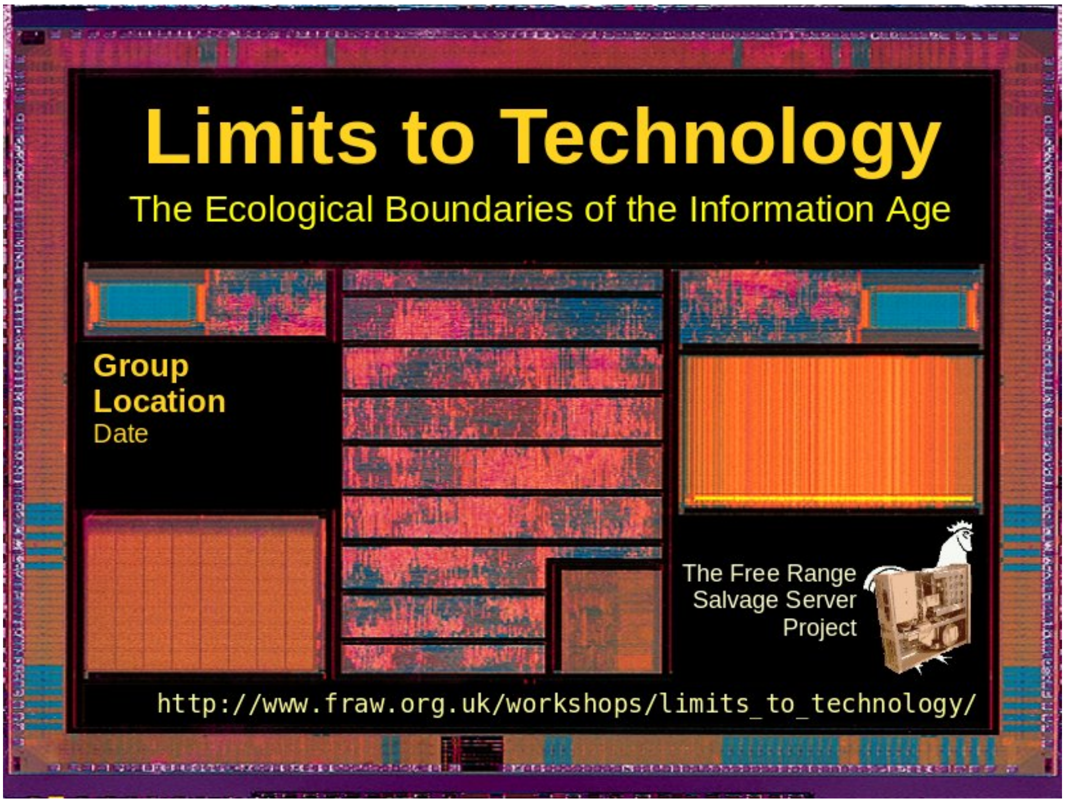
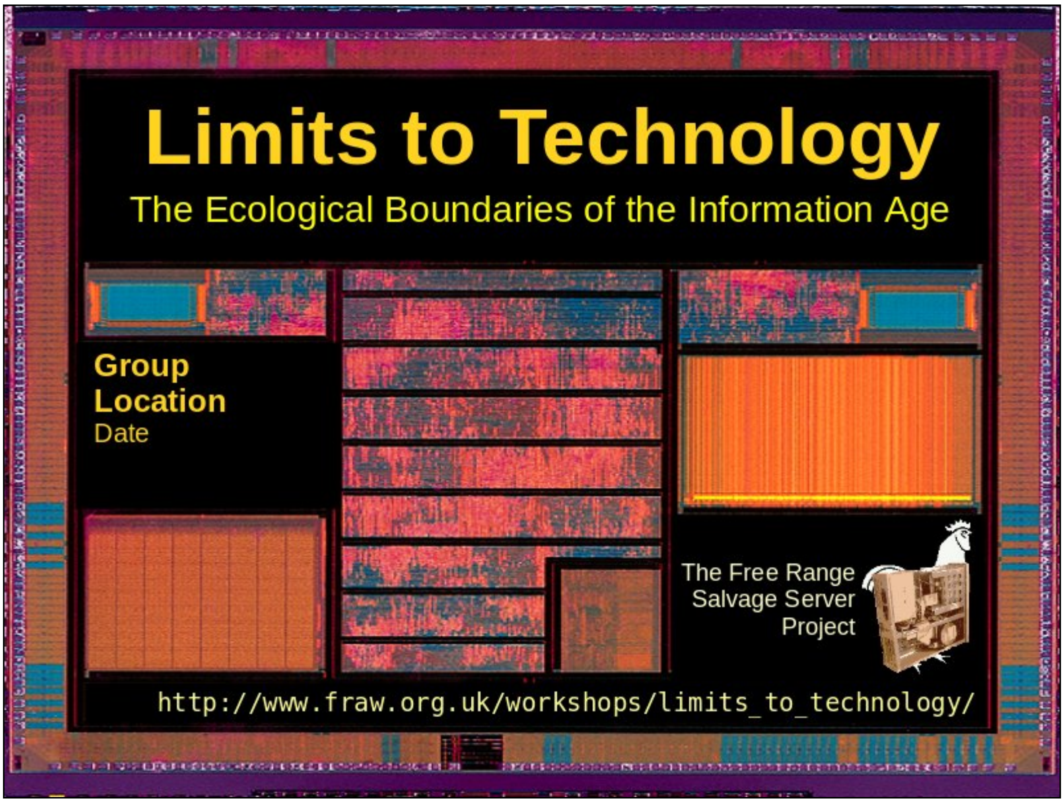

Limits to Technology
The Ecological Boundaries of the Information Age
Group
Location
Date
The Free Range
Salvage Server
Project
http://www.fraw.org.uk/workshops/limits_to_technology/

Slide Index



The "Limits to Technology"

The annotated workshop/presentation slides

"Limits to Technology" examines the role of resource depletion and the ecological limits to human society's future use of "technological systems" – a broad term covering not only our use of computers and mobile technologies, but also the electronics, metals and chemical components of everyday goods and products, and the latest "green technologies". Like the human system in general, our use of technology is subject to certain resource specific limits; by understanding these limits, and how they affect us all, we can address our minds to devising new ways to live our lives in an inevitably more resource-constrained future.

Modern technology is just "there" – whether you use it or choose not to, and irrespective of whether you object to it or not; in affluent societies technological systems surrounds us and guide our lives. For this reason they are seldom questioned. Given the concepts of economic growth and technological progress that dominate the media and political agenda, we don't have time to reflect on what the future of technology may be – often because many people have so many difficulties handling the implications of the technologies that they must master today.

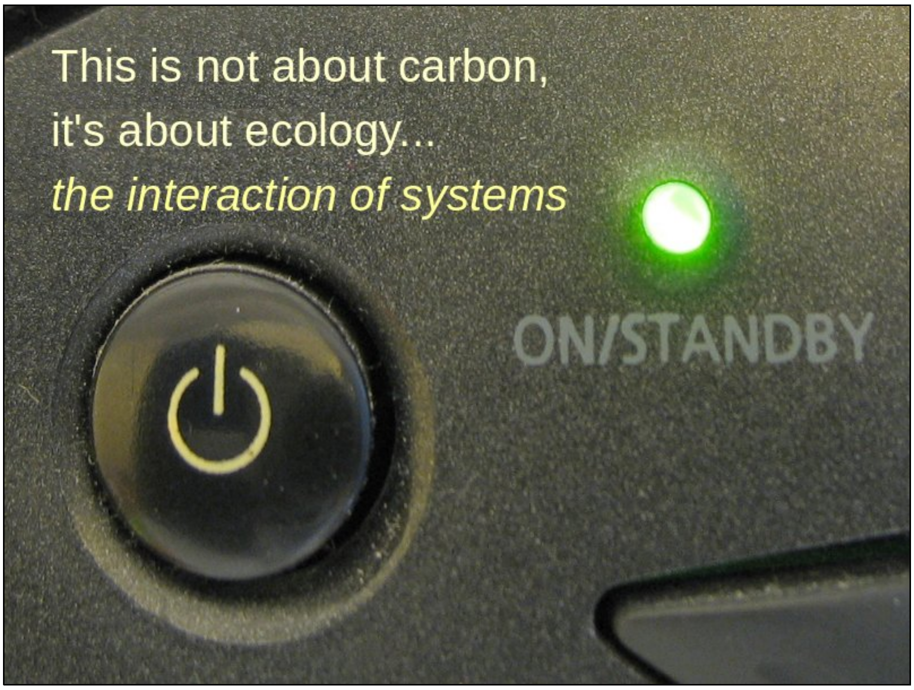
In practical terms technological systems are dependent upon the electricity grid (much of it stops working in a power cut!) and on the system of retailers and service operatives who maintain it. We seldom consider the ecological limits of technology; the dependence of human technologies upon the systems, and upon the natural resources, that enable it to function. Even with the recent concern about carbon emissions, whilst we might focus on the amount of electricity all our gadgets use we seldom give a thought to the impacts of creating all these systems, and how changing trends in energy and resource production might adversely affect our continued "enjoyment" of modern technology.

"Limits to Technology" has been developed by Paul Mobbs[1] and the Free Range Network's 'Salvage Server' Project[2] in order to highlight, and to allow a discussion to take place on, the "ecological boundaries" of modern technology.

Technology is just a tool – on its own it is neither good not bad. Whether technological systems create a future for the better, or the worse, depends upon our ability to make them sustainable in the longer-term. Otherwise our unseen dependency on these systems has the potential to create a human crisis in the future if we cannot sustain their operation. This, given the available information on the ecological dependencies of technology, is the question that we should all be posing to those who guide our *Technological Society*[3] today.

If you have any feedback, or you are interested in organising a local event with the Free Range Network, then please get in touch – tech@fraw.org.uk

1. Introduction



***Ecology*[4] is usually considered to be biological – something related to "life". Generally ecology is understood as the "study of the relations between natural species and their environment". The "ecology of technology" is therefore the analysis of the relations between our technological tools, the factors that influence their operation, and how this changing relationship might affect the technological mediation of human society's relationship to its own natural environment.**

This presentation is not simply about carbon or pollution – it's about our ecological relationship to modern technology and the resource constraints that might change this relationship in the future.

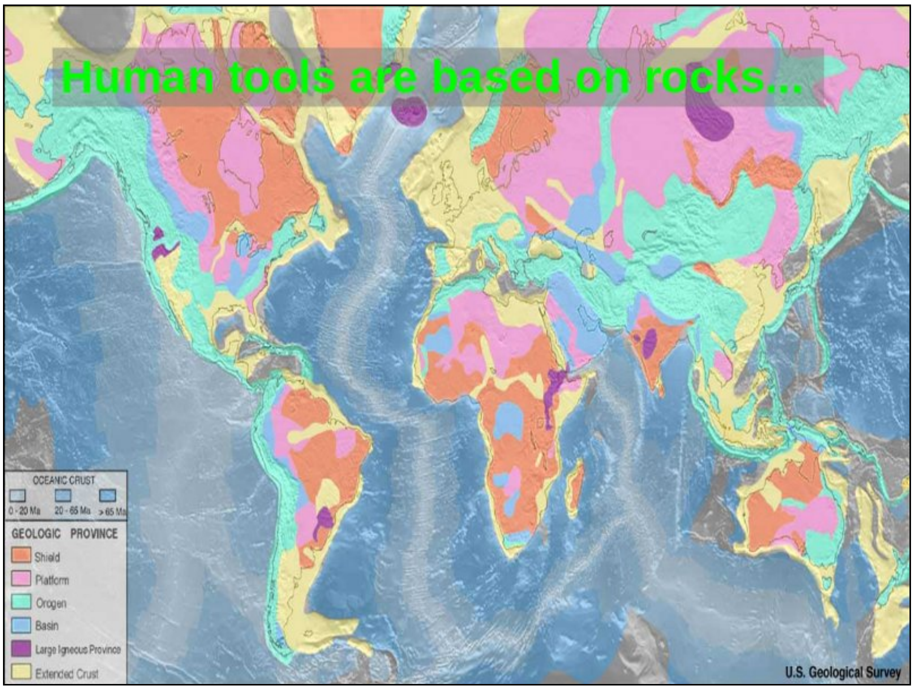
People often confuse science and technology. Science is the knowledge of the natural world that has been gained through studying natural phenomena. Technology is of course based upon scientific principles, but in reality it's the *cultural expression* of science in the tools created by society. As a society we pick and choose what knowledge is implemented – for example television is considered by most to be good but human cloning is considered bad. The difficulty is that the modern obsession with consumer technology, and the importance that governments and economists attach to supporting consumption, is clouding our ability to look objectively at how technology interacts with our lifestyle and well-being.

From the latest high-tech. gadgets to the latest in ecologically cool energy sources, society relies on a whole range of metals and minerals to create the automated and computerised command and control systems that we rely upon. Like the operation of the human system as a whole, our modern high-tech. age is constrained by natural resource limitations that will ultimately redefine our use of these technologies. Just like the general boundaries identified in "Limits to Growth"[5] nearly forty years ago, the rapid evolution of the ways we use these systems is driving the consumption of resources at a level that cannot be sustained in the longer-term. That's not to say that we won't have digital electronic[6] systems in the future, but it raises questions about their application, price, availability, and thus the role that technology plays in our everyday lives; certainly it cannot continue as we experience it today.

From washing machines to downloadable music, and swipe cards to the latest mobile phones, technology enables our lives to function. Of course these gadgets are the easily visible parts of the "technological system"; behind the façade of consumer electronics are information systems that manage everything from electronic payments through to the logistics[7] of production and delivery; in turn these systems are wholly reliant upon software production, data processing and communications systems that only exist because of the development of high speed transistors over the last fifty years; and underpinning it all are the electricity supply and production systems that power the networks. These also rely on these same systems of computerised command and control to function – as do the production and supply networks that keep the whole system energised by producing primary energy resources[8].

Like the biological human system – based upon food, water and other biological resources – the Information Age[9] is subject to certain "ecological limitations" that govern it's essential inputs – metals, chemicals and the energy to process them. As a result society's future lifestyle and well-being are going to be determined by the availability, and ultimately the shortfall in supply, of a number of different natural elements. These elements form the inner workings of most of the systems that make modern society function, although many people may have never heard of them. As we reach the limits imposed by the natural geological or global geopolitical[10] restrictions on production their use must also be constrained. More generally, the types of device that we are creating today are by their nature inherently energy intensive to produce. Therefore, as we reach the peaks of oil and gas production[11], the mass production and support of our easily available, cheap, and thus ubiquitous technological devices – even if we have the raw materials available – represents yet another challenge to our "modern" way of life.

2. Human tools are based on rocks: *a. We haven't yet left the Stone Age!*



***The Stone Age[12] hasn't ended!*; today we're digging up vastly more stone than humanity ever dug in pre-history. We might call it iron, or silicon, or cat litter, but it's still rock of one type or another. Our tools might be more advanced than flints and hand axes, but we're still just as reliant on finding the right quality of rock for the job as we were a few thousand years ago.**

Plants grow in any suitable location – give them sufficient soil, water and sunlight and they will obligingly produce food. The difficulty with our demand for rocks is that ***they can only be produced where they are found*** – and even then only when the concentrations of the specific elements we're after are at a physical or economically viable concentration. For this reason, unlike many other aspects of our biological demands, our demand for mineral resources will always have spatial and physical limitations; *we must accept the possibility of running out!*

This is not the story we see relayed by techno-savvy media outlets. The cornucopian[13] conception of technology, that always praises the "latest" and spurns the "obsolete"[14], obstructs our ability to question the inherent limitations of the technological world. Such a debate can also stir highly charged passions as sections of society have elevated the possession and use of technological systems, from the century-old telephone to the latest virtual communities[15] and social networks[16], to create practical and psychological dependencies on the 'software'-based social services that the digital hardware conveys. As a result many people consume in seemingly blissful ignorance of the ecological boundaries that challenge the future well-being of the human species – *both biological and digital*.

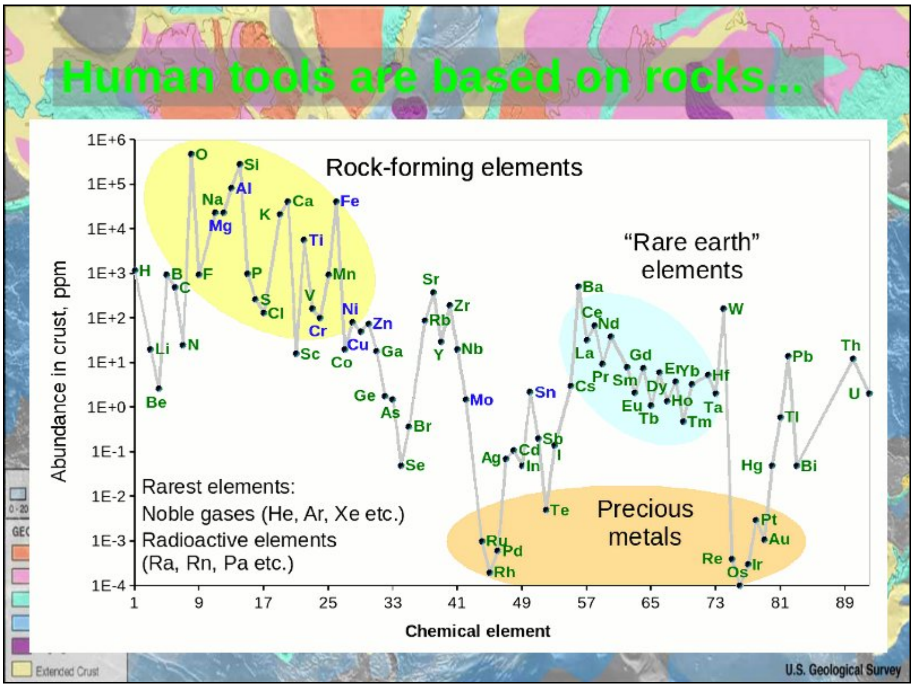
The slide shows the geological provinces[17] – the distribution of different rock structures in the crust. The light blue/cyan areas are orogenies[18] – places where the crushing and deformation (creating pressure and heat via friction) of the crust by plate tectonics[19], and the volcanism this creates, is actively generating new mineral resources. The more mature blue 'basin', yellow 'extended crust' and pink 'platform' areas hold different types of mineral resource that have been generated by geological forces over much longer periods of time, such as coal and oil. The truth that we as a society seem unable to grasp is that these natural processes are creating new mineral resources far slower than we are extracting them from the ground. Consequently we are using up the best mineral resources very quickly, and as we have to switch to the less rich sources the cost and energy involved in production rises significantly. In the end economics dictates that the costs of further production will outweigh the benefits of the goods these minerals are used to create.

These limitations on our ability to produce mineral resources must ultimately constrain our ability to develop tools and technologies – either because the cost makes such tools prohibitively expensive or rarity renders certain uses for these minerals in-viable. From the portrayal of technology by the media, to the promotion of technological innovation as part of a new 'green economy'[20] by politicians, there is an unspoken assumption that we need not change the way we live because the latest gadget, or some sort of new cheap technology, will render our existing way of life ecologically benign; *the "agent of technology"[21] promises that it can fix anything provided that we have the wherewithal to obtain it.*

The reality of our technological society is that these new tools and gadgets suffer the same systemic weaknesses as biological systems; irrespective of whether we take a high or low tech. approach, we're still going to run out of resources, at some point, if we strive to grow the global economy[22] year-on-year. The reliance of our advanced technological society on a range of uncommon resources also means that the use, and the seemingly inexhaustible supply, of these systems is open to debate. We should all question, with evidence of shortages ahead, whether technological dependence makes our lives more or less sustainable; and thus whether we should be redefining our relationship to modern technology in order to avoid a calamitous systems failure as raw materials run short.

2. Human tools are based on rocks: *b. The elements*

The universe is made up of 92 naturally occurring chemical elements[23]. The way they are created, and the way in which geological processes concentrate them into mineral deposits, affects the amount that is theoretically available in the Earth's crust. How viable it is to produce this theoretical quantity depends on our ability, and the economic viability, to extract these elements from the rocks that contain them.



