Cientifica Ltd

Using Emerging Technologies To Address Global Risks

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Cientifica Ltd

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- Company restructuring
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Cientifica's twenty years of expertise in technology business allows us to quickly evaluate a new business proposal. Our unique combination of in depth technical knowledge with practical experience of venture capital and public funding enables us to advise businesses from start up to sales.

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Foreword

What Is Technology For?

This is a question that often comes up in my dealings with global policy makers who spend huge sums on scientific research while simultaneously being fearful of its consequences. Many believe that it is somehow important for the economy in an undefined and non-quantifiable manner, or that it is some kind of logical next step along the path that starts with scientific curiosity. Perhaps a better way of viewing technology would be as a mechanism through which science is applied to meet the needs of society, and that holds true whether the needs of society are getting rich quick, curing cancer, or both.

But there is another less beneficial view of technology. The idea that technology is responsible for environmental degradation, especially when coupled with population growth, is a powerful one that has held true since the industrial revolution. It is human nature to fondly imagine an agrarian pre-industrial utopia, while forgetting the regular plagues and famines that resulted in an average life expectancy of 35 years in pre-industrial Britain. The idea that technology is a bad thing is a situation that has existed for much of the 20th century and persists into the 21st, partly as a result of confusion between technology itself and those individuals and corporations who control and exploit it.

But it is time for a change. In fact a change is inevitable. Human history is littered with technological advances that have changed everything, and much faster than anyone could have imagined. The agricultural, industrial and information revolutions have resulted in massive changes to the economy, society and the way in which we interact with the environment.

Since the second world war, science and technology have moved faster and had a more profound impact on human society than at any other point in human history. We have moved from black and white television exploding onto the market in the early 1950s to more than 800 million people using Facebook within 60 years. While television took 3 decades to diffuse around the world, Facebook did it in 3 years. Technology has driven economic growth around the world and led to vast improvements in the quality of life for much of the global population, but it has come at a price: the rise of consumerism has resulted in environmental degradation on an unprecedented scale.

It is time to reappraise our relationship with technology and take control of its direction. With an increasing global population becoming ever more affluent, the pressure on resources coupled with climate change will inevitably lead to more wars, water shortages, famines and mass migration. Or will it?

After 30 years of working in advanced technologies, from developing new materials and detectors for the European Space Agency to working with the United Nations and World Economic Forum on technology policy, I am convinced there is a better way to use technology. If profound economic, societal and environmental changes are inevitable then why do we still address them in the same way we have for millennia, by being helplessly reactive? In the 21st century, science and technology has advanced to a stage where we can start taking control of the fruits of scientific progress rather than being powerless in the face of their development and exploitation.

We already have many of the technologies we need to address major global problems such as water shortages and disease, and there is no reason why inevitable environmental disasters such as oil spills still have to be tackled using antiquated technology when a hundred million dollars could give us the technologies to reduce the impact of future oil spills to almost zero. Many other emerging technologies are being developed that would allow the world to support 10 billion people without compromising the tremendous growth in quality of life that has taken place over the last century.

This report looks at how we can harness technologies for the global good. While we still lack the political will and necessary international institutions, we now have the knowledge and the tools to make the transition from being mere consumers of, and in some respect slaves to technology, to making use of the new scientific revolution to mitigate and minimise global risks. While it would be foolish to claim that the wise use of science and technology will usher in a utopian age, there is little doubt that we now have the tools to create a sustainable and responsible world where human suffering and environmental degradation can be alleviated while maintaining economic growth. The alternative future, and one we may be sleepwalking towards, is the post apocalyptic or dystopian one of *Mad Max* and *The Road*.

