goods. So drawing upon our earlier example, the rising cost of mobile phones which are now quite essential, mean less is spent on games consoles. This further raises the cost of advanced semi-conductor components for the phone.

We might also consider the dependent economy, by which I mean the network infrastructure for mobile phones, or the internet infrastructure for computers. As fewer users buy phones/ computers, or use them less, the cost of maintaining the network rises per user. In addition the cost of maintaining the infrastructure itself is likely to rise for the reasons already mentioned.

Thus we have yet more positive feedbacks driving our civilisation to lower and lower levels of complexity. Eventually networks, or major network functions will become unviable and effectively have to turn-off.

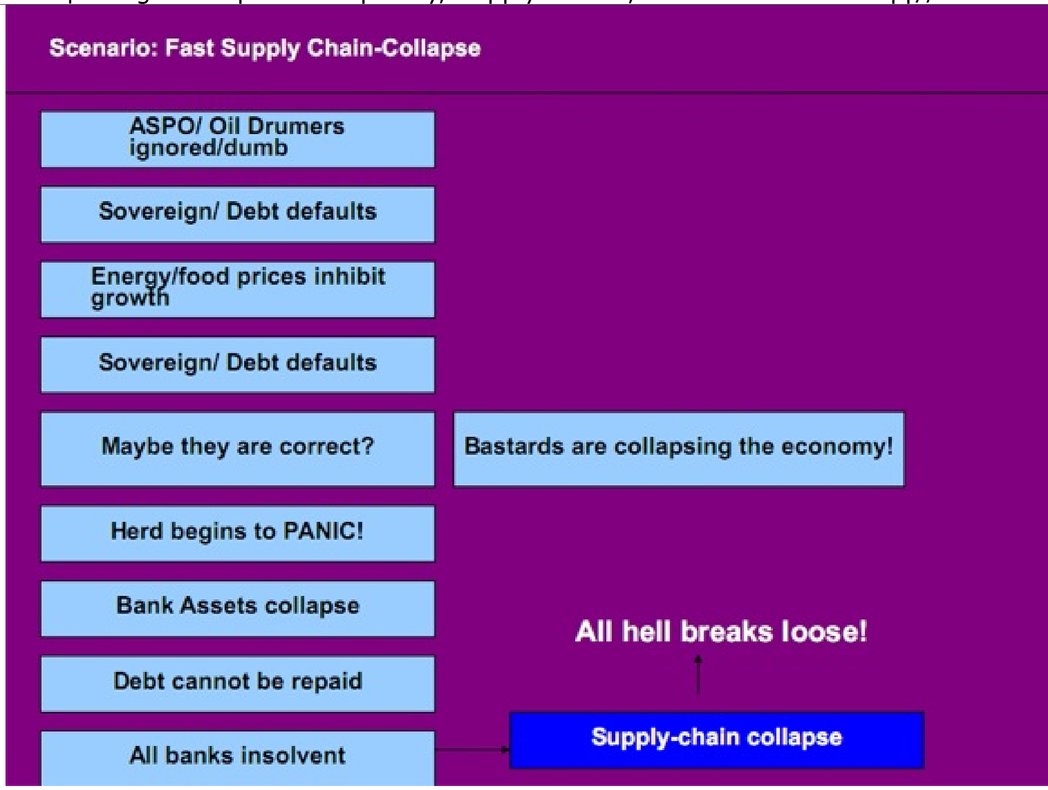


Slide 21: Infrastructure creeping collapse

We might ask how fast such a collapse occurs. We are reminded that most of our critical infrastructure has the most complex supply-chains, is the most resource intensive, is the most dependent upon cross-subsidisation, is the most expensive, and has components with short lifetimes.

The bathtub graph shown describes the probability of failure over time of many components of our infrastructure. We could consider such infrastructure to be scattered with multiple time constants. The systems functionality is set by the shortest critical time constant. That many of our key components (computers, servers, routers etc.) have lifetimes of only a few years does not look good.

In an early slide I discussed how interconnected our infrastructure is. Here a problem is that that even if one sector is maintaining its functionality, it is vulnerable to cascading failures transmitted from other sectors that cannot maintain upkeep of functions.