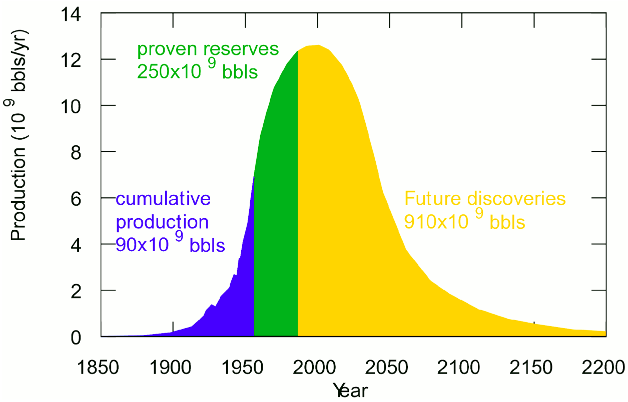
Chemical elements are atoms – unique parcels of matter that have been created over the history of the universe. Atoms cannot practically be made by humans (it's theoretically possible in nuclear reactors or particle accelerators, but the amount of energy required makes it practically impossible on an industrial scale). For this reason the only viable supply of elements are the various gases, mineral ores and salts that occur naturally in the environment.

Stars "burn" hydrogen[24] (H) – the most common element in the universe – fusing it together to make helium and the subsequently heavier elements. As a star runs low on hydrogen it begins to fuse helium (He), Lithium (Li) and other elements, creating even heavier elements in the process. This can happen up to the element manganese (Mn), but from iron (Fe) onwards it requires an energy input[25] to create new elements; from iron onwards the elements are created in exploding stars – supernovae[26]. When stars explode the elements that they have created are scattered around nearby space. As gravity makes the dust and debris of space clump together to form a new star and its solar system, the heavier elements are incorporated inside the planets. In turn, life utilises these elements – *quite literally then we are all made of "star stuff"*[27].

The elements in the Earth are brought to the surface by geological processes – *but only in certain proportions* (shown in the graph on the slide). The hot spots, volcanoes and the grinding up of crustal material by tectonic processes is able to dissolve, precipitate[28] and distil[29] chemical elements into a wide variety of rock salts[30] and mineral ores[31]. The commonest eight elements in the crust – oxygen (O, 47% of crust), silicon (Si, 27%) aluminium (Al, 8%), iron (Fe, 5%), calcium (Ca, 4%), sodium (Na, 2%), potassium (K, 2%) and magnesium (Mg, 2%) – make up 97% of the Earth's crust. Mineral ores are often made up of these elements combined with smaller quantities of the less common elements. Some elements, because they are non-reactive or because they are rarer in the rocky planets of the inner solar systems, are not very common at all – for example helium, which as a very light and non-reactive gas can easily escape into space.

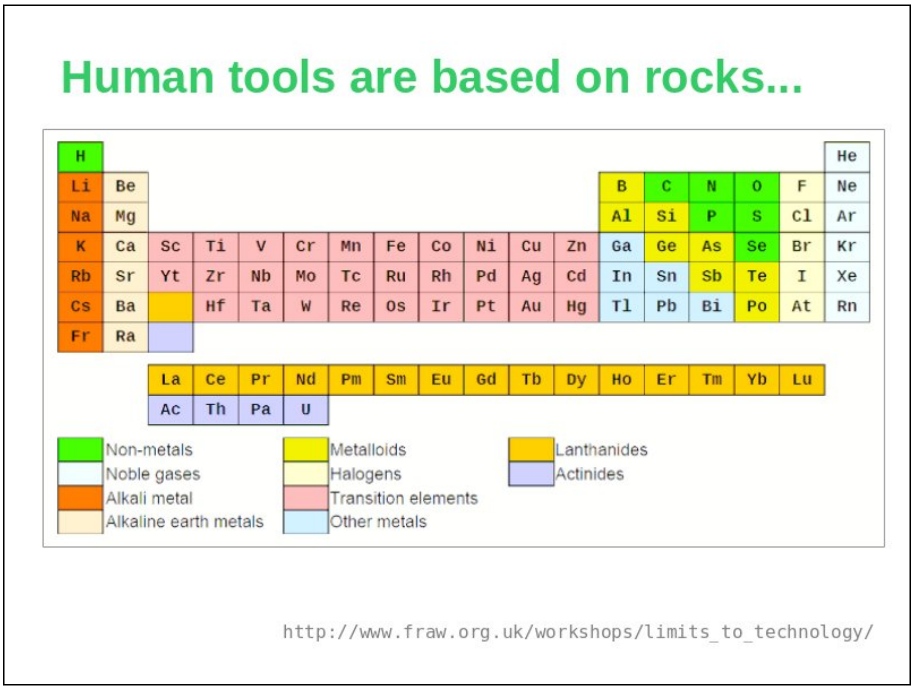
The importance of geological processes is that they are able to take these minute quantities of the less common elements and, by the chemistry of geological processes, concentrate them into mineralised fissures and rock strata. This may happen deep underground during ancient orogenies, but erosion brings them to the surface over hundreds of thousands of years where they become accessible to us. Some elements, such as lithium, are washed by weathering processes into shallow salt lakes where heat from the sun can evaporate the water and create a workable mineral deposit.

For economic reasons the largest and richest minerals deposits are worked first, and as they are exhausted we switch to lower quality and/or more remote sources. This means that over time production inevitably reaches a peak[32] and then declines in accordance with the Hubbert's peak theory[33] – for example the levels of regional oil production, and imminently, global oil production (as shown below).



2. Human tools are based on rocks: *c. The chemical elements and life*

Life processes are based upon the elements carbon (C), oxygen (O), hydrogen (H), and nitrogen (N) – coincidentally some of the commonest elements on the Earth's surface. Originally all human tools were based on either stone or plant and animal matter. As we have developed a more complex society so the materials that we rely upon have become relatively 'purer' and 'rarer'.



The slide shows the naturally occurring elements as a periodic table[34], a form devised over 140 years ago before all the elements in the table had been discovered. You see this image often, in schools and in TV science programmes, but it represents far more than just a list of the chemical elements. The chemistry of atoms is determined by the electrons that orbit the nucleus. Electronics organise themselves into concentric shells[35], and it's the number of electrons in each shell that determines the chemical characteristics of the element. In the columns of the table the elements all have similar properties because they have a similar shell configuration[271].

The elements on the left are the 'alkali' metals; moving across you find 'earth' and 'transition' metals, 'other' metals, and then a boundary demarcated by the 'metalloids'. On the other side are the non-metals, and the halogens and noble gases. As you move from top to bottom, and from left to right, the elements get heavier. As shown in the graph in slide 2b, once you get past the first two dozen or so elements the general trend is for the elements to become progressively rarer.

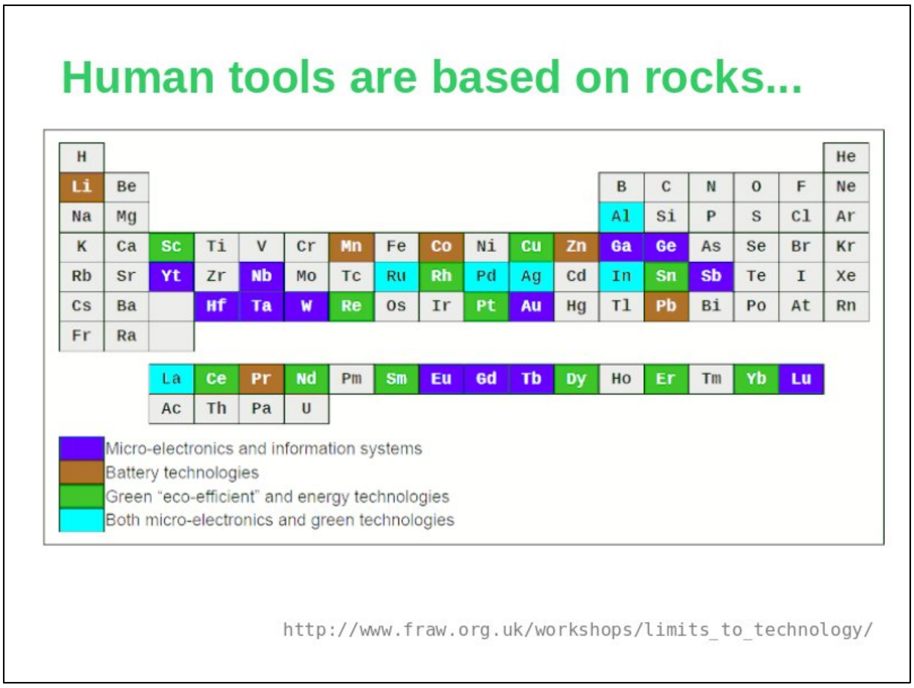
Life processes rely on the most common elements – for example the amino acids[36] that form proteins, and the DNA that carries our genetic code – are made of carbon, oxygen, nitrogen and hydrogen. Other essential elements to both human and plant life – the macro-minerals[37] – are sodium (Na), magnesium (Mg), phosphorous (P), sulphur (S), chlorine (Cl), potassium (K), calcium (Ca), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), selenium (Se), molybdenum (Mo) and iodine (I). Other elements have a role in microscopic quantities, such as fluorine (F) to harden tooth enamel.

It's no surprise that evolutionary processes, which work to find the simplest and most effective solutions through trial and error, have made the metabolism of plants and animals dependent upon the most common elements; making life dependent upon highly rare and restricted elements is not conducive to resilience and diversity. However, over the last three hundred years or so of intense industrialisation, and arguably over the last seven thousand years since humans started practising metallurgy[38], human society has become progressively more reliant upon the rarer chemical elements to support its needs.

As demonstrated by various ecological studies, organisms exhibit a tendency to establish a balance with the environment that they inhabit. This is not an absolutely static equilibrium, and often varies depending upon weather, season and temperature – all of which affect the supply of nutrients/food that they can source from their environment. The importance of food supply to the populations of a species, and to the human population in particular, was noted by Thomas Malthus[39] over two hundred years ago. In the poorer parts of the world today, where subsistence farming provides much of people's everyday needs, this intrinsic link between human society and the ability of their environment to produce the food and fuel that they require still exists. In contrast, for those in the developed world who live at the nexus of the world's globalised food and commodity systems, this link has effectively been broken – *we rely on the supply of non-biological commodities.*

The metallurgy of ancient history was primarily related to precious metals – gold and silver. Other metal goods, such as iron, bronze, lead and pewter were highly valuable, scarce, and almost entirely recycled. In contrast today's affluent societies are reliant upon the continuous supply of highly engineered commodities that enable our more energy and resource intensive society to function. Unlike the more decorative role of ancient technologies, even a temporary interruption of these non-biological supplies can catastrophically interrupt the lighting, heat and food supplies of the highly developed states.

2. Human tools are based on rocks: *d. The elements and technological systems*



Technology is both a blessing and a risk. Technological tools, and the energy sources to make them work, enable the lives of the affluent citizens of the planet to be physically easier than those who do not have these tools. However, this situation only exists provided the required energy and mineral resources are available at an affordable price.

Britain was a driving force in the Industrial Revolution not only because we had the technical, political and commercial skills to develop the first factories and manufacturing infrastructures – it was also because places such as Coalbrookdale[40] had local outcrops of the mineral resources required to supply the early foundries and mills. Only later, when canals and railways provided a means of transporting bulk goods easily over longer distances, did industrialisation penetrate to every part of the country.

Today, in the globalised world, the most affluent nations require a complex array of trading links to supply their needs. The first industrial nations, such as Britain and Germany, exhausted much of their high quality mineral resources during the early phase of industrialisation, and today they import either the commodities or finished goods they need rather than produce these goods themselves. Even the USA now imports a significant proportion of the commodities it requires as this is cheaper than mining the lower quality resources from within their own borders. More significantly, states such as Britain import a large proportion of their food because their agricultural systems have specialised in producing large quantities of a few food commodities in order to extract a higher economic return from agriculture.

Underpinning these trends has been the development of telecommunications, information technology, and the use of electronics and machine tool systems to produce and maintain these systems. In turn these systems are reliant upon a range of elements that have only become significant in their application since the Second World War. All of these elements are lower down the periodic table, and so are comparatively rarer, than the "elements of life". In the slide above the various metals essential to technological society are highlighted. Some are used primarily in micro-electronics, others in batteries, other in high-efficiency "green technology" – some are essential for two or three of these applications.

The most recent innovation has involved members of the lanthanide group – the block at the bottom that has to squeeze in between barium (Ba) and hafnium (Hf) in order to maintain the ordered simplicity of the periodic table. These are known as the "rare earth elements" (REEs) – somewhat of a misnomer since most REEs are present at a higher quantity in the crust than the precious metals gold (Au), silver (Ag) and platinum (Pt). The difficulty is that REE's only occur at extractable levels in few regions on the Earth. These new technologies are therefore wholly reliant on elements that are both physically and geographically rare.

Each increase in technological sophistication in turn generates the emergence[41] of new and increasingly complex patterns of activity in society. The difficulty is that each increase in complexity also brings with it the potential for increasing instability due to the over-dependence upon disparate resources, and the need to co-ordinate the production and transport of these resources over longer distances. Over the last two decades a new field of research has sprung up within human anthropology that examines the physical basis of how societies operate, and how technology and new forms of organisation can contribute to the success or failure of more advanced societies. Research studies by Joseph Tainter[42], Jared Diamond[43] and Thomas Homer-Dixon[44] have highlighted the importance of complexity[45] in determining the sustainability of a society. By putting increasing reliance upon scarce and rare resources and a dependency upon continuous growth – *the opposite trend taken by nature over the course of evolution* – our technological society is creating an increasingly precarious system that is prone to unpredictable and potentially catastrophic failure[46] (for an easily accessible exploration of this issue see episode 1 of James Burke's series, *Connections*[272]).

3. Finite mineral resources:
a. Going to the ends of the Earth

The economies of the affluent states and their ability to supply their citizen's needs are intrinsically related both to the availability of goods, and the capital earned from the production and development of mineral resources. If global production is constrained, then this creates material shortages, and it also has the potential to destabilise the global economic system itself.

El Chino copper mine, New Mexico, USA

This picture shows the El Chino copper mine[47] in New Mexico, USA. It was once the biggest copper mine on the Earth – but no more. It closed in 2008. Today the biggest copper mine is Minerala Escondida[48] in the Atacama desert of northern Chile. In order to supply the gargantuan appetite of the world economy for materials the scale of the production systems has grown too. For example, it's been estimated that around 1,769 tonnes of copper[49] were extracted during the Bronze Age[50] (a 1,500 year or so long period) from the Great Orm in North Wales – the largest ancient complex of copper mines in the UK; in 2007 Minerala Escondida produced, on average, two and a half times that quantity each day.

Copper provides one of the best case studies of the importance of minerals to the global economy, and also the fragility of that global system as a result of the natural constraints on human consumption. Copper is one of the most important minerals[51] in the world materials economy. It's important for microelectronics and even some medicines, although the bulk of annual consumption is for electric cables, pipes and metal alloys. In 2007, despite the fact that copper is one of the most recycled metals and perhaps 75% of the copper ever mined is still in use (a quarter of it has been landfilled[52]), around 15.4 million tonnes of new copper were produced from mines around the world. This is because as society becomes more technological, and especially as many developing countries begin to build power and telecommunications infrastructures, the demand for copper continues to grow year on year. As with many natural resources, the amount of copper in the top kilometre of the Earth's crust is huge (around 900,000,000,000,000 tonnes, or 5 million years worth of production) but only a tiny fraction of these reserves is economically viable to extract. Copper has been in use at least 7,500 years, but more than 95% of all copper ever mined and smelted has been extracted since 1900.

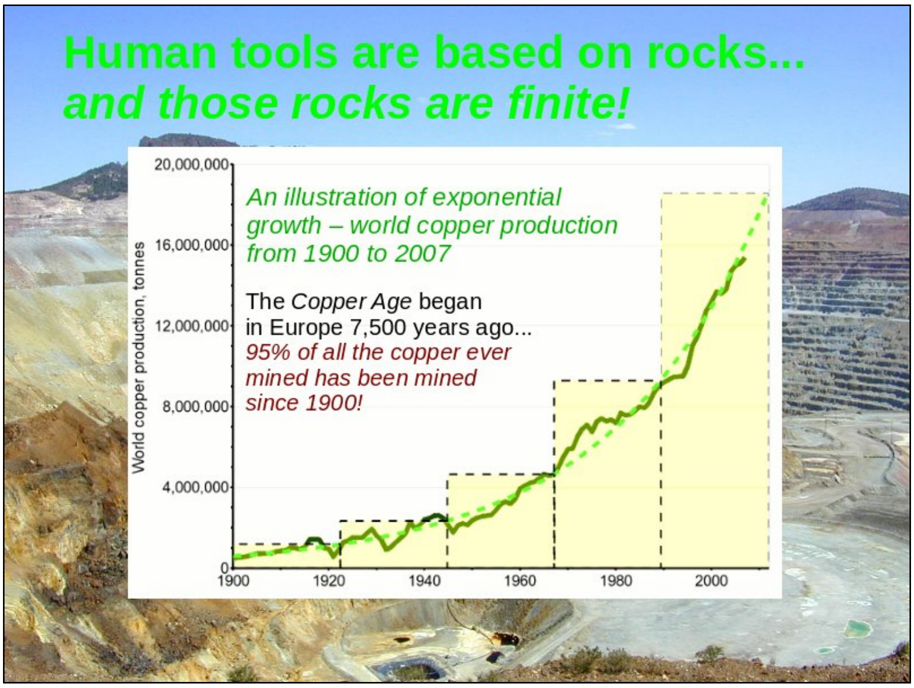
To put the the scale of of the picture above into context, El Chino measures about seven kilometres across[53]; in comparison to central London[54] that's the distance from Chelsea to Docklands. Minerala Escondida is even bigger – nine to eleven kilometres across[55]; in London that's the equivalent of Fulham to Docklands. Of course the bigger mines get, and the deeper they go, the more energy is expended in production. The most significant cost of mining is processing the ore, and being able to run one huge complex using the same processing plant for a longer period reduces the overall cost of the operation. For this reason digging a single large hole[56] to feed an adjacent large processing plant has become the standard approach in the bulk metals industry.

The greater truth about the extraction industry, from oil and coal to copper and diamonds, is that digging things up provides a far greater "hit" of growth to the economy than recycling or using renewable resources. Research suggests[57] that up to half the value of economic growth is the direct result of adding additional resources to the economy; only a fifth is the result of improving efficiency. In biophysical terms energy sources such as fossil fuels, or renewable energy, and even food, have a value which they create through their production, and thus a financial and energetic return[58] that can be recycled back into the economy. For example, renewable energy sources do not perform in the same way as fossil fuels. The returns are lower because the thermodynamic quality[59] of the energy sources involved is lower, and for this reason fossil fuels have always had an advantage over renewable energy.

For minerals it's not so much the quality of what is produced, but rather the economics of reprocessing. Recycling is usually only viable where shortages, taxes or subsidies reduce the price difference between the costs of new and recycled materials.

3. Finite mineral resources: *b. Exponential growth & copper production*

We are told by politicians and business leaders that, *"the world economy must grow!"* Seldom do they explain why. In an economy based upon debt a certain level of growth must take place in order to keep generating the interest repayments on loans. Otherwise, as shown by the recent credit crunch[60], the system implodes.



If the economy grows at a few percent every year then, like compound interest[61], the value of the increase each year will on average be greater than the previous year. Economic growth therefore has an exponential function[62] – its value accelerates with time; if we plot the changing value against time what we see is a curve rising upwards at an ever steeper rate.

If the economy has an exponentially growing trend driving its operation, then any system that is directly related to the operation of the economy will exhibit this same trend. As shown in the graph in the slide[63] above, copper production[64] demonstrates the exponential trend inherent in economic growth. We can also show this by drawing boxes onto the graph; in equal amounts of time (*the width of the box*) the amount of copper produced (*the height of the box*) doubles. Another feature of exponential systems is that, because the value doubles with time, the majority of the consumption over history will be during the recent past. As noted on the previous page, copper production each day from the world's largest mine today is 2¼ times greater than the whole of the copper produced from a large mine during the 1,500 years of the Bronze Age. In fact, although we've been using copper globally for about 7,500 years, 95% of all the copper ever mined has been mined since 1900.

If the amount we use doubles in a regular period of time then obviously we're using the finite quantity that exists in the ground *at an ever accelerating rate* – but that's not how "the experts" look at the equation. When economic geographers or resource experts look at the data for how much mineral or energy resources are left to produce in the future, the figures are usually assessed in terms of a "reserves to production"[65], or "R/P", ratio. This is produced by dividing the size of the estimated mineral reserve by the annual level of consumption, and the result tells you how many more years your resource will last.