Tim Harper, Ilkley, October 2011

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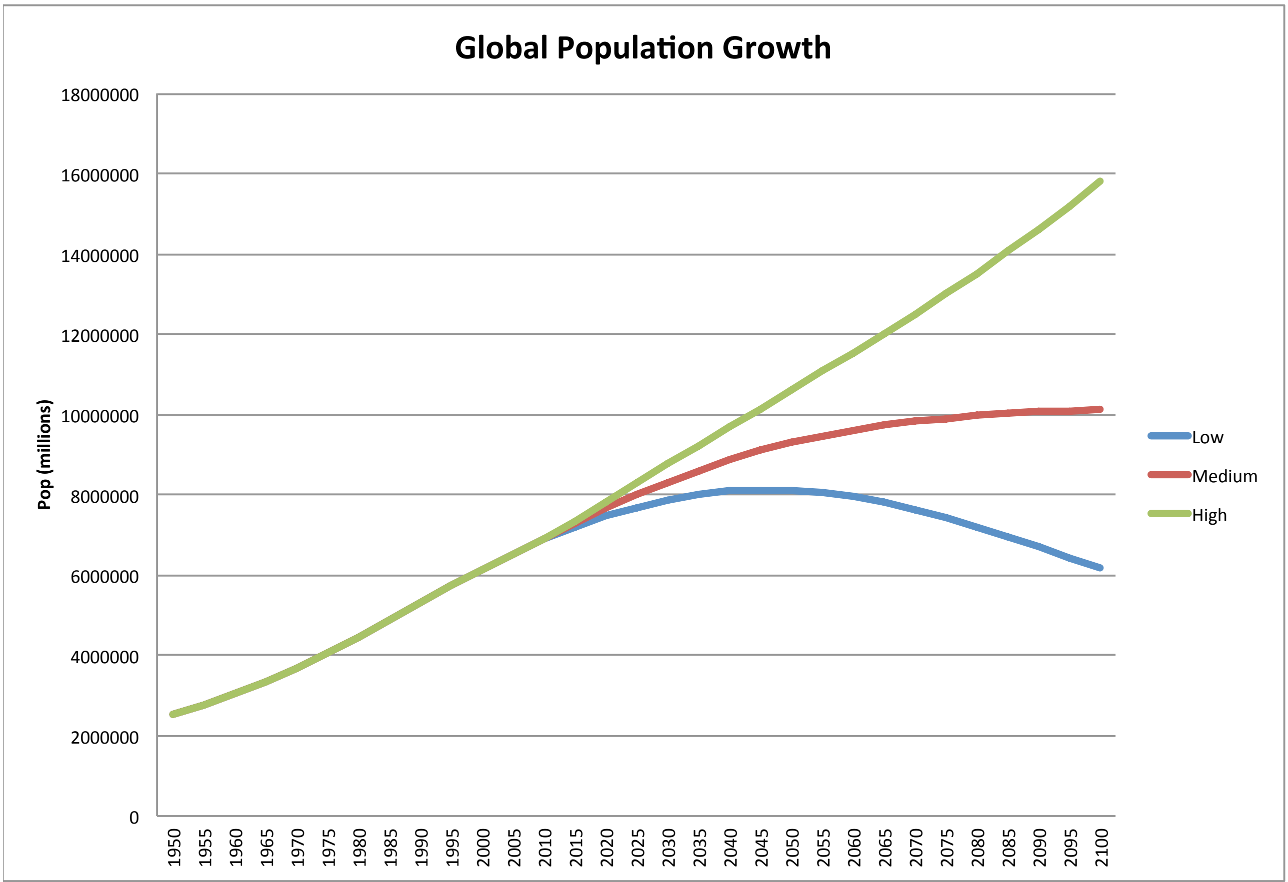
Chapter One: The Problem: Population and Resources