Slide 22: Scenario: Fast Supply-chain collapse

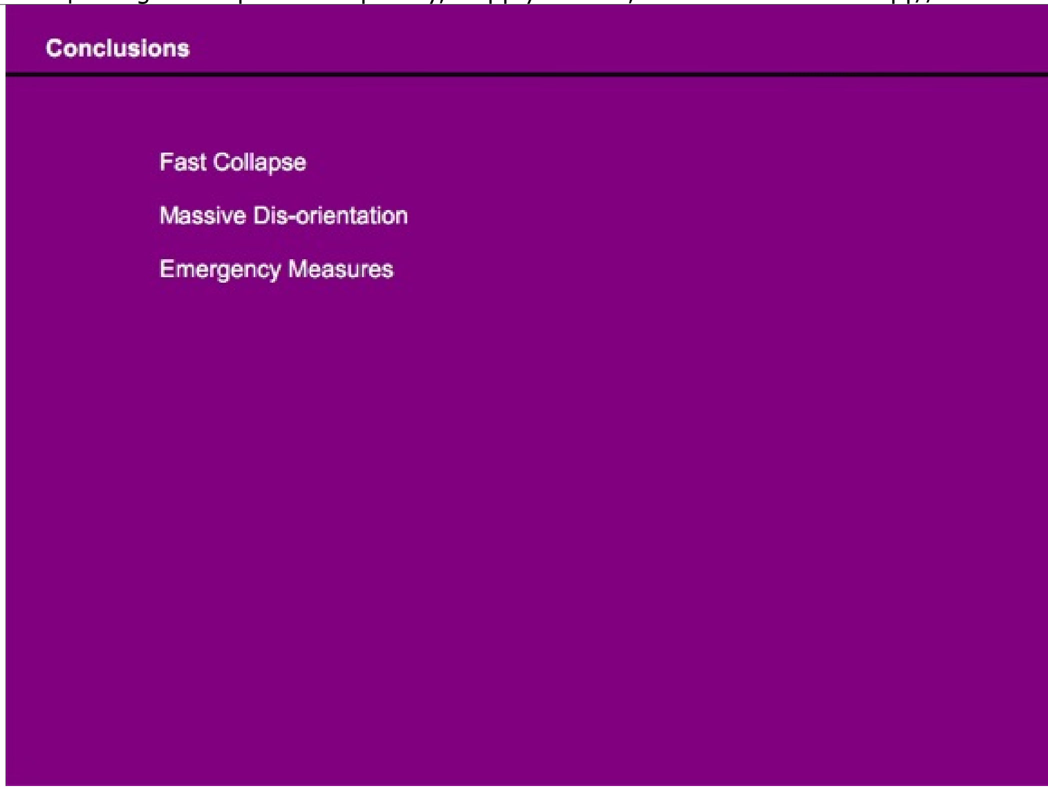
We saw that beside creeping supply-chain collapse, there is the collapse associated with a hub, in our case we mentioned a systemic failure of the banks.

Well, here is a scenario that seems likely. In essence, at some point in the future, over some period, the debt/ bond market will switch from being ultimately confident about the return to economic growth, to accepting that uncertainty and depression can only continue. As we know, markets tend to change their views over short-time periods.

An acknowledgement of this view will dry up the debt market, crash other markets, and will effectively mean that almost all debt cannot be repaid (or can, with worthless money). This means that all banks will be seen as insolvent.

The speed of such a transition could be in the order of months (baring in mind the propagation speed of the recent financial crisis). A collapse of bank intermediation services would effectively collapse our global and national supply-chains, in addition to instigating a money crisis.

The consequences would be unprecedented, including the prospect of a food crisis in many advanced economies. This would be the detonation point when the world finally absorbs the depth of its ecological overshoot.



Slide 23: Conclusions

The rate of collapse will be dependent upon the the speed of our critical systems- the operational speed of our financial markets, the speed of our supply-chains, and the maintenance rates required for our infrastructure.

In time a collapse will be seen as a series of jumps to lower levels of complexity occurring over decades. This will be set against a background of creeping failures in many of the systems we take for granted. There may be periods of stability or even slight recovery, but the downward trend will be unstoppable.

We are not in the middle of a financial crisis, but at the edge of civilisational one.

What we urgently need to develop now are emergency measures to soften the impact of such a crisis. The omens are not good, but we do have the ability to make better choices rather than worse ones.

Thank you!