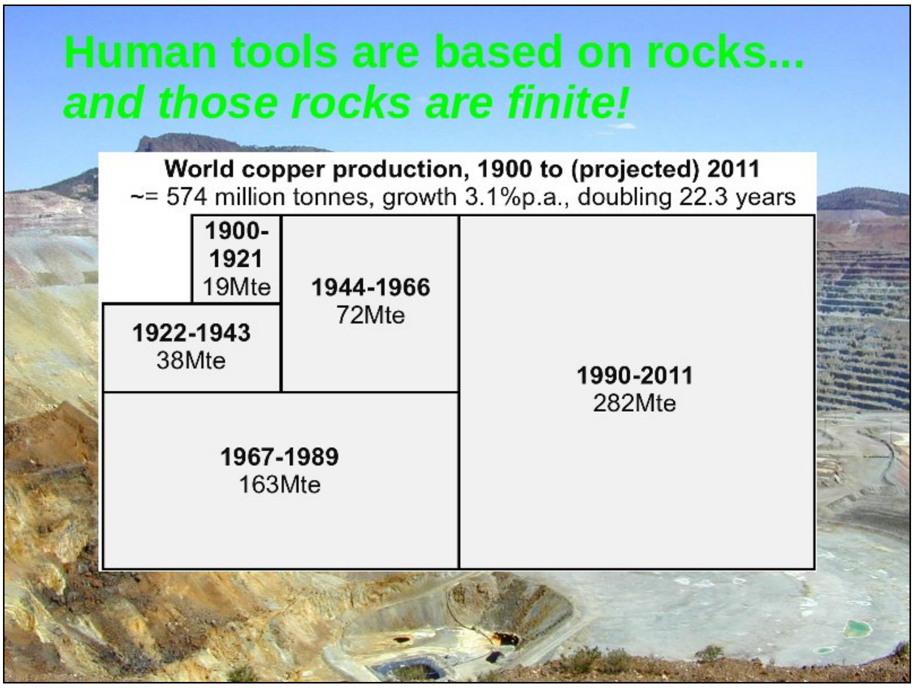
There are of course two big problems with using an R/P ratio in a world where consumption is increasing exponentially: Firstly, it doesn't include the effect of the growth in annual production because it is expressed at the current level of consumption – *with global copper production doubling every 22 years the R/P ratio can produce very unrealistic results*; secondly, the figure takes no account of the peaking of resource production (see slide 2b) as this represents an absolute limit to future production.

Of these two factors, although the ignorance of the future growth in production is important, the fact that the R/P figure ignores the peak of production can lead to a large overstatement of how much copper or other resources will be available in the future[66]. What the peaking of mineral production means is that the lifetime of the resource will be longer than that indicated by the R/P ratio figure, although the levels of production in the future might be a fraction of what they are today or in the near future. Most importantly, once production peaks we cannot grow production; and if production does not grow then the effect on the growth economy will be to make prices rise, to obstruct further development, and this might cause an economic crisis if the mineral in question is important enough (e.g., *oil*).

Minerals and fossil energy reserves are not like the fuel in a car, which can be used at a fairly constant rate until the last drop leaves the empty tank; all mineral and energy resources reach a point of peak production after which output must fall. Perhaps the most appropriate observation on the need for society to reconcile itself to such realities was made by Carl Sagan, in *Cosmos*[67] – "the universe is not required to be in harmony with human ambition."

3. Finite mineral resources: *c. Exponential growth doesn't work in a finite system*

The flaw in the central idea of neoliberalism[68] – *that economic growth can make the lives of everyone on the planet better* – is that there are not enough resources on the planet for everyone to live like Americans. There are limits to what we can achieve; copper has its own limits, and we will reach them soon.



Rather than look at a graph of past data we can also demonstrate how the idea of the exponential "doubling time"[69] will affect copper production in the future – and ultimately "break the bank" of the known copper reserves around the globe. In the diagram above each box shows the relative amounts of primary (mined) copper metal produced in each doubling period from 1900 (this the diagrammatic equivalent of the statistics in the previous graph). The last box, to fit the doubling time pattern, projects production from 2008 to 2011.

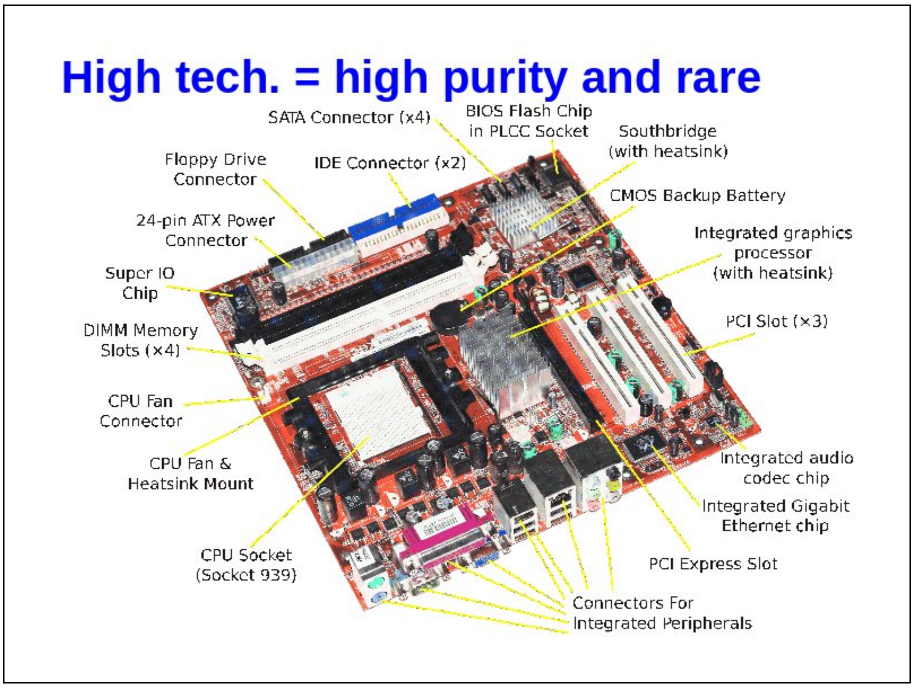
You should see a pattern emerging: The next doubling period, 2012 to 2033 will be another box along the bottom – twice as big as the 1990-2011 box, and containing 564 million tonnes of copper. The doubling period after that, 2034-2057, will be twice as big again (four times bigger than 1990-2011) aligned along the right side of the diagram. The big question for our future well-being is – *continuing the trends of the last 110 years in order to deliver the resources necessary for the world economy to continue growing* – can this growth in supply be sustained?

The USGS have identified 500 million tonnes[70] (Mte) of "currently or potentially feasible" copper reserves around the globe. The difficulty is that in the next doubling period, from 2012 to 2033, production would have to reach 564Mte to avoid any restrictions on copper production and thus sky-rocketing commodity prices. Given the likelihood of finding new reserves, extending existing ones, and increasing copper recycling further, *yes* we can probably keep the copper flowing until the 2020s. The problems arise in the doubling period after that, 2034 to 2057. The USGS identify a "resource base" of 1,000Mte which includes less high quality and marginal copper deposits – in other words, an additional 500Mte when we subtract the "currently or potentially feasible" deposits. However, given that this figure includes highly speculative reserves, it may not be possible to produce all of it. What this means is that, if copper demand continues to grow, there is no way to supply the demand for copper after 10 or 12 years into the subsequent doubling period – *let's say 2045-ish*.

Of course this isn't going to happen; economists like R/P ratios, but in reality production is likely to peak, or more likely plateau for a period, before 2025 to 2030. Some of the world's richest sources of copper are being exhausted now and, as with oil, analysts are making predictions for the peak in copper production[71] ranging from 2015 to 2035. At the same time the metals trade press has begun to run projections that there will be a significant shortfall in global supply[72] as production fails to keep pace with the accelerating demand from the large industrialising nations like China and India[73]. Copper production is also important for the production of other metals – such as gold, silver, molybdenum, selenium and tellurium – which are produced as by-products of copper refining. There's already concern that a peak in copper production would also create a global peak in silver production[74].

At the simplest level the peaking of copper means soaring prices – expensive plumbing, electronics and central heating boilers. Less obviously it will also challenge the nature conservation and landscape policies of developed states. In the late 1970s and early 1980s proposals by Rio Tinto Zinc (RTZ) to drill for copper in the Snowdonia National Park energised environmental and conservation groups. In the end RTZ backed down – at the time it was not absolutely necessary to develop a mine in Britain. The Coed y Brenin[75] copper porphyry deposit, north-west of Dollgellau[76], contains about 200 million tonnes of copper[77] (just 13 years of present global production, or over 80 years of European production), and would produce metal by-products such as gold. Within 20 years Snowdonia will once again be back on the global agenda as a source of copper.

4. High tech equals high purity & rare: *a. The thermo-dynamics of digital technologies*



The processes of eco-efficiency – *making devices more efficient to reduce their impacts* – does not easily apply to digital/nano-scale systems. They are an inherently low entropy[274] system, and therefore requires more energy to make; there is no such thing as "Green ICT", and so patterns of use must change to accommodate for resource scarcity.

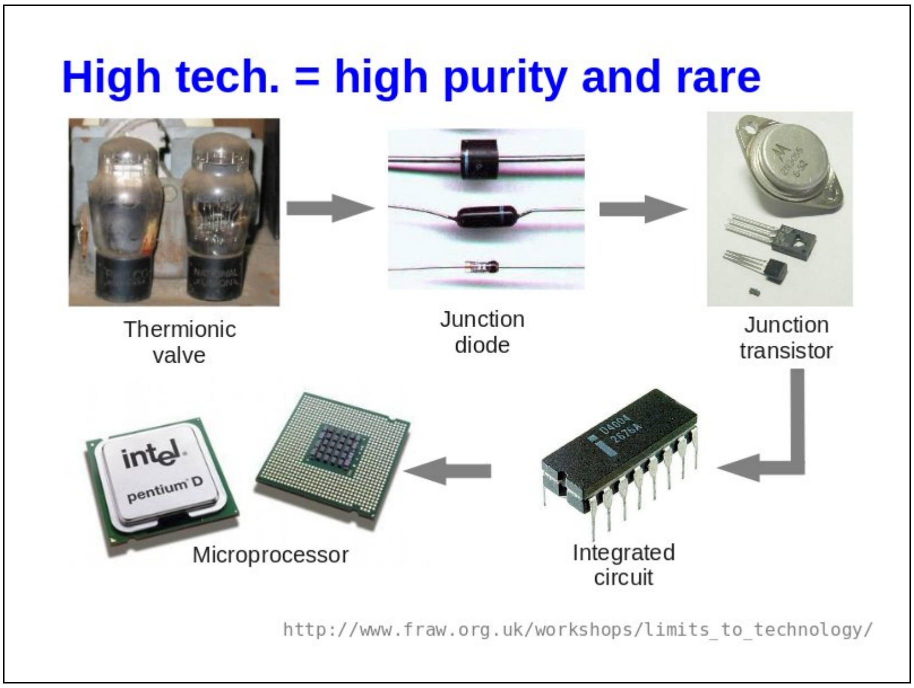
Look at this image of a computer motherboard – it's a modern treasure-trove of rare and exotic substances: Most visibly you see the relatively plentiful aluminium in the cooling fins/heat sinks on the microprocessors; the circuit board itself if clad in a thick layer of copper (Cu); the various connectors on the board are most likely made of iron, copper and tin alloys that are more conductive, often with a gold layer of electroplating to enhance the conductivity of the mechanical connection; the small round black/green and silvery components are capacitors[78], manufactured using titanium (Ti), barium (Ba) and sometimes other rarer metals; some of the minute devices on the board are also capacitors, but their small size means they contain much higher quality, and thus rarer materials such as niobium (No) or tantalum (Ta); the coils are inductors manufactured from enamelled copper wire; the board itself and most of the connectors are made from laminated materials or thermoplastic resins that depend upon the availability of cheap oil; the semiconductor chips are made of silicon doped with rare elements, and which have circuits "imprinted" onto the surface through etching and the formation of microscopic conductive layers by the condensation of vapours[79] of rarer metals; the large black circle in the middle is the button battery that powers the memory containing the BIOS settings when the computer is turned off – made from various materials such as manganese, lithium, silver, zinc or copper; most of these components are fixed to the board with solder[80] made from an alloy containing mixtures of tin, copper, silver, bismuth, indium, zinc, antimony and some other metals. Finally, these devices are manufactured in large fabrication plants, mostly in east Asia, often using electricity from predominantly coal-fired plants, and then shipped around the globe using oil-fired ships and freight distribution systems.

By their nature devices that rely on extremely pure materials, engineered at microscopic levels of detail, require far more energy to create than "old fashioned" devices. *There is no "techno-fix" to this problem – it's a fundamental physical principle*. They might be more efficient or require less energy during their operational lives but because these devices require far more energy to be expended in their production they are often no more efficient overall when we look at their life-cycle of operation (e.g., the comparison between flat screen and vacuum tube monitors on desktop computers – it's debatable whether flat screens have a lower impact than older 'tube' monitors as life-cycle studies indicate that there is no significant difference between the impacts of either technology[81]). Consumers may obsess about the red lights on standby devices and their array of warm power supplies, but in reality around four-fifths[82] of the life cycle energy use of a computer is expended in production – less than a fifth is consumed in its operation. We have to think beyond the power cord in order to **tackle to impacts of ICT** [273].

The construction of these systems is no accident. It represents a progression in human technology that, in order to become more complex, must utilise more specialised materials, larger systems, and thus greater energy and resource consumption. Perhaps more importantly these systems have a symbiotic relationship to economic growth; information systems have been the means by which economic globalisation has been able to reinforce and develop the growth economy[83] beyond the national or regional economic systems that existed in the years following the Second World War.

To understand the significance of our dependence upon low entropy materials, and the use of scarce resources in their production, we need to understand a little more about the technological systems that are at the heart of modern electronics and information systems.

4. High tech equals high purity & rare: *b. The evolution of digital electronics*



In terms of human history electronics is a very new technology; we've been working metals for thousands of years but electricity has only had a practical application for less than two centuries. Much of the development of our use of electronics has taken place since the late 1950s, and much of this development relies on the use of basic logical building blocks arranged into functioning circuits.

If you look in the back of a radio made in the 1950s, pretty much the only ubiquitous luxury (i.e., not lighting or heating) consumer gadget at that time, you'll see a number of glass bulb-shaped devices. These are thermionic valves[84], also known as “vacuum tubes”. These devices have been in general production since the beginning of the Twentieth Century but their cost, power consumption and low reliability limited their application. What has enabled the transition of electronics from a crude source heating and lighting to systems for information processing and data exchange has been the development of solid state systems[85] that replaced the thermionic valve. It's the change from mechanical to solid state devices that has enabled the production of the complex systems that we use today – *lower cost, smaller power consumption, faster operating speed and higher reliability have all contributed to finding new applications that were physically impractical to create using valve technology*. However, every stage in the development of solid state systems has in turn raised the energy density of the devices that are produced – the race to produce smaller and faster electrical devices has in turn consumed more energy and rare resources than before.

The basis of solid state electronics is the junction diode[86] – like the thermionic valve it conducts electricity in one direction only (from positive to negative). This in turn gave rise to the transistor[87], created by putting two diodes back-to-back, which replaced the amplifying role of 'triode' valves. Then, by combining ever greater numbers of transistors together, the integrated circuit[88] was developed – this could carry out more complex “passive” (as in analogue or systematic) electrical functions. Latterly, by increasing the scale of integration to far higher levels, the programmable microprocessor[89] was developed – this device can react to different or changing circumstances using rules designed within its programming, allowing it to carry out far more complex operations than the passive devices that preceded it.

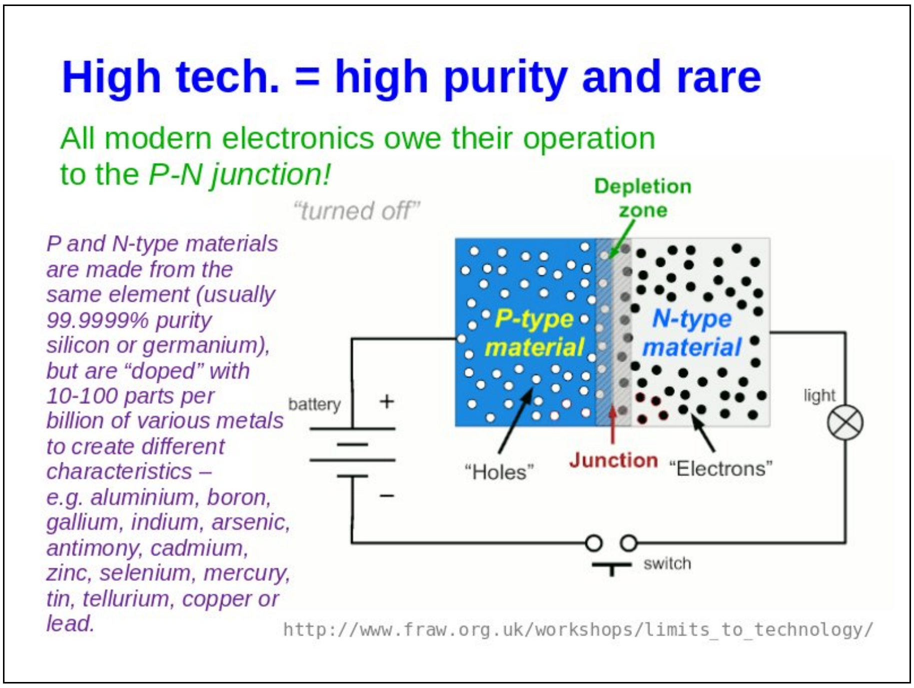
To the promoters of modern technology this process is wholly positive – *it's indicative of the “force of progress”*[90]. In contrast if we look at the absolute impact of these new technologies on the ecological footprint of humanity then, even though they are in isolation more efficient, their widespread adoption is amplifying the ecological impacts of our technological society.

Solid state devices are based upon semi-conducting materials[91], such as silicon or germanium[92]. These have to be created from highly pure materials, and the physical characteristic of any high purity substance is its low entropy[93]. Entropy is often portrayed as some form of destructive, all consuming force, but this is to view entropy as an end-point of the universe rather than a continuum of states that can be created by natural and human-made processes. ***The best way to think of entropy is as a measure of “organisation”***: To make a very pure substance, or to have a high energy levels flowing through a system with little waste, is to exclude entropy; conversely to have a heterogeneous mixture, or to use energy very inefficiently, generates a lot of entropy; *thinking more generally, mixing increases entropy, whilst purification excludes it.*

Our technological society is based upon highly pure materials that form the operating core of highly engineered devices; this makes modern technology a low entropy system. In order to work within the Second Law of Thermodynamics[94] and overcome the naturally higher levels of entropy that exist in nature, creating a low entropy system requires that we invest a lot of energy into the systems that manufacture these materials and devices. *Whilst we can improve the production process, we can never eliminate the energy required to overcome entropy.*

4. High tech equals high purity & rare: *4c(i). The P-N junction*

Be it a diode, transistor, integrated circuit or microprocessor, the building block of digital technology is the semi-conducting *P-N junction*[95]. It's the characteristics of the way P-N junctions are created, and the impacts of the miniaturisation essential to the latest generation of programmable and mobile devices, that's driving the economic and physical impacts of electronics.



The importance of low entropy materials within modern electronics are illustrated by the fundamental characteristics of the P-N junction. This is a very complex idea so, rather than exploring electronic theory let's think about the entropy of these devices more simply; *using the analogy of a bowl of marbles*.

Take a large bowl and fill it with an equal number of clear and coloured marbles (say 500 of each) and give the contents a thorough mixing. The bowl now represents a high entropy state – the proportions of the mixture are unlikely to change with time because they couldn't possibly get any more mixed up than they already are. This represents, in probability terms, the *ground state*[96] of the system: It has a low probability that it can naturally increase its entropy level any further within a reasonable length or time; and it cannot improve its quality or "order", thus reducing entropy, without an external input of energy. For this reason it remains in a stable state.

Now take a clear marble from the bowl. By exerting energy to remove the marble you have created greater order; there are now more coloured marbles, and as a result you have decreased the system's level of entropy. Under the Second Law of Thermodynamics you have to exert energy to reduce entropy; more problematically, as you move away from the natural ground state, the level of energy required increases for each incremental decrease in entropy. You can understand this if you think about removing more and more marbles from the bowl. Removing that first marble was easy, as is removing the next few; but as the proportion of clear marbles to the content of the whole bowl decreases you have to spend more time rooting through the bowl in order to find each of them. On average the time taken between finding each marble, and thus the energy exerted, will increase exponentially as you remove each clear marble. Finding the last one is likely to take far longer than the first ten or fifteen!