Population Growth

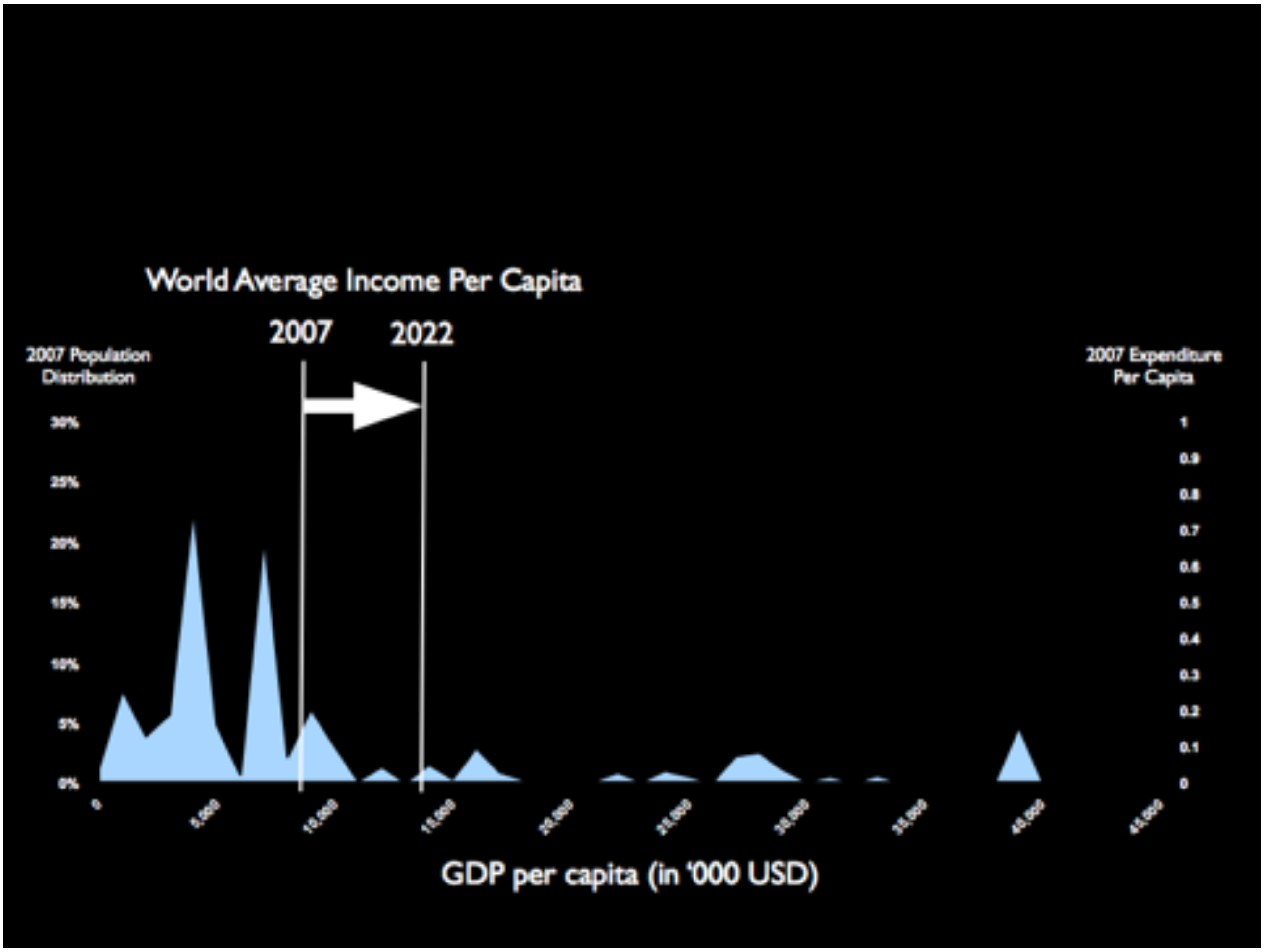
While there is still argument about climate change, population growth is an established fact. Whether - and how much - fertility rates decline as a result of rising affluence or climate change is still uncertain, but the medium scenario is that the planet will have to support 10 billion people by 2100, almost five times as many as in 1950.



Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2010 Revision, http://esa.un.org/unpd/wpp/index.htm,Sunday, September 25, 2011; 6:48:17 AM

Increasing Wealth, Increasing Demand

The focus on population numbers misses an important point. The global population is growing, but also growing wealthier as a result of the emerging economies of India, China and Brazil. As people are lifted out of poverty they are lifted into the global consumer society and have discretionary income. People then have new demands such as mains electricity, domestic goods, internet access, mobile telephones, computers and automobiles. This occurs in many emerging economies when incomes reach around US$ 10,000 per year.



Source: Cientifica Ltd using data from the UN and OECD

Although an increasing number of people are being lifted out of poverty, the distribution of global income is not homogeneous. As can be seen below there are two large groups of people about to hit the critical $10,000 GDP level which triggers the move from subsistence to active consumerism. The result will be a rapid rise in the demand for resources, not the more gradual increase predicted by linear growth models.

The effect can be clearly seen in Boeing's estimate that China will need 5,000 new planes worth $600 billion by 2030, as growing wealth among the middle class triggers an air travel boom, with only 16 percent being replacements for ageing aircraft and the remaining 84 percent extra purchases[1].