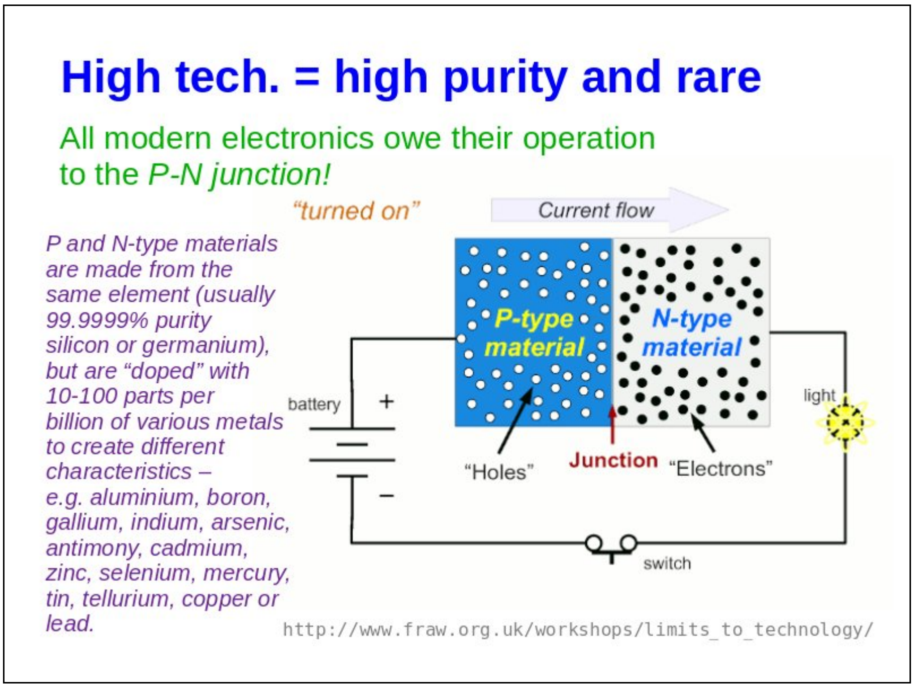
We can think of these processes in terms of other materials too. For example, the natural ground state of iron is rust – once we make iron and steel goods we have to keep painting or treating the surface to prevent the build-up of rust reducing their serviceability or ultimately destroying them. In general then, a truly sustainable society would seek to operate using goods designed as near as possible to the natural ground state of easily available materials.

Highly engineered, high maintenance and microscopic devices are by their nature very low entropy systems, and thus require a highly energetic and complex societies/systems to produce them. The difficulty is that this same tendency to create highly organised and centralised societies holds within its operation the seeds of its destruction if it is unable to sustain the level of food, energy or materials production necessary to maintain itself[44].

So, back to the P-N junction...

Electricity is most simply understood as the movement of electrons, carrying negative charge, down conducting wires. In semiconductors the flow of electricity is more complex because the physical properties of semiconducting materials can create positive charge too. The simplest way to envision this is by the movement of "holes" in the structure of the semiconductor that carry positive charge, and which move in the opposite direction to the negatively charged electrons. At the junction of the P- and N-type materials the charges cancel each other out, creating a 'depletion zone'[97] that prevents the junction from conducting any electrical current. In general the positive holes and the negative electronics are continually cancelling each other out as they move around, and the ability of the semiconductor to conduct depends upon the balance of the electricity flowing through it. The diagram above shows a P-N junction that's not energised – *what happens when we press the switch?*

4. High tech equals high purity & rare:
c(ii). The resource limitations of semiconductors



When the switch is pressed the battery is connected to the circuit, current flows into the light via the P-N junction and it converts electrical energy into light energy. *That's an immense over-simplification of the solid-state physics that took place when you applied a voltage to the junction!*

Connecting a battery is not as important as the voltage that the battery produces – the voltage must overcome the physical resistance of the depletion zone. When we apply a 'forward positive voltage' to the junction's P-type material the depletion zone shrinks. Eventually, when it reaches the *threshold voltage*, all electrical resistance breaks down and the diode will conduct – *in one direction only*, from the P-type material (the anode) to the N-type material (the cathode). This is called rectification[98], and one of its practical applications is turning radio waves into the audio and video signals you receive on an analogue radio or TV.

Why entropy is important is because the P- and N-type materials *are not pure semiconductors*; they're highly pure (for microchips, 99.9999% pure) semiconducting materials that have been 'doped'[99] using minute quantities (perhaps only a ten parts per billion) of various metal compounds – such as gallium, indium, copper, mercury, lead, zinc or cadmium. The effect of these impurities is to change the characteristics of electron or hole production, or the voltage or current capacity of the junction. When we look at the transistor (in the next slide) the level of current amplification, the speed or frequency bandwidth of switching operations, and the working voltage are all affected by the doping materials used in the construction of the junction(s).

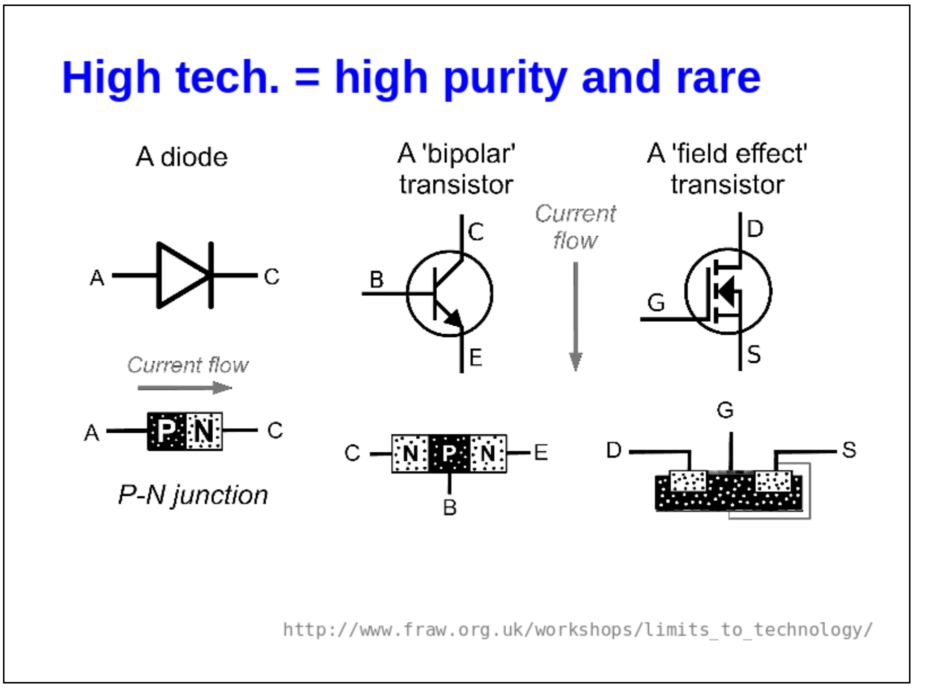
Returning the to the bowl of marbles again, silicon dioxide[100] (*silica sand* – the raw material for silicon production) is roughly 46% silicon and 54% oxygen – so let's say our bowl contains 460,000,000 silicon marbles and 540,000,000 oxygen marbles. ***To make microchip-grade silicon the sand has to be processed to remove all but 1,000 of the oxygen marbles!*** To change the characteristics of the junctions we then have to add a few tens to a few hundreds of other marbles made from other highly pure compounds. It's for this reason that making the raw materials, and then creating semiconducting materials is a very energy intensive process – *it involves an awful lot of marble sorting to create such purity!*

Whilst silicon is very plentiful – it makes up a quarter of the mass of the Earth – some of the materials that are essential for doping are not. It's common to talk about the world "running out" of something or another; this too is an extreme over-simplification of the problem. In reality, for any non-renewable resource, you start "running out" the moment that you first start using it, and all that really changes is the depletion rate. Therefore it's more exact to say that consumption "runs down" or depletes a non-renewable resource since, against a growing demand for resources, we can never prevent further depletion through measures such as recycling and reuse.

Theoretically we could extend the life of the resource through recycling, but once again we hit the thermodynamic limitations of low entropy materials. Microprocessors contain minute quantities of the all important doping compounds at far lower concentrations than the levels at which they occur in nature. Therefore it's less energy intensive to produce them from the natural ore compounds rather than trying to recover them from used semiconductors. In the real world these rare metals are often only one valuable by-product from the mining and refining processes, and so the overall economic viability of one metal is governed by recovering a number of compounds rather than producing just one product. However, when these ores are exhausted, and we attempt to reclaim the materials from used semiconductors, we then have to pay the higher energy cost imposed by taking a less rich source material and extracting just the one (or a few) material(s) that we want to recycle from the mass of silicon.

This is the ecologically problematic aspect of modern electronics that the environmental movement has yet to recognise; *it's not the production details of the individual gadgets that's the core of the problem, it's the physical characteristics of this type of technology as a whole*.

4. High tech equals high purity & rare: *d(i). The driving technological trend behind growth*



Irrespective of their function, most digital technologies are modular[101] – and the basis of this modular technology is the semiconductor. Understanding how the diode and transistor influence modern electronics allows us to understand the significance of why shortages of essential materials might have such a wide-ranging impact on society.

A bipolar transistor[102] is the equivalent of putting two diodes back-to-back, but it has some extremely valuable electrical properties. As we increase the voltage to the central control contact (called the *base*, B) of the transistor the depletion zone across the device shrinks. Eventually the transistor conducts between the two main terminals – the *collector* (C) and the *emitter* (E) – but the current flow is many times greater than that applied to the base. This means that as well as being a simple off-on switch, the transistor can also act as an amplifier. Similarly the field effect transistor, or FET[103], uses one type of material (either P or N) engineered onto a larger substrate of the opposite type. Rather than a simple junction the *gate* (G) terminal creates an electric field that controls conductivity along a channel, controlling the flow of holes and electrons between the *drain* (D) and *source* (S) terminals to control the current flow – although an important characteristic of the FET is the gate is electrically isolated from the main channel, and can switch at a greater speed.

By combining transistors in different networks we can create different types of device: In analogue systems transistors were discrete devices[104] that accomplished only very simple functional tasks; in modern digital technologies transistors are formed into integrated networks that form logical or structural elements of the whole system – for example adding numbers, counting, timing or storing data. Often this additional complexity is controlled through the use of simple, hard-wired programming (also called firmware[105]) that can vary the actions of the device in response to changing external stimuli.

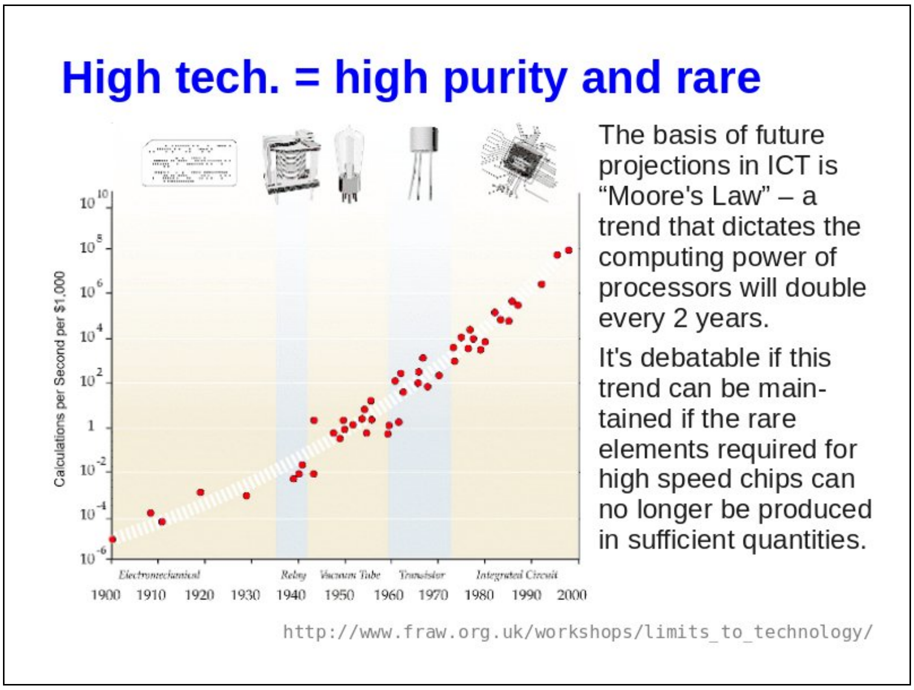
OK, so why is the structure of transistors so important? In field effect transistors – which are the building blocks of all modern computer chips – the 'gate' and the design of the conductive material below determines the operational characteristics of the transistor, and is critical to the development the latest generation of high-speed computer chips – where metals such as hafnium are essential to keep increasing the speed of operation[106]. Without these high-tech. devices, engineered to exacting standards using minuscule quantities of uncommon metals, the whole paradigm of consumer electronics – where packing more transistors into the same space[107] to increase power and reduce the cost (per unit of processing power) – would end.

Despite many statements to the contrary there is no such thing as "Green IT"[108]. The inherent characteristics of modern digital systems mean that they will always be low entropy, and therefore resource hungry, technological constructs. Despite the hype surrounding the idea of nano-technology[109] and its ability to make new super-efficient gadgets, this technology suffers from this same physical difficulties that afflict digital technologies in general; in order to engineer microscopic systems we will always have to invest the energy required to overcome the natural high entropy state of matter.

What this means is that there are physical limits – be they related to producing nano-scale devices, or simply a shortage of raw materials – that will affect our ability to produce ever more powerful transistor networks. In fact, it's not necessary for a raw material to "run out" in order to change the paradigm of digital/consumer electronics. All that needs to happen is that rising materials prices overturn the falling cost per unit of processing power that has driven the adoption of the transistor since it was first commercially produced half a century ago. When we reach this point it will create a problem for the technology dependent global economy, and so to understand what these limits will entail we need to look specifically at how technology drives the global economy.

4. High tech equals high purity & rare: d(ii). *The driving technological trend behind growth*

Technology is not passive – it's an essential factor in how society stimulates economic growth (which is why government's are fixated by scientific research and high technology). This of itself represents another limit as there are physical restrictions on how far we can push the miniaturisation of transistors and thus increase the power of digital technologies.



Just as transistors transformed the nature of consumer electronics in the latter half of the Twentieth Century, today digital electronics is once again transforming the nature of the economic system. As a result the energy demand from the use of information and communication technologies (ICT[110]) and consumer electronics[111] – presently 15% of global electricity consumption – has been forecast[111] to double by 2020 and triple by 2030[113].

This seems contradictory – *if these devices are far more energy efficient, why is their use causing energy demand to rise?* It's partly because they are more energy dense technologies, and so require more energy to produce (the low entropy issue, outlined earlier); but the main reason is that these "game changing" new technologies enable wholly new uses that were not possible with the previous generation of technology, and they often do so at a lower cost which enables far more people to buy them than before (e.g., the development of mobile phones). The result – higher energy consumption overall. In fact, over the history of the Industrial Revolution there has been a correlation between energy consumption and economic growth. The alleged "decoupling" of energy and growth over the last few decades in Europe or the USA is a statistical slight of hand – the growth in energy consumption has simply been exported to the manufacturing nations of Asia.

For digital technologies there is a trend that very simply demonstrates the importance of increasing processing power to the impact that these technologies have on the global economy – *Moore's Law*[114]. This states that every two years the power of computers double whilst their costs halve; it's this fourfold improvement in efficiency that's driving the growth of ICT as new systems are able to achieve greater economic efficiencies for the organisations employing them (call centres, on-line shopping, electronic distribution of print/multimedia works, etc.). The graph[115] in the slide above shows how this trend has reduced the cost of data processing (expressed as the number of calculations per second that can be bought with $1000) as each successive generation of technologies has led to increased speed and a reduction in size of electrical devices.

This trend is not a straightforward as it seems. As computers have become more powerful the software and the data they process has becoming more bloated[116] – and having to process more data means that the extra computing power is often nullified by the additional data load. Of course this could be reduced if we improved the utilisation of data through better programming, but whilst the power of digital systems continues to grow there is no economic advantage in writing better software. The planned obsolescence[117] of proprietary software also means that the imperative is to replace rather than upgrade systems, so incremental improvement is not an option. More importantly, the interaction of bloat and increasing power means that the speed advantage of cramming more transistors onto chips is not as great, and consequently the economic advantage to chip/system manufacturers to develop new digital devices is not as great either[118].

In future the constricting factors on the production of digital technologies are: The physical barriers of making chips smaller; a shortage of metals (such as indium, gallium, hafnium, or rare earths) used to fabricate the latest high-speed chips; and the diminishing economic returns of making more powerful chips. Individually or in combination these have the potential to end Moore's Law, and without Moore's Law the economic advantage of digital technologies will end too. Rather like the issue of peak oil and economic growth, the effects of ending Moore's Law could be equally significant to the ability of the Information Society to continue to "develop".

4. High tech equals high purity & rare: *e. Entropy and ecological footprint*

Any new technological system adopted by society has a tendency to redefine the relationship between the human species and its environment. The difficulty is that, for the last two hundred and fifty years of industrialisation, this effect has created more and more ecological damage. Digital technologies have perhaps the highest ecological footprint of all our previous technological systems.

High tech. = high purity and rare

The thermodynamics of digital electronics means that they will always be high energy systems in order to create the low entropy materials they contain.

E.g., a (rather old) study of a 32MB memory chip found that the 2 gram chip required 1,600g of fuel, 72g of chemicals, 32 litres of water, and 700g of gases to make it; the silicon for memory chips takes 160 times more energy to produce than standard silicon metal. ***A laptop memory chip takes more energy to make than using the laptop for it's 3 year lifespan. Four-fifths of the lifecycle energy of a computer (2,000kWh or 145 litres of petrol) is expended in production.***

http://www.fraw.org.uk/workshops/limits_to_technology/

The transistor replaced the power-hungry thermionic valve used by the first generation of consumer electronics in the first half of the Twentieth Century. Transistors used less power and so initially the switch to transistors in electronic goods saved energy. However, as electronic goods became cheaper to produce and operate, the number of devices in use increased rapidly to the point where the system consumed more resources and power than the previous generation did. This process, called the "backfire effect"[119], is common with other types of technological advances that redefine the economics of the way the economy operates. In general eco-efficiency innovations *rarely* save the amount that they are projected to in isolation because the greater economic efficiency in one sector of the economy allows the savings to be re-spent in other sectors; eco-efficiency creates further economic growth and thus a rebound in consumption[120] overall.

The fact that transistorised gadgets were smaller also meant that they could become portable[121], and this has in turn magnified the level of resource consumption[122] as mobile devices spawned the sale of disposable cell batteries[123] rather than the rechargeable 'accumulator battery'[124] that was popular with older valve sets. Like the steam engine or the thermionic valve before, the transistor's ability to miniaturise electrical gadgets created whole new applications that could not have possible existed using the limited capabilities of the previous technology. Such functional creep within technological innovations can also act to radically drive consumption further – and turn seemingly more efficient systems, that try to make the most of limited resources, into ones that ultimately consume more resources[125] by enabling an overall growth in economic activity.

Generally we only see a small part of the impact that our individual ecological footprint[126] – our demand for goods and services – puts on the planet[127].

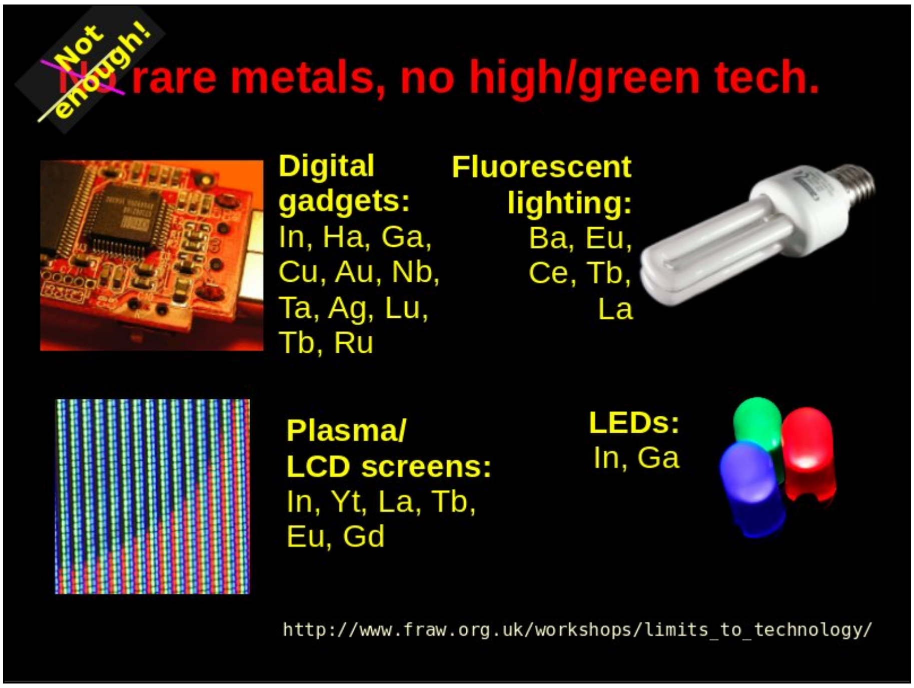
Whilst the effects described above work at the level of the whole economy/society, our individual use of digital technologies also has significant effects on our own ecological performance. Recent studies show how even the smallest parts of the electronic gadgetry that we use today can have large ecological impacts[128] – especially the production of computer microprocessor and memory chips[129]: The total weight of secondary fossil fuel and chemical inputs to produce and use a single 2-gram 32 megabyte DRAM memory chip are estimated at 1,600 grams and 72 grams respectively; use of water and elemental gases (mainly nitrogen) in the fabrication stage are 32,000 and 700 grams per chip; and the production of silicon wafers[130] from quartz uses 160 times the energy required for ordinary silicon metal.

A century ago our use of resources overall, compared to today, was smaller and their relatively higher price made a long service life and a high level of recycling/reuse the norm. The types of material we were using then were also more plentiful – as noted in slide 2d, modern technology relies on materials that, compared to our traditional use of iron, lead, tin or copper, are in far shorter supply.

Recent research suggests[131] that in the average lifetime of an American they will consume: 8,322 tonnes of phosphorus; 1,576 tonnes of aluminium; 630 kilos of copper; 410 kilos of lead; 349 kilos of zinc; 131 kilos of chromium; 58 kilos of nickel; and 15 kilos of tin – all relatively long-standing components of industrial technology. As the result of the boom in high-technology they will also consume: 6 kilos of uranium; 1.6 kilos of silver; 180 grams of tantalum; 48 grams of gold; 45 grams of platinum; 32 grams of indium; 10 grams of germanium; 5 grams of gallium; 4 grams of rhodium; and an unknown amount of hafnium and other rare earth metals. The effect of high technology has been to radically increase our planetary demand for rare resources.

5. Rare metals:
a. The essential elements of digital technology

Modern technology in general – not just electronics – is reliant on a variety of rare and unusual materials. Rather than looking at the "surface" of modern technology we need to delve down inside its inner workings, to relate the availability of resources to social and technological processes. Only then can we appreciate the impacts of resource depletion on our modern lifestyles.



Whilst relevant, the amount of a certain mineral that exists in the ground is not the prime determinant of how viable the use of a resource is. The theoretical possibility that someone, somewhere in the world owns the rights to dig up a mineral is not the limiting factor; what determines the accessibility and price of commodities, and the systems we create with them, is the value of *how much material we can produce to meet our needs today*. Therefore it's the long term sustainable level of production, and the economic and ecological costs of that level of production, that dominate the viability of any technology.

In addition, given that low entropy systems require large amounts of energy to create them, the viability of these low entropy systems is also contingent upon the cost or availability of the energy required to produce, process, purify and manufacture the raw materials into a usable device; and of course to affordably power/drive the wider system that the device is intended to be a part of.

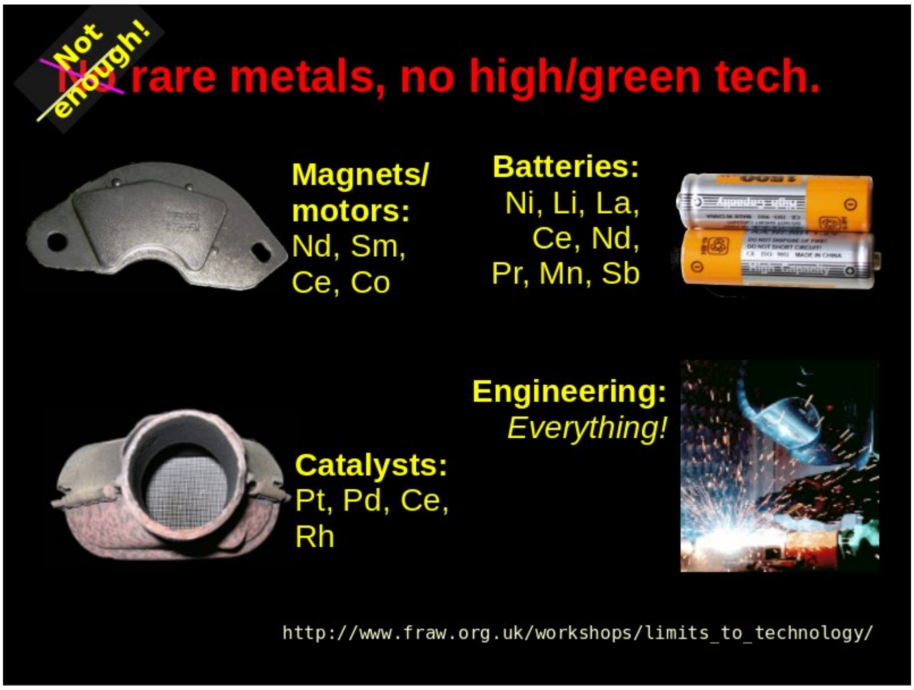
For this reason we can't say that "running out" of these materials is the principal limitation on our use of modern technology. The reality is that "not having enough to meet present demand" is the limiting factor because this raises the price of the material, and thus the finished product, and this changes the equilibrium between the technology and the wider economy. For those materials that require large amounts of energy to produce (e.g. silicon or aluminium), changes in the energy market (e.g., peak oil) could significantly change the way we use technology.

The result of any change to the economic equilibrium caused by using certain technologies will be that society will change their patterns of use – substituting their use of one device for another, using it more or less, or they might stop using it altogether. Due to the complexity of the modern economy how this process might work in response to the shortage of any one or a group of materials cannot be easily projected. It's as much an issue of politics, geopolitics and economic power (issues that we touch on later) as it is our technical ability to be more efficient in our production of goods in order to reduce costs.

In any case it's not just the amplification or switching capabilities of semiconducting junctions that are important to electronics. Whilst P-N junctions can also be used to control the flow of electrons, similar types of structure can be used to create light. Light emitting diodes[132], and their much hyped plastic-based replacement organic LEDs[133], use indium (In), gallium (Ga), cerium (Ce), terbium (Tb) and gadolinium (Gd) doping to convert electrical energy into light at a semiconductor junction. In solar photovoltaic cells[134] the process works in the other direction, converting light into electrical energy using a slightly different type of semiconducting junction. Whilst the older silicon cells used few additional metal elements, the latest thin-film solar[135] technologies use less plentiful metals such as indium, selenium (Se), gold (Au), gallium, platinum (Pt) or ruthenium (Ru).

Other technologies, from household lights to TV screens, use a variety of rare metals. In plasma screen displays[136] the phosphor[137] that emits light is in most cases a rare metal compound (e.g., europium, Eu). Liquid crystal displays[138] (LCDs), which use microscopic thin-film transistors[139] to create the image pixels, are also reliant on metal compounds such as indium (In), tin (Sn), cadmium (Cd), yttrium (Yt) and lanthanum (La). Even the energy efficient lights[140] that we're encouraged to buy to "save the planet" rely on metals such as europium and terbium to produce the range of lighting 'colours'[142] now available (older fluorescent lighting[141] used less rare antimony and manganese phosphors). The highly engineered electronics that drive the screen/lamp are also reliant of a variety of metals that are in short supply, such as copper (Cu), hafnium (Ha), silver (Ag), niobium (Nb), tantalum (Ta) and lutetium (Lu).

5. Rare metals:
b. The pre-requisite for green technologies



The great hope of those trying to combat climate change or waste and resource depletion is that eco-efficient "green technologies" – from fuel cells and industrial catalysts to renewable energy technologies – can be substituted for more ecologically damaging processes or technologies. In reality many of these technologies are reliant on metals that are rare, and this limits their viability.

"Green" or environmental technology[143] is a generic term for devices or strategies that seek to minimise the impact of industrial society on the planet. This might be by substituting new technologies for older, less efficient ones (e.g, lightweight aluminium for heavier steel), or completely changing the form of the technology for a less damaging one (e.g., electric cars to replace combustion engines). In reality there is no such clear distinction (e.g., using the examples above, aluminium takes more energy to produce than steel, and currently electric cars do not have a significantly better ecological impact than combustion engine vehicles[144]).

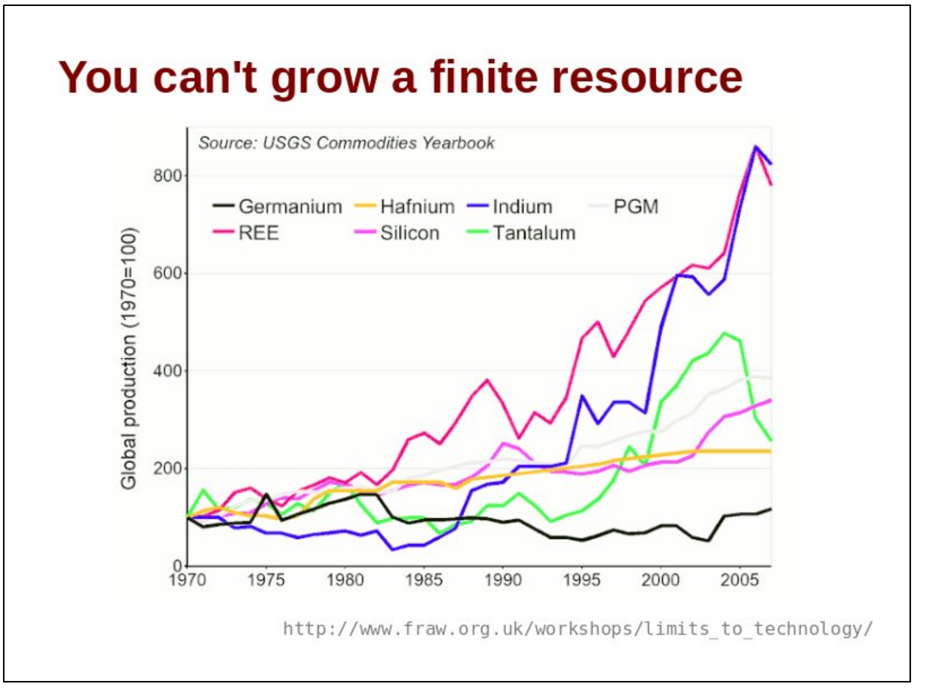
Whilst many of these technologies are undoubtedly "better" than the conventional systems that exist today, the fact that they are reliant upon resources that are in short supply does not mean that we can regard them as "sustainable". Whether a particular green technology is better depends not just upon whether we can make it cleanly, or whether we can use it more efficiently, but most importantly whether this use can carry on for generations without any problematic impacts accumulating.

The rarer metals, especially rare earth metals, have grown in importance to green technologies over recent years. A number of these elements have electro-chemical properties that make them ideal for use in different rechargeable battery technologies[145]: The oldest rechargeable battery technology, lead-acid batteries[146], now commonly uses alloy plates containing antimony (Sb), tin (Sn), or selenium (Se); nickel-metal hydride batteries[147], popular in new hybrid and electric cars because they're less volatile in a crash, are a complex cocktail of metals such as lanthanum (La), cerium (Ce), neodymium (Nd), praseodymium (Pr) cobalt (Co), manganese (Mn), and aluminium (Al) – as well as nickel (Ni); lithium ion batteries[148], the most charge dense and thus compact of commonly available battery technologies (which is why it is so widespread in consumer gadgets), uses primarily lithium (Li) and manganese in their construction. Fuel cells[149], which are proposed as the basis of the new "hydrogen economy"[150] (a flawed concept, for reasons too complex to explain here) are also reliant on metals such as platinum (Pt) and palladium (Pd). A number of these uncommon metals also have catalytic properties[151], which means they're widely used in industrial chemical production, industrial processes and pollution control systems – such as the platinum, cerium or rhodium (Rh) based catalytic converters[152] that reduce the pollution levels produced from car exhausts.

Finally many of these novel metal elements have magnetic properties[153] that, compared to the older iron/nickel/cobalt magnets you may have played with at school, are two or three times as powerful. If you can exert the same magnetic force with a smaller mass of metal then it is possible to miniaturise devices. As a result rare earth magnets[154] – utilising neodymium (Nd), samarium (Sm), cerium (Ce) and cobalt (Co) – are commonly found today in a range of electronic hardware: Most computer hard disks use rare earth magnets, such as neodymium, as part of their control systems; electric motors, such as those used in hybrid and electric cars, use rare earth metals to reduce the size and weight of the motor; many small power generating devices, most visibly rooftop/small wind turbines or wind-up devices, also use rare earth magnets in their permanent magnet alternators – and even some of the large grid-generation wind turbines now use permanent magnets to increase their efficiency (through the direct conversion of the rotary motion to electricity, using permanent magnet alternators, without the use of a gearbox and drive-train).

Without these uncommon metals many "green" technologies not function. Many new/efficient production techniques require these metals too.

6. Depletion:
a. Why you can't grow a finite resource



Economies have traditionally grown because "more stuff" can be produced, and where producing more is not an option substitutes have been found. That it not the case for many types of mineral as they often cannot be substituted in the role they perform (as chemical elements, there are often few simple or cheap alternatives). As we reach the limits of energy and resource production in general, these restrictions will bite ever harder.

We cannot "make" chemical elements – we can only use what is available. As described earlier in relation to the composition of the Earth's crust, the amounts of any mineral we can produce are restricted by the ore quality, where is occurs and its depth. The more low quality the deposit, the higher the input of energy and technology required to produce a return, and in turn the higher the cost of the material produced. As modern technology now relies on metals that are not widespread in the Earth's crust, the depletion of existing deposits, coupled with constraints on global energy production, raises questions about the sustainability of technological society in general, and the globalised growth-oriented economic system that modern technology supports.

If we look at the change in production levels of just a few selected metals (from the US. Geological Survey's data[155]), shown in the graph on the slide, we can see the way in which certain metals have taken on a more significant role in the global market. Rare earth elements[156] (REE), indium and tantalum have lept up in their relative levels of production compared to the other metals used for high-tech goods (silicon, germanium, hafnium and platinum group metals). This is because new semiconductor technologies, especially the miniaturised surface-mount devices[157] that are used in mobile phones and miniaturised digital equipment, are heavily dependent upon these metals (for example, many display screens use indium, and the capacitors on the circuit boards use tantalum). Whilst their production has slowed as a result of the recent recession, demand remains high.

Recycling[158] these devices, e.g. mobile phones[159], can recover some of the minerals that are used in their manufacture, but not all, and certainly not the entire quantity that they contain (it's the entropy issue – recovering most/all of the materials they contain would take an exponentially greater level of energy and processing). For this reason, like the example of copper earlier, these metals also have a restricted lifespan.

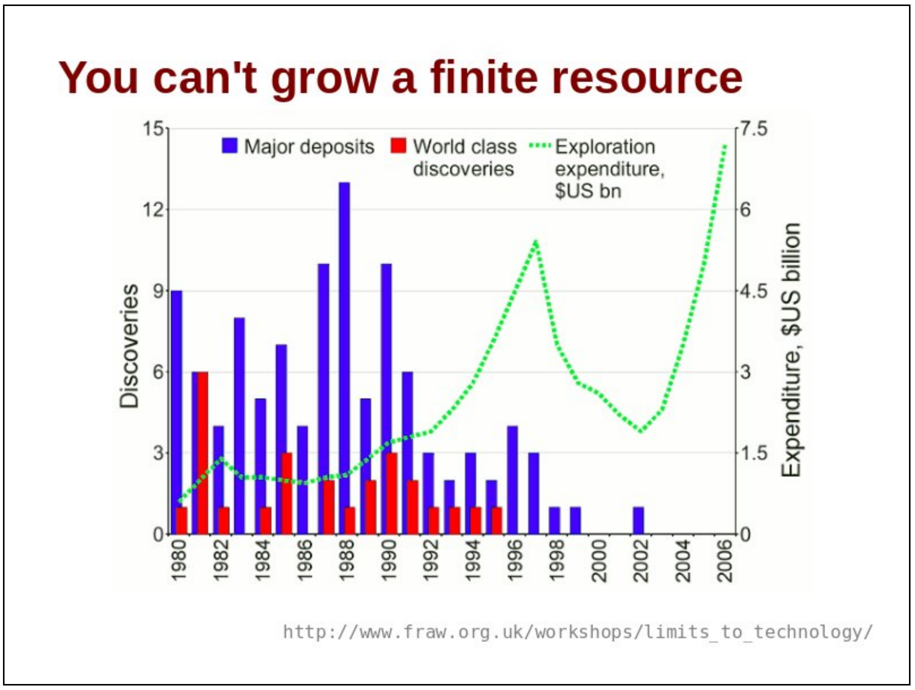
Another metal that is widely used in new gadgets, gallium, isn't shown in this graph because it's production has shot up 25 times higher than its 1970 production levels – *including it would have made the other data very difficult to read!* Gallium does not occur on its own as a distinct metal ore; it's a contaminant of other metal ores that is produced as a refining by-product. This limits production because so much of the primary resource would have to be mined – such as aluminium from bauxite ore[160] – that it would be economically impractical to refine the ore just to produce gallium. This means that, given its high rate of consumption, the demand for gallium could easily exceed supply in the near future, and for this reason gallium has been identified as one of the most critical of the high tech. metal resources[161].

If we look elsewhere we see a similarly problematic pattern: It is estimated that a fifth (e.g. zinc) to a quarter (e.g. copper) of the total metal resource has been removed from further use or recycling through the landfill of waste[52]. Landfill is a guaranteed way to increase the entropy level of the resources involved because they become mixed with all sorts of other problematic materials that restrict our ability to cleanly recover them from the waste; only incineration is worse because it tends to reduce many rare metals back to their oxide states, making their recovery a more energy intensive process.

If our use of metals is growing exponentially, but we are working within a finite resource base, then, like the example of copper used earlier, *we are always accelerating towards the limits of production.*

6. Depletion: *b. Peak discovery precedes peak production*

The commodity might be different but the geophysics of mineral extraction and production are broadly similar. As with the debate over global oil production, global minerals production, especially the rarer metals used in digital technologies, is now entering a period of uncertainty as some of the richest deposits go into decline, and geopolitical restrictions limit production from alternative sources.



Just as in the historic debate[162] over the global peak of oil production, the issue of future metals supply depicts two stark realities:

Firstly, just as with oil in the mid-1960s, there is evidence to show that the global discovery of metal deposits hit the buffers in the 1980s[167] (shown in the graph above) – and despite increased investment in mineral exploration there have been few significant discoveries over recent years. That's not to say that we will never find new sources of minerals, but statistically, as time passes, we will find progressively smaller and less concentrated deposits. This means that, for some of the most important mineral resources, we're producing more each year than can be found through exploration for new sources. As shown in the graph above, the problem is not investment – as economists often claim. Very large sums of money are being directed at the problem, but it is not producing the kind of return that it did in the past and consequently the level of new discoveries is declining. The mining industry requires either a large return on exploration investment, or very high prices for smaller returns, in order to stimulate exploration and investment in new production – as the returns on exploration fall the only option to maintain future exploration is for prices to rise even further.

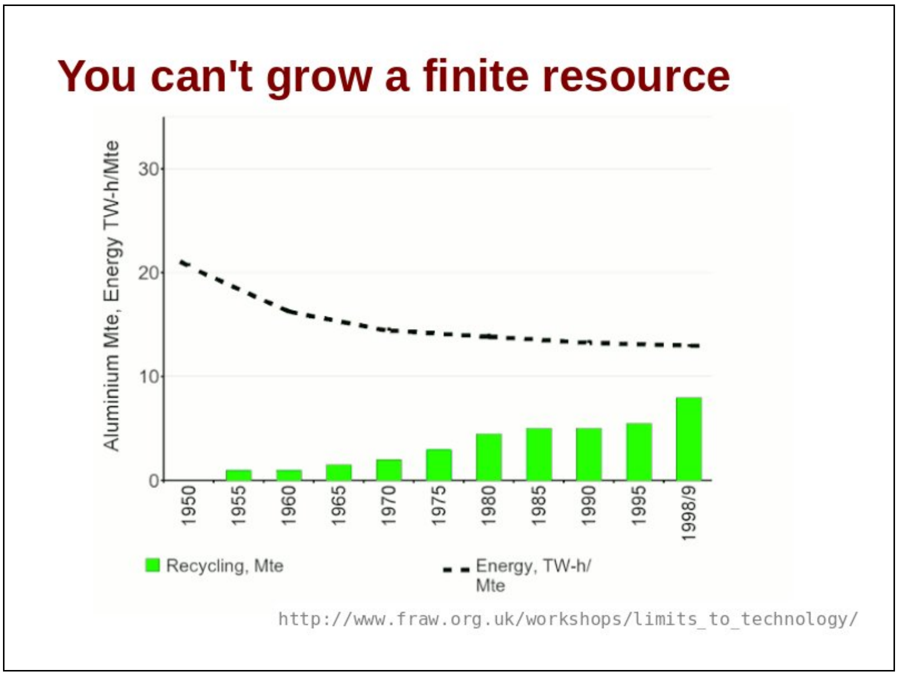
Secondly, given current trends, there is clearly evidence that in the near future our demand for certain minerals will not be met from the world's current production infrastructure. As is the case with oil[163], the global production and trade in many minerals is dependent on a few large sites producing a large proportion of global demand (e.g. Minera Escondida in Chile, described earlier, producing 9.5% of the world's copper). Eventually, as metal extraction and production continues inexorably, production too will hit a peak – "peak metals"[164] – and then enter a longer period of decline. As is the case with oil, there will still be minerals to work in the future, even after the peak of production, but as they are of a lower quality and in more extreme locations they will require more energy and resources to produce – and will therefore be significantly more expensive.