These new demands compound the pressure placed on global resources by population growth and imply resource scarcity may happen faster and be more severe than previously thought. And population growth is not the only challenge facing the world. The world is changing at a faster pace than ever before, at such a pace that understanding the nature of the change is challenging, and taking action to manage it almost impossible with the current system of international governance.

[1] Wall Street Journal 8th September 2011 Boeing Sees China on the Rise (accessed 1/10/2011)

1	Climate change, environment, and sustainability	Carbon productivity and adaptation becoming an increasingly dominant factor in all business decisions
2	Rapidly growing demand for energy	Energy security becoming a bigger geopolitical concern
3	Limited resources	Resource demand rapidly outpaces supply (oil, gas, coal, water, biomass, and other raw materials), price volatility
4	Increasing scarcity and unequal distribution of water	Demand for clean water rapidly outpaces supply in regions where majority of the world's population lives*
5	Growing demand for food, nutrition, and health	Agricultural production struggling to satisfy increasing demand for high-calorie quality food and health care
6	Demographics, including shifting populations and mobility	Over 1 billion new consumers (e.g., China and India); aging population; exploding demand for transport
7	Shifting centers of economic activity	Dramatic realignment of GDP, urbanization, new geo-political balance
8	Social life in a technological world	Connectivity transforms the way we live and interact
9	Corporate global citizenship	Companies increasingly consider all stakeholders, particularly with respect to environmental sustainability

Nine global trends identified within the World Economic Forum that will drive the need for technology innovation-based solutions.

Pressure On Resources

Resources of all kinds are under increasing pressure. Energy and water are two of the most commonly cited, but the rapid growth of population puts increasing pressure on mineral resources from rare earths to coal and steel.

Xinhua News agency reported recently that three rare earth mining districts near Ganzhou City have been ordered to halt production by year-end[2]. This is a huge problem, because, as Japan's Nikkei news service reports, Ganzhou is the number one producer of dysprosium. Dysprosium plays a critical role in many clean energy technologies, especially its role in improving the performance of magnets required for everything from hybrid automobiles to wind turbines, and is one of the elements the US DOE has highlighted as being of critical concern in regard to future supply disruptions and effects on critical technologies. The DOE is also concerned because dysprosium, like other rare earths, has no suitable replacement.

Many of these looming shortages can be addressed by simple supply and demand. As resources become more scarce and demand rises then so will prices. Some rare earths are available in the US, although this will take time as it requires the re opening of mines closed due to price competition from China. While supplies of rare earths have also been discovered in Afghanistan, accessing and exploiting them is currently difficult.

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[2] Ceramic Tech Today 8th September 2011 Enormous rare earths crisis brewing: China shutting down 3 major dysprosium mines (accessed 1/10/2011)

The demand for resources also increases pressure on the environment. The exploitation of tar sands in Canada has been used by many environmental groups to illustrate how our thirst for resources can result in large scale and highly visible damage to the environment. Less visible but with environmental consequences just as serious is the new technique of hydraulic fracturing, or fracking, used to release deposits of shale gas. The technique of fracking involves propagating an artificial rock fracture by injecting pressurised fluid, and then propping it open using sand or other particles to allow the extraction of gas or other materials. There is, however, growing concern over the effects of the technique, which can range from contamination of groundwater to triggering earthquakes. As a result the practice has been banned in much of Europe.

Some resources are more finite, and while alternatives can be created for many materials, some have no substitute or replacement.

To take just one example, *Scientific American* highlighted the looming phosphorous crisis as long ago as 2009[3]. Nitrogen, phosphorus and potassium are the components of fertilisers that have allowed us to feed a rapidly increasing global population and produce crops in areas where agriculture would have previously been at best a marginal activity. While there is plenty of potassium left to mine, the global supply of phosphorous is extremely limited, with four countries - Morocco, China, South Africa and Jordan - controlling 80 percent of the world's reserves of usable phosphate.

The use of fertiliser to increase the global food supply by the required 50% up to 2050 in order to meet the needs of a rising population will put additional pressure on phosphorous reserves.