Certain minerals, such as copper, are reaching an historically huge level of demand and future production cannot possibly be matched from the remaining potential sources for more than a few decades. In other cases, such as gallium (described on the previous page), the material is a by-product from a process and expanding production further would require the uneconomic production (that is, we'd have to produce more than could be sold) of one resource to produce smaller amount of another – this again would raise prices.

Over the last few years there have been books written[165], science magazine[166] articles published, expert reports[167] and presentations[168] produced, and even scoping studies[169] commissioned by the European Union to see if a problem exists[170]. However, as has been the case with peak oil, the public, the "consumers" of these goods, have yet to be explicitly told about the problems that we face in the future. In part this is because, rather like the general unquestioning assumptions about the operation of the neo-liberal economic system[171], the groups that represent the economic consensus in Western states continue to promote the notion that there can never be a shortage of resources[172]. Such claims that "the economy will always deliver" are not technically wrong, *but they are not scientific either*. They are based on past observation, from an era when the production of energy or minerals was not constrained. Following confirmation of a global peak in oil (or gold/copper) production, such claims are unlikely to materialise because it changes the conditions upon which these processes have operated in the past.

6. Depletion:
c(i). Aluminium and the restrictions of eco-efficiency

Aluminium is not in short supply – 8% of the Earth's crust is aluminium. Even so, the changes to aluminium production in recent years show the limitations of seeking "greater efficiency" as a means of reducing environmental impacts and resource depletion. The difficulty is, against the background of growing demand, such measures rarely deliver a real-terms saving in impacts.



If you look at the graph above the data, from the point of view of improving the ecological efficiency of aluminium production, it looks very positive[173]. From the 1950s until the late 90's the energy used to produce a tonne of aluminium has fallen consistently. At the same time the amount of aluminium recycled has grown consistently. This data is of course expressed in parameters that are wholly separate from the demand for aluminium in total, and hence the total amount of aluminium mined and processed. In reality (as we'll examine in the next slide), and in contradiction to the spin of the aluminium industry, the ecological impacts of aluminium production have risen consistently over the last half century.

Aluminium[174] is one of the most energy-dense mass produced metals in use today. It's unlikely to run out as it is the third most plentiful element on the surface of the Earth (after oxygen and silicon). What might run out/be constrained instead are the energy sources required to process it from the its natural mineral ore, bauxite, into aluminium metal. This means that, even though aluminium is plentiful, decreasing the energy required to produce new metal and increasing recycling is essential to increasing the sustainability of the aluminium system.

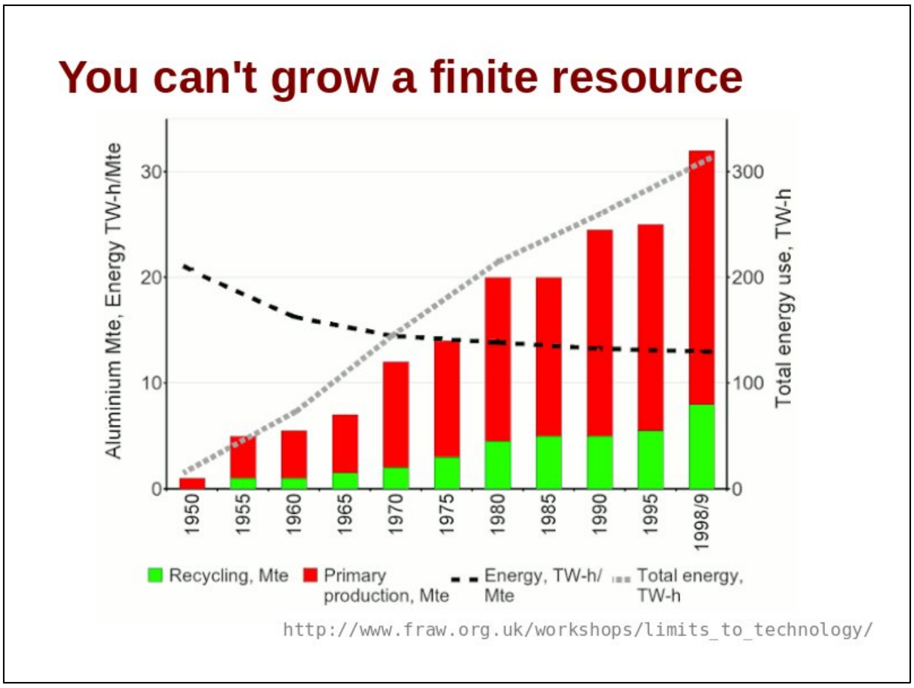
The graphs (above and in the next slide) show how the aluminium industry developed in the last half of the Twentieth Century. Over this period the amount of energy used to produce aluminium fell by about a third, whilst at the same time recycling went from zero to about a quarter of annual aluminium consumption. ***The problem is that over this same period aluminium consumption has grown by over twenty times, and even with the improvements in energy efficiency and recycling the total energy used to produce aluminium has risen fifteen times as a result*** (the *total energy line* on the next slide relates to the right-hand-side scale, which is ten times bigger than the left-side scale).

If we're short of something we could recycle our waste products and recover the resources they contain; it's one of the basic principles of eco-efficiency. In many cases, and aluminium is the most stark example, it takes a lot less energy to recycle materials than manufacture them from their raw material feedstock. Recycling can of course extend the lifespan of the materials we that have already produced, ***provided that the demand for their use does not grow***. Therefore the efficacy of recycling is not just about the processing of waste products, it's making sure that the demand for the material does not grow and continue to deplete the resources in the ground. Unfortunately such an approach is not on the agenda of the mining and metals industry whose primary aim is to maximise the return on the resources they own. In general (with the exception of some very special cases) eco-efficiency improvements to processes are limited and rarely exceed the average increase in demand created by economic growth.

Perhaps the most interesting feature of the reduction in energy use per unit of aluminium produced is not the amount of reduction, but the shape of the line – *it's an exponential reduction over time*. We see this shape all over the engineered environment, from the movement of heat through an insulated wall to the fall-off in material quality with increased levels of recycling. What this line represents is the restrictions of the Second Law of Thermodynamics – or perhaps the better known trend in economics, the *Law of Diminishing Returns*[175]. Theoretically it takes 6¼kW-h of energy to produce a kilo of steel. The reduction from over 20kW-h in the 1950s to nearer 12kW-h today represents a good improvement, but the thermodynamic restrictions mean that we will never reach that theoretical figure. The reductions that each new innovation makes as we move towards this total will, on average, save less than the previous one.

6. Depletion:
c(ii). Beyond eco-efficiency... there are limits!

The language of sustainability is the language of management and control. It's about the implementation of policies and strategies that seek to improve efficiency and ecological performance, but the overall growth of that system is not a matter for debate. The fact that there are ecological limits to growth, and that the limitations of eco-efficiency can't avoid them, challenges the political vision of sustainability.



If you look at the graph above you'll see how the limitations of eco-efficiency play out for aluminium. As industry uses more aluminium to replace traditional uses for steel – for example the 'lightweighting'[176] of packaging and vehicle bodies – the use of aluminium has grown rapidly. Consequently, despite "eco-efficiency" improvements, the ecological impact of aluminium is on average rising progressively year-on-year.

Whilst recycling/eco-efficiency measures might produce some improvement in the overall impacts of the use of bulk resources – such as paper pulp, aggregates or iron – recycling the rarer constituents of modern technology presents a wholly different set problems. There are complex issues related to economic theory about the behaviour of the economy in response to eco-efficiency measures; and the low entropy nature of these devices complicates matters further because of the minute quantities of materials involved. Greater efficiency creates greater economic productivity which drives the continued use, and even growth in the consumption, of finite resources.

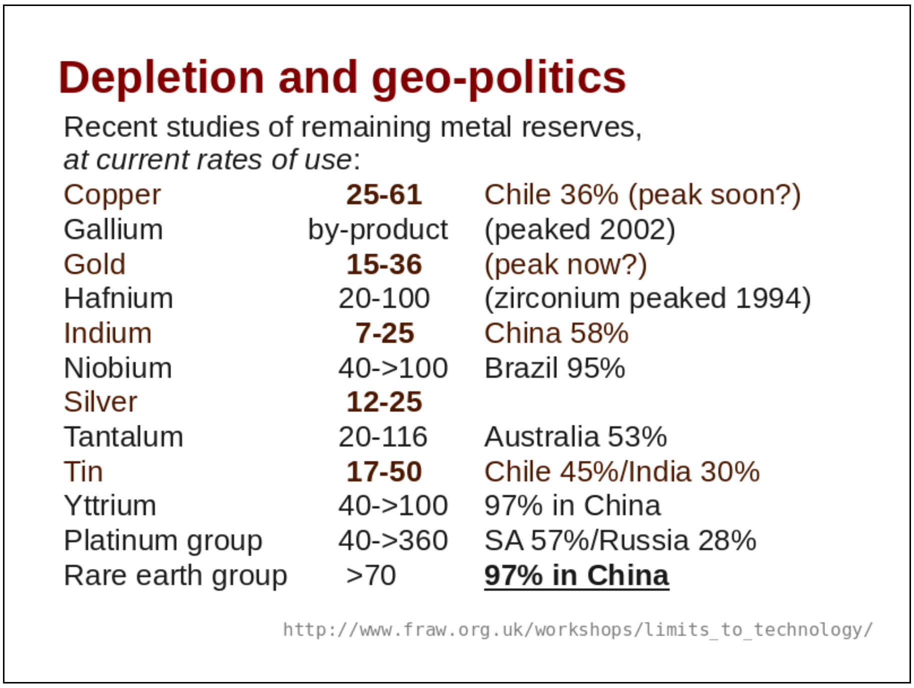
For the highly specialised minerals at the heart of modern technology the same is not necessarily true. If we are using metals such as hafnium or gallium at concentrations of parts per million, and even parts per billion, then conventional recycling is not suited to their recovery. We might recovery the "easy" constituents of mobile phones or computers – such as platinum, gold or tin – but the more exotic materials are simply oxidised and dispersed into the environment in the metals recovery furnace. Even for these metals, 100% recovery is not possible or economically practical – again, it's the restrictions of the Second Law of Thermodynamics. Consequently the use of these finite materials cannot be extended significantly through reclamation – arguably, as they are often occur in scrap electronics at lower concentrations than the mineral ores that they are produced from, producing new material from mined ore will always be more economically advantageous.

This presents a problem – aluminium may not be running out but there are many essential materials, used in minute quantities, which are. Action needs to be taken to safeguard their future availability, but unfortunately such discussions are not taking place. Instead of a realistic debate on the nature of the ecological limits to human society what we see is the adoption of new technologies – from wind turbines and smart meters to nuclear reactors – as a totem for the types of change that governments/industry believe will secure their ideal future. For example, the recent film, *The Age of Stupid*[177], shows how such technological fallacies can detract from viewing a problem in a more systematic way; rather than advocate limits to growth it promotes totemic technological solutions on the basis that, perhaps in a semi-conscious way, the piecemeal reorganisation of industrial society avoids the need for more fundamental changes to our lifestyle – *it allows us to hold the belief that by buying the right brand, or supporting the right policy, we can have our cake and eat it!*

In fact the evidence shows that major changes in consumption – having quantitively "less"[178] – are what is required. Such facts pose unwelcome consequences for the "Western"/consumerist outlook on life, and as a result the present debate on the environment and human society does not to encourage the public to look at these issues too deeply. As a result of this over-simplification the solutions promoted (e.g. *Age of Stupid*) create a flawed and misleading – perhaps delusional – over-confidence that we can manipulate the technological basis of society as a remedy, when in fact it is the growing use of these technologies that is the root of the problem.

7. Geopolitics:
a. There's only a generation of "the easy stuff" left

Conventional measures of mineral resources exclude the effects of growth. As we move into a more resource-poor world it also excludes the most important factor in the production of energy and mineral resources – *the private interests of nation states*. As we move from a period of "cheap and easy" into an era of "scarce and expensive" resources, geopolitics has resurfaced.


Depletion and geo-politics
Recent studies of remaining metal reserves, *at current rates of use*:

Copper	**25-61**	Chile 36% (peak soon?)
Gallium	by-product	(peaked 2002)
Gold	**15-36**	(peak now?)
Hafnium	20-100	(zirconium peaked 1994)
Indium	**7-25**	China 58%
Niobium	40->100	Brazil 95%
Silver	**12-25**	
Tantalum	20-116	Australia 53%
Tin	**17-50**	Chile 45%/India 30%
Yttrium	40->100	97% in China
Platinum group	40->360	SA 57%/Russia 28%
Rare earth group	>70	**97% in China**

http://www.fraw.org.uk/workshops/limits_to_technology/

Throughout the presentation we've rattled-off a lot of exotic names for minerals and metals that most people have not heard of – but the easy availability of which are essential to the "modern" way of life (there's a table in the "further information" section that lists them, along with their main uses, and there are links to on-line information sources for each).

We might talk of "how much" material we have in the world, but what's more important from the point of view of our present lifestyle is *the likely period we have left to use them*. The 'R/P' or "reserves to production" ratio[179] is a measure of how long our use of a resource can continue. We take the value of what we believe is in the ground, and divide by how much we're digging up each year, in order to project how many years of production we have left. The R/P figures (the second column) in the slide above combine data produced by the US Geological Survey[180] (USGS), the lead body on global minerals production, and from recent reviews by the European Commission[169] and other consultants[167]. In reality this is an erroneous figure because mineral resources reach a peak of production[33] and then enter a long period of decline. For this reason, well before the date predicted by the official R/P ratio, supply will become limited, affecting both the price and the availability of the technologies reliant on these metals. For some metals this has already happened. Gallium and zirconium (the source of most hafnium) production has peaked[32], and evidence is mounting, from industry sources[181] and from researchers[182] that gold production[183] has peaked.

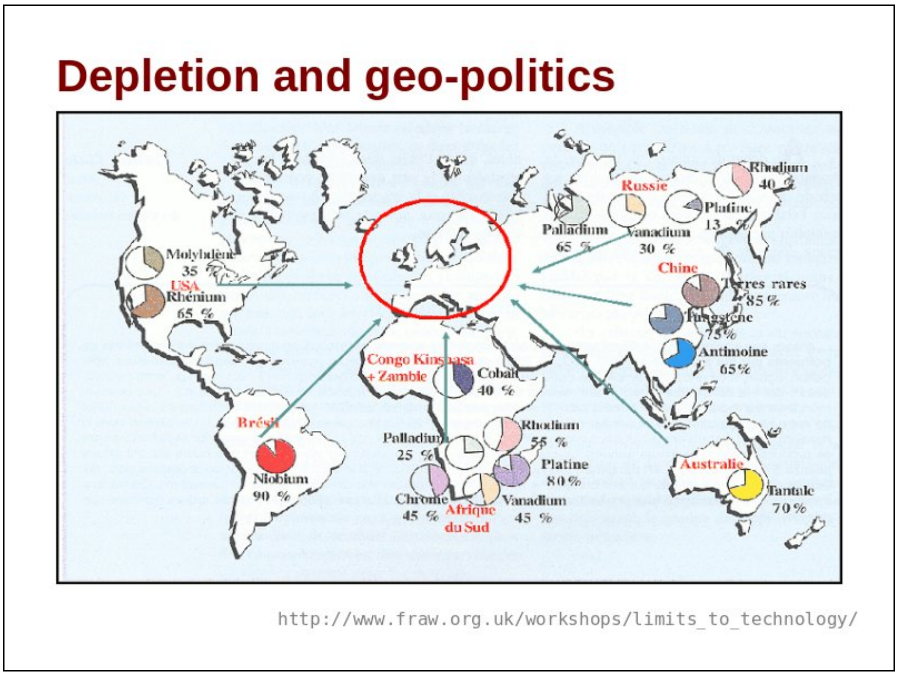
The last column of the slide lists the countries that produce the majority of the world's production. As noted earlier in relation to copper, for many metals a large proportion of production comes from just a few very large mines. Unlike conventional agricultural resources, where supply can be drawn from a wide area and can shift with the global market, mineral resources can only be produced where they are found. Like the issue of oil and the Middle East, as pressure is put on global metal resources just a handful of states will have the ability to dictate the form of the world's trade in high-tech minerals. As shown above, only a few countries produce a large proportion of the world's high-tech. minerals.

This is where the issue of "geopolitics"[10] arises. Unlike the Cold War, where the world was essentially divided by support for two rival camps, the new resource-related geopolitics of the Twenty-First century allows nation states – and also political, ethnic or religious groups within the areas of resource-rich states affected by mining – to use control over the flow of minerals to their own advantage. With just a few countries able to supply essential minerals they can have the power to dominate consumption by other nations. Conversely, and perhaps more damagingly for the well-being of the population, states with a weak government or civil society also have the potential to be destabilised by outside interests (an issue known as "the resource curse"[184]).

The issue about all metals generally – and the much rarer platinum group metals, hafnium, germanium, gallium, rare earth group, yttrium and indium in particular – is that the concentrations at which we find them naturally in the environment will determine how much we can produce. For this reason we will always be reliant on those nations whose land contain the right type of geological formations to hold the minerals that we need.

Ultimately it's our demand for these metals that's the problem; if we didn't want them then the problem of *poor-but-resource-rich* versus *cash-rich-but-resource-poor* nations would not arise. For this reason it's demand, not ownership, that drives the operation of resource geopolitics. *Like an addictive drug, it's those who "need" the energy or mineral resource that have the problem!*

7. Geopolitics:
b. Why we're reliant on a fragile global supply system



Two hundred and fifty years ago Europe was the first region to industrialise; as a result it has used much of its best mineral resources and is now dependent upon external sources of raw metal ores or refined metal. As the supply of the essential elements of high tech. systems are constrained it is the richest nations who will be exposed to the greatest disruptions due to a shortfall in production.

Only when metal ores are concentrated to a sufficient level above background levels are they economically viable to recover. In effect metal ores represent another level of entropy; the energy provided through the Earth's geological processes, usually associated with volcanic activity in the geological past, has concentrated many useful minerals into valuable veins of ore[185] against the general trend of homogeneous mixing that is the usual trend around the globe. The problem is that these ore bodies are so few and far between, and may be so deep or geographically remote, that our access to the "resource"[186] is limited to a small quantity compared to what actually exists in nature. Once these high grade deposits are exhausted, even though we may be surrounded by minute quantities of these elements in nature, it's not economically viable to recover them for use in mass production.

Today Europe is dependent upon the supply of essential minerals/metals from around the globe[169]. Whilst the US may have some of its own large sources, or potential sources should the economics (that is, price) change, the scale of resource use in the USA means that it's still not able to meet many of its essential mineral needs from within its own borders. Rather like the issue of oil and gas consumption, the issue of who has access to which mineral resources will come to dominate the global political agenda over the next few decades.

The clear concern here is the role of China, which has already said that it is going to restrict the export of rare earth metals[187] in order to ensure that it has sufficient supply to meet its own needs. Rare earth metals are absolutely critical[156] to the production of existing and new high tech. systems; the difficulty is that China's production of rare earth metals will only cover its own needs in 2012[188], meaning that the rest of the world will have to source their goods from China, or not at all, as China produces 97% of rare earth metals. This would hamper the production of the types of highly efficient "green technologies"[189] required to adapt Western society to lower energy patterns of activity. Certainly if China stopped rare earth exports[190] it's arguable that, compared to present scales of consumption, "there will be no more television screens, computer hard drives, fibre-optic cables, digital cameras and most medical imaging devices".

The reason that these metals are so useful is that they have unique properties at the atomic level. It's theoretically possible that in future certain nanotechnologies could replace some of these applications, but once again we're moving towards a more highly organised, low entropy and thus higher energy system of materials production and processing. These technologies have not been proven to be adequate replacements in any case, and their wider ecological impacts are still disputed[191]. The nanotechnology industry itself has still not fully quantified the impacts[192] these substances might have. For example, researchers recently proposed to weave carbon nano-fibres into clothing[193] in order to generate electricity, even though there are still no clear regulatory systems in place either to assess or control the hazards from such nano-tech gadgets[194] or to control their handling and final disposal[195].

What this all comes back to is *the entropy curve*. The more advanced and the more energised society becomes the further up the entropy curve we move. The difficulty is that we have to use proportionately more energy and specialised resources in order to do that. A failure in supply doesn't just result in a proportionate decline; it's an exponential decline, and so even small interruptions to energy or material supplies can have a very significant impact upon the societies that are wholly reliant on their utilisation. Therefore, *fundamental systemic insecurity within the modern lifestyle* ***is*** *the modern lifestyle.*

7. Geopolitics:
c. Why shortages can make us ignore our ethical principles

Our dependence upon scarce mineral resources poses some difficult questions for our "civilised society". If our computers and HDTVs require these resources then just how much are we willing to compromise to have them? This is not an abstract question – it's one that's already being played out in the global market for resources.

Coltan[196] has entered the public's consciousness through recent media coverage[197] on the trade in "blood metals", where slave labour[198] is used to produce the resources that generate the wealth to continue the military conflict in the Democratic Republic of Congo. Coltan is the mineral formerly known as columbite-tantalite, the ore from which niobium (formerly columbium) and tantalum are extracted. Unfortunately, for electronics manufacturers, and for the Congo, it's found in only a few places on Earth.

As depletion and geopolitics drive up raw materials prices so the industries that require these materials can become less choosy about where they come from. For this reason electronics, especially PCs and mobile phones, are becoming dependent on the trade in "blood metals" – exemplified by the case of Congo, where extraction fuels conflict[199] through the illicit trade[200] in valuable resources.

As with many such problems the response of consumers is to buy "certified goods" that have been audited and guaranteed not to contain materials from such sources. *This is possibly one of the most short-sighted and delusional approaches practised by the global market.* We buy things because we can afford to buy them. If this illicit material were not produced there would be a shortage of supply, prices would rise significantly, and so would the cost of the finished goods. Therefore, irrespective of whether you buy certified "conflict free" or "rainforest friendly" goods, the fact that these illicit supplies bolster the world market mean that you are still directly benefiting from their production through the lower price for what would otherwise be a very expensive resource.

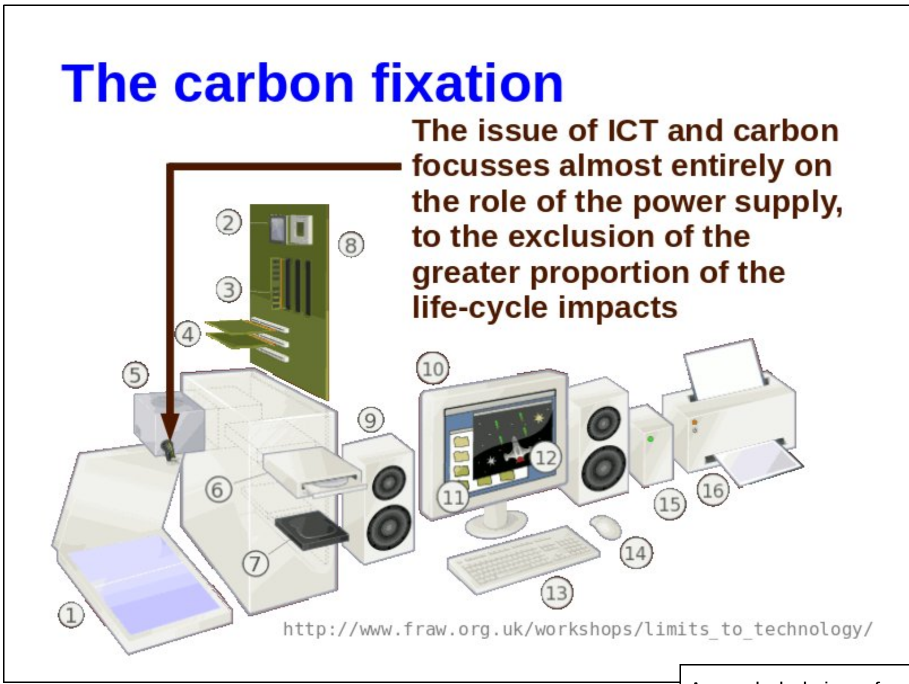
Coltan is used to create capacitors, small devices that store electrical charge. Tantalum and niobium have properties which enable them to do this extremely well, and so they are used to create the micro-miniaturised capacitors required by palmtop/laptop computers, mobile phones, hand-held consoles, and other small electronic devices. Congo is the source of much of the world's illicit coltan and, driven by the demand for mobile devices over recent years, as alternative supplies run short, Congo becomes more important in the global supply equation.

Africa is subject to various pressures due to the mineral resources that exist there. In the Congo it is extraction, but other areas suffer a different problem related to the resource cycles of modern technology. The highly complex mixtures of materials inside electrical gadgets, and the problems of recovering the substances they contain without causing any toxic pollution, mean that when many of these devices reach the end of their life they are exported from Western states to Asia and Africa for "recycling". In many West African states[201], India[202] and East Asia[203], this is creating a highly toxic legacy for future generations. As such schemes tend to only target the easy to extract metals (e.g. gold or steel) it means that the metals valuable to digital devices are scrapped or lost in the system. Even when old computers and mobile phones are exported to Africa for reuse they will still, after a short period (many digital devices don't respond well to the heat, dust and humidity of the tropics) be discarded – and the lack of any formal collection and processing for e-waste[204] in most Africa states means that they are unlikely to be responsibly recycled.

Geopolitics holds many difficult problems for the global political and economic system to resolve. It has the potential to break the global trade system since the only way for the consuming nations to coerce the producing nations into supplying them would be by force (economic or otherwise). For consumers too it creates a dilemma because, whether we buy certified goods or not, the illicit trade in minerals benefits us all through lower prices and plentiful supply – the only way out of the dilemma is not to consume! (we'll focus on this at the end).

8. The carbon fixation:
a. Limited viewpoints

Modern technologies are complex, contain a myriad of potentially harmful substances produced through polluting processes, and may source their raw materials from conflict zones; yet the debate over "green technology" is dominated by just one factor – electricity consumption and the carbon emissions generated. *This is not a realistic way to understand or solve these difficulties!*



An exploded view of a personal computer:
1. Scanner
2. CPU (processor)
3. Storage (RAM)
4. Expansion cards
5. ***Power supply***
6. Optical disc drive
7. Secondary storage
8. Motherboard
9. Speakers
10. Monitor
11. System software
12. Software
13. Keyboard
14. Mouse
15. Ext. hard disk
16. Printer

We commonly see new electronic or "eco-gadgets"[205] being advertised as being better for the environment because they use less electricity than the older version. This is a highly suspect claim as in most cases the use of electricity in the home or office represents one of the lesser impacts of any high-tech. device. In many different ways it is consumer electronics in general that is now driving demand[206] to a greater extent than the traditional corporate use of high technology (see next slide). However, unless we look at these systems in terms of their life-cycle impacts[207], rather than just looking at the current flowing down the power cord, then we're going to make some very stupid decisions about how best to interact with modern technology.

As noted in *Slide 4e* earlier, it doesn't make much difference to obsess about the power supply when four-fifths of the life-cycle impact of the machine is taken up by production and manufacturing. Even if you reduce the power use by a half, that's just less than a ten percent saving on the life-cycle impact – *arguably if you use the device for 10% to 15% longer than its design lifetime you'll save more than trying to find a more efficient power supply*.

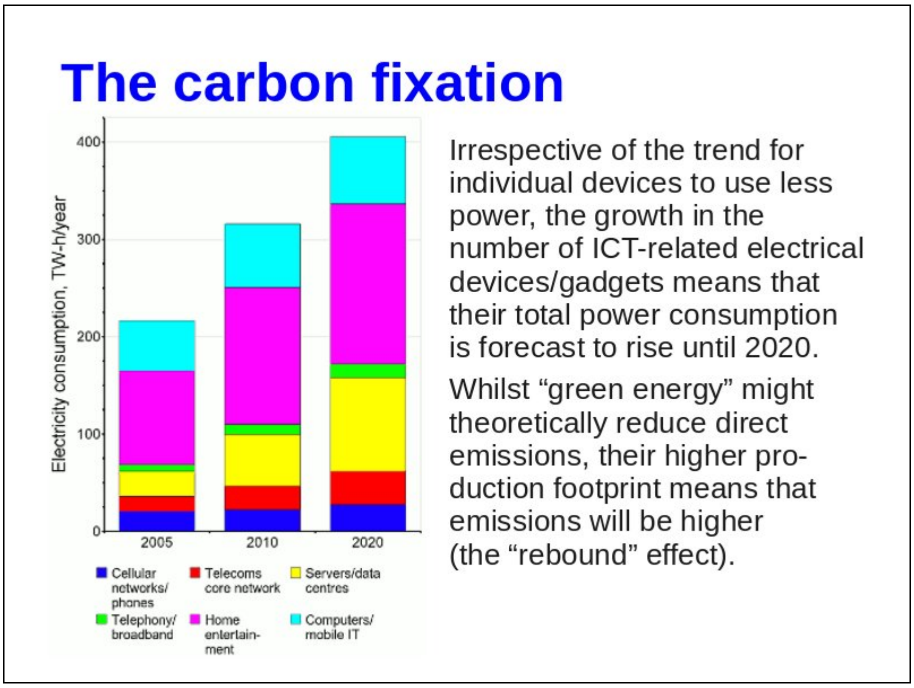
A good example of this problem is Apple's new iPad[208]. Shortly after its launch the Treehugger site had an article on the iPad[209] that's a good starting point for anyone thinking of getting one. Apple has made much of its recent efforts to remove toxins – such as brominated flame retardants[210] or PVC[211] – from their gadgets, but as yet they have absolutely no concept of the resource depletion issue. Removing toxic compounds actually helps their own profitability since the responsible use and disposal of toxic compounds brings with it a number of additional costs – "clean manufacturing" can cost less as a result. Unfortunately the issue of resource depletion raises questions for Apple's gadgets that cannot be easily resolved – especially as Apple's consumer base is dominated more by fashion-conscious "conspicuous consumption"[212] rather than "essential consumption".

As noted in the Treehugger article, the iPad's LCD display uses in-plane switching[213]; this technology requires two transistors per pixel instead of one – *more production energy, more resources, and thus a potentially greater impact*. However, as with most consumer products on the market, the comparative impacts of Apple's design criteria[214] are not part of the appraisal process for the environmental information produced on the iPad[215]. Apple could have opted for a less resource intensive display technology, but as yet such design considerations are not part of Silicon Valley's technical brief[216]. In the same way that the objectives and impacts of economic growth are not part of the assessment for most sustainability appraisals, the relative impacts of the features/specifications of consumer electronics are excluded from the debate on the environmental impact of goods.

Perhaps due to the separation of modern technology from the wider ecological debate, there seems to be a sense that people have the right to access[217] digital devices – irrespective of the impacts that they might have, or the impact on resource availability in the future. We may argue about air travel but digital footprints are equally dire. Even those who advocate an ecological viewpoint often end up trading vices over different means to perpetuate the use of these systems in a slightly more eco-efficient manner[218], even though objectively the resource constraints mean that such changes will make little difference to the outcome in ten or twenty years time.

8. The carbon fixation:
b. The growing impact of electronics

The debate on carbon steers clear of one of the most important realities – *we can't solve climate change and have conventional economic growth*. The carbon reduction options that growth-based economics can accommodate can't cut emissions quickly enough, or by the required level. The human ecological crisis requires a wholly new approach to meeting our needs.



The increasing level of electronic connectivity in society has an impact on carbon and resource depletion. As electronic networks grow they require more servers, and more power, and higher bandwidth in order to satisfy their users demand for more connectivity. What's been driving the demand for network processing power over the last few years has been "Web 2.0"[219] – making web services more interactive through designing content to be dynamically composed and configured to the needs of each user. Web server hardware is becoming more energy efficient, and so individually they use less power, but, like the general problems of eco-efficiency noted earlier, the increase in network demand is rising at a greater rate – and so overall the impacts of Internet use are rising rapidly[220].

Today the Internet and its associated gadgets and hardware is using about 5% of global electricity production[221], and producing as much carbon as the airline industry[222]. More recent studies commissioned by the European Union forecast[223] put the total electricity drain of ICT at about 8% of EU electricity generation, equivalent to 98 mega-tonnes (or 1.9%) of EU carbon emissions; this is projected to rise to 10.5% of electricity production in 2020 – *the results of this study are shown in the graph above*.

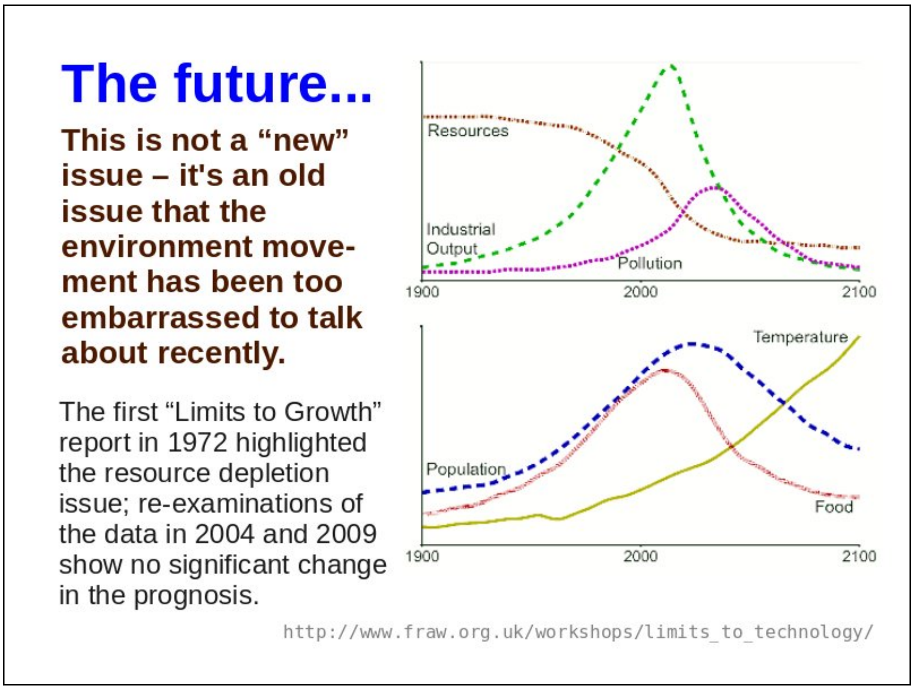
Recently claim and counter-claim[224] has been plastered across the media on precisely what the impact of a web search is, but whilst the impact of our individual actions on-line is open to debate, its collective impact is significant[225]. The problem is that, as with much of the fluster surrounding the disjointed and isolated examination of carbon emissions, studies of the impact of the ICT sector[226] primarily examine the power consumed in operation, not production and maintenance. In turn this means that the policies and strategies[227] based upon such studies, because they are ignorant of the life-cycle impact of production, are ignoring a large proportion of the total energy, carbon and resource impacts of ICT. Nor are such studies internalising the issue of resource depletion[228] within their scope or projections, and how the restrictions on certain essential resources used within the ICT sector might restrict the ability to change or improve present systems[229].

For example, take the latest "great concept" within the ICT world – *cloud computing*[230]. This is the idea that, rather than having your own powerful personal computer and a large capacity of data storage, you hold your data on-line on a "cloud". Effectively you use on-line services to rent the space and the processing power for complex operations, rather than everyone doing this in isolation at the point of access. The argument is that the power of computing can then be managed from highly efficient data centres[231], and by running services using the latest low energy hardware the energy consumption of ICT can fall[232].

This of course ignores two obvious problems with the structure of the ICT industry – *growth and bloat* (as noted earlier in slides 4d/e). For cloud computing bloat represents a problem because it creates capacity problems for the network and the servers that power it (as shown by the recent increase in the levels of data storage on servers[233], well above the increase in server capacity overall). This means that the efficiency of the system as a whole, not just the processing of the data, becomes critical to the overall environmental performance of ICT[234]. Recent studies have highlighted this problem[235], and note that, because the network as a whole does not work in an efficient manner, the savings claimed by cloud computing are unlikely to materialise; and, contradicting industry claims, recent research shows that the projected rise in data centre energy consumption is likely to be exceeded by up to three times[236].

9. The future:
a. "Limits to Growth"

For those interested in ecological limits not much of what has preceded this slide should be surprising *This is a debate that has been ongoing since the late 1960s*, and in the 1970s it spurred the formation of the environmental movement. However, as environmentalism has focussed on "consumer solutions", and influencing the political sphere, it has lost the insight of what "limits" mean for our society.



As noted earlier (slide 2c) the idea that humanity has limits to its development was first proposed by Thomas Malthus in the 1790s. In the 1960s this was given a modern view by Paul Ehrlich[237], and his book *The Population Bomb*[238]. Along with the works of other early environmentalists, such as Rachel Carson[239] and her book *Silent Spring*[240], it stimulated the modern debate on human ecology and the impacts of the human species. They influenced the development of the *Blueprint for Survival*[241], published in *The Ecologist* magazine in 1972, which in turn led to the development of the social and political lobby for the environment in Britain, including groups such as Friends of the Earth and the Green Party. The most significant development inspired by Ehrlich's work was the report commissioned by the Club of Rome, *The Limits to Growth*[242] (LtG). This took the basic capacity ideas argued by Ehrlich and others and used a computer model to simulate how the environment would behave as human impacts increase.

In the most simple terms we can illustrate the limits to human development by projecting future demand against the known finite capacity of the planet to meet those needs – a process refined by Professor William Rees and Mathis Wackernagel in the 1990s to produce the concept of the ecological footprint[126]. By combining various impacts and the capacity of the environment to sustain them we can gauge the "number of Earths" required[243] to support the demands of the human species – and the fact that we are already in a serious deficit on such measures is the reason that we have problems with climate change, species loss and pollution. This approach has also been used to illustrate the impact of different nation states on the global environment[244].

The *LtG* study uses a more complex computer model to project, using different scenarios, the likely change in trends as a result of the excess demand of the human species on the environment. This is not as simple as it sounds because certain effects, such as pollution or the effects of falling food availability on health and mortality, take time to have an effect on the global environment – creating a time lag in the impacts upon the system. By combining different impacts, and the ability of the environment to sustain them, the *LtG* study projected the change in human population, industrial output, food production, non-renewable resources and pollution.

At the present time the *LtG* study does not directly express the impact of climate change as part of its results – which is why we've added the *Temperature* line to the illustration of the scenarios illustrated in the *Limits to Growth* report (from the global temperature data predicted by the IPCC's *Fourth Assessment Report*). Many groups looking at the issue of energy depletion see the middle of this century as a critical period because, following the peak of oil and gas production, human society will have physically less energy each year to operate with. At the same time studies of the depletion of other mineral resources highlight the middle of this century as being the time at which some essential metals will begin to experience production difficulties[165]. Others, relating the fact that the issues of population, energy production, food production, water supply and climate change will all begin to have a serious impact around the middle of this century, instead talk of a "spike"[245] in the human system which, although not directly based upon the *Limits to Growth* study, broadly mirrors its findings.

By adding temperature to the Limits to Growth impacts we can understand something very important about the impacts of population and resource depletion – *long before climate change becomes seriously problematic to the human species the effects of population and resource depletion, <u>if unchecked</u>, are likely to cause a catastrophe within the human system.*

9. The future: *b. The 'elegant' solution*

The assumption within all public and corporate models is that not only is economic growth "good", but it must never stop. The reality is that this cannot continue – once energy and resource constraints bite, the conventional economics models will fall apart. We need a new approach, and if politicians will not countenance a change in development policy then it must be created by those willing to undertake a change in lifestyle.

The future...

The assumption in government policy is that we'll "innovate" our way out of the problem, as we have done in the past. That's an extrapolation from past trends (which we've been doing for the past 400 years).

Resource depletion invalidates the basis of the growth economy; it's not "the end of civilisation", just the end of growth for the sake of economic growth.

There is a very elegant and simple solution, but it involves a little reading, personal study and reflection on what to do with your life:

CONSUME LESS!

(I'd explain the detail but that's another gig in itself!)

It is not "wrong" to assume that we will develop new and better technologies and thus overcome any future restrictions on the human system. ***However it is not a proof either, it is an "article of faith" based upon a belief in economic models***.