"...Life can multiply until all the phosphorus is gone, and then there is an inexorable halt which nothing can prevent.... We may be able to substitute nuclear power for coal, and plastics for wood, and yeast for meat, and friendliness for isolation -- but for phosphorus there is neither substitute nor replacement." *Asimov on Chemistry* ***(1974) Doubleday Company, New York.***

The solution to this looming crisis has to come from technology. Fortunately, as we will see, the combination of nanotechnologies, life sciences and computing provide myriad possibilities for changing our attitude to resources, both in terms of how they are used and how they are sourced.

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[3] Scientific American, 3rd June 2009 Phosphorus Famine: The Threat to Our Food Supply (accessed 1/10/2011)

Chapter Two: The Solution: Emerging Technologies And Their Impact

What Are Emerging Technologies?

Emerging Technologies were defined at the 2010 meeting of the World Economic Forum's Global Agenda Council on Emerging Technologies as ones that:

- Arise from new knowledge, or the innovative application of existing knowledge;
- Lead to the rapid development of new capabilities;
- Are projected to have significant systemic and long-lasting economic, social and political impacts;
- Create new opportunities for and challenges to addressing global issues; and
- Have the potential to disrupt or create entire industries.

Emerging technologies are critical to long-term global prosperity. They represent the innovation that adds necessary economic and social value to materials, products and processes. And they provide potential solutions to a wide range of pressing global challenges including energy generation and storage, health care, climate change, food security and access to clean water. Yet without better global cooperation on technology innovation, many potential emerging technologies will not mature to the point at which they can be used effectively.

The interplay between emerging technology platforms, innovations and global trends is shown below.

Global Trends	
Climate change, environment, and sustainability	Increasing scarcity and unequal distribution of water
Rapidly growing demand for energy	Corporate global citizenship
Limited resources	Social life in a technological world
Shifting centers of economic activity	Demographics, including shifting populations and mobility
Growing demand for food, nutrition, and health	

Technology Innovations			
Vaccines	Carbon sequestration	Smart grids	Better health diagnostics
Advanced sensors	Soil management	Smart materials	High conductivity materials
Next generation electronics	Efficient resources use	Bottom-up manufacturing	Safer nuclear power
Point of use energy generation	Climate control	Renewable energy sources	Substitute materials
Better food preservation	Resilient crops	Immersive communications	Targeted pesticides
Smart drugs	Increased land productivity	High value crops	Biofuels
Water desalination	Thermal insulators	Efficient resource extraction	Water separation
Strong, lightweight materials	Irrigation	Disease management	Sustainable production processes
Automated traffic management	Better batteries	Advanced prosthetics	At-source water purification

Technology Platforms			
Nanotechnology	Synthetic Biology	Information technology	Bio-interfaces
Geoengineering	Robotics	Biotechnology	Web 2.0
Cognitive technology	Computational chemistry	Artificial Intelligence	Data interfaces

Source Andrew D. Maynard and Tim Harper, World Economic Forum Annual Meeting 2011 “Building a Sustainable Future: Rethinking the Role of Technology Innovation in an Increasingly Interdependent, Complex and Resource-constrained World”

While the technology platforms tend to receive the most attention, the innovations generated are often the result of a complex interplay between these platforms. Smart materials, for example, can be the result of combining nanotechnology, biotechnology, computational chemistry (for materials design) and bio-interfaces. High value crops may require biotechnology for the selection of genetic traits, something that would be impossible without information technology to decode the genome, while nanotechnology allows the efficient delivery of nutrients. The use of geoengineering for climate control, should it ever become necessary, would require the use of almost all areas of emerging technology to ensure that any changes to a local or global climate can be modelled, predicted and managed.

The Impact Of Emerging Technologies On Business

The average lifetime of a company on the Fortune 500 is less than 30 years. Of the current crop of technology enabled companies

•Apple is valued at $340 billion

•Google is valued at $176 billion

•Facebook is valued at $84 billion

This sends a clear message that without continuous and radical innovation many of todays largest companies may find themselves a case study in a future incarnation of Clayton Christensen's *The Innovators Dilemma*.

But being successful in the 21st century is not just about innovation. Many large companies, where levels of innovation are traditionally low, are embracing 'open innovation' (i.e. breaking down the barriers between internal and external research and development in order to make innovation more efficient) while others, especially in the pharmaceutical sector, still rely on innovation by acquiring innovative companies. If innovation alone were the key to success then any corporation with sufficiently deep pockets should be able to keep on top of its game simply by making enough strategic acquisitions.