Extrapolating past trends into the future relies upon assumptions about how the system performed in the past. Previously, because the human population was smaller and our demands upon the Earth were less, our activity was not constrained. In the future this is not true – there are demonstrable limits to our future use of resources, and the ability of the biosphere to mop up the impacts of this activity. These realities invalidate the simple extrapolation of past trends.

For example, *Hotelling's Rule*[246], named after the US mathematician Harold Hotelling, states that the price of an exhaustible commodity should rise in the short-term, but as people switch their demand to the alternatives the price will reflect the price of these alternative options. The problem for this theory, which underpins the idea that the economy will adapt to any problems that arise, is that there are no realistic alternatives for either the dense energy resources or the rare metals that modern society now relies upon. Just as high energy prices of 2005-8 precipitated the recent credit crunch[247], so the loss of non-substitutable resources will end the 250 year period of growth in the human system. In effect the abstract economic theory of *Hotelling's Rule* will be defeated by the hard ecological fact of *Liebig's Law of the Minimum*[248] – the observation that ecosystems are constrained by the least available resource.

Presently there is only one option that can pull the present trends in a direction that addresses these problems simultaneously – *a managed contraction of the global economy.* The observations of the early environmental movement in 1970s have not been invalidated; if anything the limitations on our future development are more pressing, and thus the outcome of present patterns of economic activity are seemingly more intractable – as shown in the recent re-evaluation[249] of the *Limits to Growth* (LtG) model by the Australia's scientific research agency, CSIRO[250], which concluded –

"The observed historical data for 1970-2000 most closely matches the simulated results of the LtG 'standard run' for almost all outputs reported; this scenario results in a global collapse before the middle of this century... contemporary issues such as peak oil, climate change and food and water security resonate strongly with the feedback dynamics of 'overshoot and collapse' displayed in the LtG standard scenario."

In Britain we will have to reduce our economic activity – or "have less" – to solve our present difficulties. Britain is in ecological and economic "overshoot"[251], and we must take action before we run out of energy, or money, or both. The realistic way to reduce our impact on the environment, and manage the decline in resources, is to reduce economic growth – also called "de-growth"[252]. Perhaps not directly, but because the strategies that make a significant difference to the level of energy and resource use will lead to a reduction in economic activity.

For example: The best way to reduce consumption is not to make things "more efficient", it is to make them last many times longer by manufacturing them to higher standard – consequently less are sold, and as a result the standard index of growth, GDP[253], will fall; likewise, as most of the energy and resources used by modern gadgets is expended in their production, the best way to cut energy and resource use is not to simply recycle the waste products but to adopt measures that mandate the repair and reuse of goods – the result over time being lower economic activity and thus negative growth.

9. The future:
c. Possibilities

Our use of technological systems, from the steam engine to the Space Shuttle, has developed against a background of the seemingly limitless availability of energy and material resources. The peak of production of oil, gas, copper or gold doesn't mean that this process will end, but we will have to adapt our use and our expectations to work within these new limits. These trends portend some very great changes to our use of technology.

The future...

We can still have digital electronics/the Internet in the future but they will have to work more slowly/with lower bandwidth.

At present more powerful computers are not deliverying significantly more capacity because each generational improvement results in a greater level of data/software bloat (*Wirth's Law*).

Resource depletion will make the price of all goods greater, but the trade-off will be the ability to make them last longer and perform more useful functions – *we must value them more!*

http://www.fraw.org.uk/workshops/limits_to_technology/

As noted earlier in slide 4d(ii), software and data bloat mean that the increasing speed of microprocessors hasn't led to a proportionate increase in the perceived speed of computer systems (*Wirth's Law*[254], the practical reality of *Moore's Law*). This is because the present models that dominate the production and use of software work towards designed obsolescence rather than qualitative evolution. It's the general trend for increasing power, and the resultant perceived obsolescence[255] of older technology that pervades consumer electronics (and consumer society in general[256]), *that is at the heart of the problems we now face*. To resolve these problems all we need to do is change the model of production.

The shortage of rare earth metals, indium and gallium primarily affect the high speed processors that have arisen over the last decade or so. If we were to focus on designing long-lived systems, utilising more common materials, then we could continue to have micro-electronics for many years to come. There is a very simple solution to bloat too, albeit one alien to Microsoft's business model[257] – *we redesign software systems, through incremental improvements rather than wholesale revision, so that they can run just as well on slower processors*.

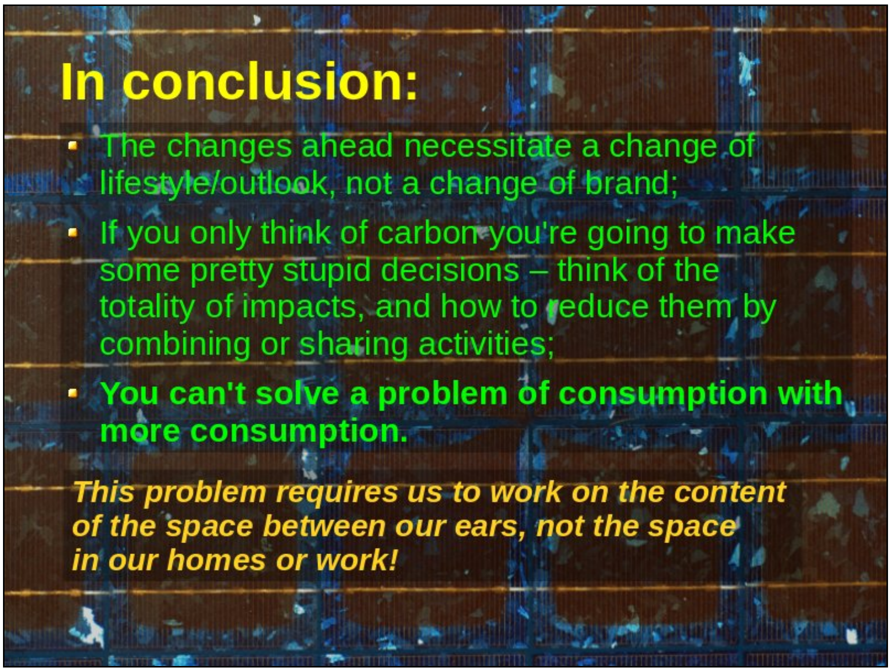
Of course, resource supply problems mean that the costs of all goods – food and other essential supplies as well as the more luxurious high tech. goods we routinely use in the most advanced nations – will increase. If we are to be able to use these high-tech. gadgets then, to have an equivalent cost, they will have to increase their viable operating life by a number of times (*if a computer costs three times as much, but you can make it last three times longer, then the equivalent cost is much the same*).

One of the problematic developments of the last decade has been the development of higher-bandwidth radio and TV services. Consider this: *Why do we need high definition TV*[258]*, blue-ray DVDs*[259] *and the like?* The answer is that we don't; this "need" is driven by the recent trend of having massive video screens in the home. Without high definition transmissions, enlarging the conventional image to fit the large screen makes it all chunky and fuzzy. With a conventional sized display the existing transmission/standard DVD contains sufficient information to produce a reasonable picture. As HD devices must also process and display far more picture information, it significantly increases their power consumption compared to standard display systems too. It's these kind of high bandwidth systems, dependent upon high speed microprocessors that utilise rare and increasingly scarce metals, and which consume more power than the alternative systems available, which are more likely to be excluded from the market by the pressures of resource depletion. Consequently it's to our advantage if we resist becoming dependent upon them today because that investment, if it produces no return or costs more to operate in the future, could be better spent elsewhere.

We've had a telephone system[260] for nearly a century; data was piggy-backed onto that system from the 1970s[261]. If we engineer systems in the future to internalise the need for "efficient utility", to be repairable and reusable using long-lived materials ("permaneering"[262]), there is no reason that we can't have computers, electronic communications and related technologies in the future – provided that we design-out the energy and resource problems inherent in current technologies. Digital broadcasting, not just TV and radio but also the ubiquitous use of mobile phones, may have a greater problem because of its inherently high energy and resource consumption. Given the apparent dependence of people upon mobile devices their loss may involve some more uncomfortable changes for modern society.

10. Conclusions

In a pessimistic sense the outlook is grim – *but that's only if we are unwilling to change and adapt ourselves to resource depletion*. We can change the present system but that's clearly "business as *unusual*". For this reason it's not on any mainstream political agenda, *but if we accept this political inertia these problems will develop into a major crisis!* We must act to ensure that inertia "from the top" does not prevent individuals starting their own process of adaptation today.



We have many declarations from governments and corporations about addressing climate change or improving performance through 'green growth'[263]. In reality these measures will not and cannot address the problem because they are not looking at the interaction of systems. Instead they focus on simple inputs to isolated processes because that's the type of construct that the business world understand and work with. These problems may finally have begun to enter on the fringes of the mainstream print[189] and broadcast[264] media, but as yet, like the more high profile problems of peak oil or energy security, they are not part of the main political agenda. From our experience of discussing these matters with politicians, this is because these difficulties cannot be resolved within the present neoliberal economic consensus – *it represents problems and changes that are not "business-as-usual" for our existing governmental institutions!*

Even so, that does not mean that the average person need sit and wait for action from the top. Many of the problems that will be created by the limits to human development will initially be felt as an inconvenience to our everyday lifestyles – high prices forcing us to cut our budgets on luxuries, power cuts, load shedding[265], problems with just-in-time delivery[266] systems, and the knock on effects that these difficulties will have on public and private services. Solving these problems isn't a matter of walling yourself off, or buying lots of goods and gadgets to see you through, it's about developing a dynamic resilience to these challenges by improving your own skills and capacity to solve problems.

Often the term "resilience" is used, particularly in relation to the recent panic over terrorism, to mean being able to react and continue working the same way[267] afterwards. We use this term in its ecological sense[268], because when these problems begin to obstruct our present lifestyle patterns we'll have to adapt and change to meet each successive tightening of the ecological limits on humanity as they arise. If we rely on "tools" – *gadgets or technology* – to support ourselves then these can break, be lost, stolen, or just wear out. If we focus instead on the "knowledge" we carry in our heads, the basic skills of supporting ourselves, feeding ourselves and working with others to provide local networks of support – *as human communities have done for millennia* – then we develop a far more secure and resilient way of living.

It's for this reason that the greatest change we need to make is not the brands we buy, it's being able to supply more of our essential needs ourselves. That requires that we develop a vision of what our lives, and our future, will be devoted to; and in turn that requires us to develop a personal vision for change. As this must relate to your own capabilities it's not something that you can be simply taught or bought "off the peg" – we have to devote ourselves to a long process of self-development.

In terms of how that relates to technology, and the resource constraints on our future use of complex systems, this process of change is absolutely related to your own skills and abilities. Individuals within human societies have always specialised their skills in order to provide for their needs[269]; the most well used, day-in-day-out skills of cooking or growing food are shared by all, but the more highly developed skills (pot making, woodwork, or electronics and engineering today) tend to be centred around small groups of people – many of the early studies of economics[270] focussed entirely on such relations in society. Developing a secure future is about developing your own basic skills of resilient self-support, but also developing networks of reciprocal relationships within a community of other interested people around you in order to secure your more specialised needs.

11. The end of now... *sometime!*

Accepting you have a problem is the first step to doing something about it; without acceptance we cannot act to change our lifestyles. If we proceed from a simple "belief", because others have told us so, then again action cannot have certainty. If we are to devote ourselves to building a world within the limits of energy and resource availability that will apply themselves over the next few decades, we have to begin by educating ourselves – and then proceed to consciously change our world.

Our personal knowledge forms our view of the world. Understanding not only confers an ability to interact with the world, it allows us to envision a different way of being and act to change our world to make that different vision become a reality.

A "crisis" is a "problem" that's been ignored for too long – how you relate to these problems will therefore define how bad they become. Don't ignore these issues, but don't panic either – often the media or political groups talk-up a "threat" in order to augment their own power or credibility; in reality the "threat" is not an issue that applies to all. For example, if the global peak in oil production makes oil prices rise to levels where air travel becomes very difficult, then for those who regular fly abroad that's a great inconvenience – *for those who choose not to fly at all it makes little difference*.

We can't "solve" this problem – there is no "solution" that addresses the complex difficulties of resource depletion *AND* which can maintain the current form of mass consumption society – *the two are mutually exclusive*. However difficult it may be we have to resolve these problems by accepting that change is not only necessary, but if we fail to change our lifestyles sufficiently, it will be imposed upon us by the shortage of resources that will develop over the first half of this century. This represents a profound change to our lifestyles. Certainly it's something that's difficult to adopt because it challenging many of the certainties about our world that, unquestioningly, we accept as fact.

If that's a little overwhelming consider this – *if it's not "bad enough" to begin to change your lifestyle today, what would you describe "bad enough" to be in the future? – and by then could you begin to change your lifestyle as easily as you might begin to do so today?* ***If not now, then when?***

What next?

This paper has been developed to accompany the "Limits to Technology" workshop/presentation produced by Paul Mobbs and the Free Range Network. It's designed to be an *aide-mémoire* and guide to the many other sources of information that exist on the issued covered in the presentation. **To this end it's extensively referenced; *these references are not for decoration – if you are unsure about certain terms, or you want to develop your depth of knowledge about certain elements of the presentation, follow the links/references in order to learn more.***

If you're just reading this, and haven't been to the workshop/presentation, then go to the Free Range Network's website for this presentation to learn more: **http://www.fraw.org.uk/workshops/limits_to_technology/**

This initiative has been developed as an extension to the Free Range Network's previous work around the issue of energy and resource depletion, and the different ways in which it affects our lives. For further information on this issue see:

The Energy Beyond Oil Project – http://www.fraw.org.uk/projects/energy_beyond_oil/

The Salvage Server Project – http://www.fraw.org.uk/projects/salvage_server/

The Great Outdoors Project – http://www.fraw.org.uk/projects/great_outdoors/

The Free Range Network organises various events, and works with other groups around the UK, to develop training and information workshops. Details of future events can be found on the Free Range Activism Website – **http://www.fraw.org.uk/** – and if you are interested in organising an event locally then get in contact with us – **frn@fraw.org.uk**.

References/further information

The technically problematic elements

Element/use	R/P*	Peak year	Supply source %
Copper (Cu) *plumbing, roofing, alloys, medial applications, cables, efficient electric motors, micro-electronics, solar cells*	25-61	2015-2035	Chile 36%; Peru 8%; USA 8%
Gallium (Ga) *LCD displays, solar cells, micro-electronics, white/organic LEDs, medical therapies, metal alloys*	by-product	2002	no data available
Germanium (Ge) *solar cells, fibre optic cable, infra-red optical systems, high index glass lenses, industrial catalysts*	by-product		no data available
Gold (Au) *medical therapies, micro-electronics, anti-corrosion coatings, financial commodity*	15-36	2001?	Can. 13%; SA 11%; USA 10%; Aus. 10%; Peru 8%
Hafnium (Ha) *micro-electronics, metal alloys, plasma-arc cutting tools*	20-100**	1994**	no data available
Indium (In) *LEDs/organic LEDs, touch-screens, micro-electronics, solar cells, cryogenics, superconductors, medical imaging*	7-25		Ch. 58%
Lithium (Li) *batteries, medical therapies, high temp. lubricants, special metal alloys (especially aircraft), nuclear power*	>70		Chile 44%; Aus. 25%
Manganese (Mn) *steel/aluminium alloys, batteries, chemical processes*	25-50		SA. 21%; Ch. 20%; Aus. 16%
Niobium (Nb) *micro-capacitors, specialised metal alloys, super-conducting magnets, high refractive index glass/lenses*	40->100		Brazil 95%
Silver (Ag) *hybrid cars, solar cells, concentrating solar mirrors, emissions control, nanotechnology, micro-electronics, lead-free solder, photography, industrial catalysts, medical applications*	12-25		Peru 17%; Mex 14%; Ch. 12%; Chile 10%
Tantalum (Ta) *batteries, micro-electronics, medical applications, specialised alloys (high temp. nuclear and military applications)*	20-116		Aus. 53%
Tin (Sn) *lead-free solder, electrodes, metal alloys, glass production*	17-50		Ch. 45%; Ind. 30%
Yttrium (Yt) *display screens, lasers, superconductors, LEDs, medical therapies, gas mantles*	40->100		Ch. 97%

Platinum Group Metal (PGM)	42-360	SA 57%; Rus. 28%
Platinum (Pt)	fuel cells, hybrid cars, pollution control catalysts	
Palladium (Pd)	fuel cells, industrial catalysts, seawater desalination, micro-electronics, medical applications	
Ruthenium (Ru)	solar cells, metal alloys, wear-resistant metal coatings (switches/pen knibs), thin-film micro-electronics	

Rare Earth Elements (REE)	>70	Ch. 97%
Cerium (Ce)	magnets, welding , fuel cells, glass production	
Dysprosium (Dy)	lasers, nuclear reactors, magnets, motors, nano-fibres	
Erbium (Er)	metal alloys, glass production, lasers, medical apps.	
Europium (Eu)	lasers, plasma displays, fluorescent lighting	
Gadolinium (Gd)	medical therapies/imaging, nuclear reactors, displays	
Lanthanum (La)	batteries, electron microscopes/imaging systems, catalysts, medical apps., welding, high-power lighting	
Lutetium (Lu)	catalysts, medical applications, micro-electronics	
Neodymium (Nd)	hybrid cars, magnets, audio pick-ups, lasers, electrical components, glass production, cryogenics	
Samarium (Sm)	hybrid cars, magnets, high-power lighting, catalysts	
Terbium (Tb)	display screens, micro-electronics, magnetic sensors	
Ytterbium (Yb)	fibre optics, lasers, steel alloys, medical imaging	

** where reserves-to-production (R/P) ratio is a single figure, calculated from USGS data; where it is a range, sourced from reports on mineral scarcity. ** resource is a by-product, figures represent the data for the primary resource. Abbreviations: Aus, Australia; Can, Canada; Ch, China; Ind, Indonesia, Mex, Mexico; Rus, Russia, SA, South Africa.*

Note: if you click on the name of the element you can go to the Wikipedia page that describes it. If you click on the symbol for the element (in brackets) then you can go to the USGS's information page for that metal/group of metals.

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▪ platinum group metals (PGM) – http://minerals.usgs.gov/minerals/pubs/commodity/platinum/;
▪ rare earth elements (REEs) – http://minerals.usgs.gov/minerals/pubs/commodity/rare_earths/
- **6b. Peak discovery precedes peak production.** Created by Paul Mobbs, released under the Creative Commons Attribution Share-Alike license 3.0. Source data from *Material Scarcity – An M2i study*, Huib Wouters and Derk Bol, Stichting Materials Innovation Institute, November 2009 – http://www.m2i.nl/images/stories/m2i%20material_scarcity%20report.pdf
- **6c(i/ii). Aluminium and the restrictions of eco-efficiency.** Created by Paul Mobbs, released under the Creative Commons Attribution Share-Alike license 3.0. Source data from: *Material Scarcity – An M2i study*, Huib Wouters and Derk Bol, Stichting Materials Innovation Institute, November 2009 – http://www.m2i.nl/images/stories/m2i%20material_scarcity%20report.pdf ; *The Aluminium Industry's Sustainable Development Report*, The Aluminium Institute, 2002 – http://www.world-aluminium.org/cache/fl0000107.pdf ; and *Aluminum*, Mineral Commodity Surveys (MCS), US. Geological Survey, 2009 – http://minerals.usgs.gov/minerals/pubs/commodity/aluminum/
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▪ *Faced with a gun*, Global Witness, July 2007 – http://www.globalwitness.org/fwag/ ;
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- **9a. "Limits to Growth".** Created by Paul Mobbs, released under the Creative Commons Attribution Share-Alike license 3.0. Source data from *Limits to Growth – The 30 Year Update*, Donella Meadows, Jørgen Randers and Dennis Meadows, Earthscan, 2004, ISBN 9781-8440-7144-9 (paperback), £14.99.
- **9b. The 'elegant' solution.** Created by Paul Mobbs, released under the Creative Commons Attribution Share-Alike license 3.0. Imaged sourced from OpenClipart: 'Look It Up' – http://testvm.openclipart.org/detail/johnny_automatic_look_it_up.svg – artwork by 'johnny automatic' – http://testvm.openclipart.org/user-detail/johnny_automatic – and is public domain.
- **9c. Possibilities.** Created by Paul Mobbs, released under the Creative Commons Attribution Share-Alike license 3.0. Image sourced from OpenClipart: 'Local Operations and Classical Communication' – http://testvm.openclipart.org/detail/boirac_Local_Operations_and_Classical_Communication.svg – artwork by 'boirac' – http://testvm.openclipart.org/user-detail/boirac – and is public domain.
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