The problem with much thinking about corporate innovation is that it assumes a static market. While there may be growth in the market sector, large organisations often become over-specialised and over-dependent on a single market sector which may decline in size due to factors beyond the company's control such a public sentiment or political expediency.

But combining technology with catching a global trend - for example sustainability - can make far better business sense. While scientists can change their field of research from materials science to nanotechnology to cleantech depending on where the best chance of funding happens to be, companies are far less nimble.

As we approach a tipping point in our understanding of the world as a result of 5000 years of science, companies who can make the best use of emerging technologies while addressing global needs will be the new technology titans.

Re-evaluating Our Relationship With The World After 5000 Years Of Science

As a species we have been modifying our environment ever since the invention of the plough and the spread of agriculture some 10,000 years ago. We have been making scientific observations of the natural world and trying to understand the connection between that which we can observe and that which we can experience for over five thousand years as we can see from ancient astronomical observations.

As each new wave of knowledge - from agriculture to the Industrial Revolution - has generated ever more wealth, the global population has increased and in turn our effect on the environment has become ever more profound. While a hundred years ago this was, by and large, limited to local effects such as the 'dark satanic mills' of northern England or the northeastern

United States, the mass industrialisation and globalisation of the second half of the 20th century has led to accelerated environmental degradation on a rapid and global scale.

The reason for this unwanted effect lies in our historical approach to technology. Some two hundred thousand years ago human beings learnt the importance of materials. Bashing rocks together could make a spark that could create fire. A stick sharpened against a rock could be an effective hunting tool. We gradually realised that by choosing the right materials our tools could be more effective, and our use of materials evolved slowly during the following two hundred millennia.

But it is important to realise that technology never evolves in a linear fashion, and in almost every case it is the combination of different technologies that provides the disruptive breakthroughs. The use of charcoal to produce higher temperatures combined with the right choice of materials led directly to the Bronze Age, and the flourishing of ancient civilisations such as the Sumerians who also practiced early agriculture, a combination of technologies that produced a step change in human knowledge and created similar impacts on both population growth and on the environment.

Similarly, the British Industrial Revolution was powered not only by the invention of the steam engine which enabled water to be pumped from coal mines, improving both the efficiency and safety of mining, but also from advances in ship design and navigation which led to the slave trade and the availability of natural resources such as cotton where mechanisation could add significant value to the finished product.

As our understanding of the natural world became increasingly advanced, our use of materials has become ever more sophisticated. For most of human history anything invisible to the naked eye simply did not exist. Following the invention and popularisation of the optical microscope by Anton van Leeuwenhoek in the Netherlands, a whole new world was opened up leading to new insights in fields as diverse as metallurgy and the causes of disease.

Perhaps the most significant turning point in the last one hundred a fifty years was the invention of synthetic chemistry. Up to this point almost everything used by society had to be manufactured from natural resources which then had to be modified in some way. The early 20th century revolution in chemistry which led to new dyes, fertilisers and ultimately drugs and plastics, represented the first time in human history where something could be made which did not exist anywhere in the natural world.

While this turning point, our ability to create entirely new materials, has underpinned much of the industrial growth of the 20th century, it has also been responsible for an increased demand for resources such as oil which provide the basic hydrocarbon building blocks for most polymer chemistry. Although new materials have been created, they are still dependent on the extraction and inefficient processing of basic primary materials.

With the advent of new tools to understand the world, from the electron microscope to the atomic force microscope, scientists have been able to manipulate materials on ever smaller length scales. Electron microscopes have advanced from magnifications of 400x in the early prototypes of the 1930s to over 2,000,000x, allowing individual atoms to be imaged. The appearance of the atomic force microscope in the 1980s allowed atomic scale imaging to performed in air or liquid, revolutionising our understanding of biological processes which were difficult to see under the ultra high vacuum conditions of an electron microscope.

But concentrating on a single area of technology rarely yields a technology with the capacity to change the world. Transformative technologies almost always comes from the combination of different technologies, and from contrasting scientific disciplines such as materials and life sciences.

From Fighting Against Nature To Harnessing It

While we have a range of highly sophisticated technologies available, almost all of them are dependent on acquiring some natural resource, whether wood, oil or biomass, transporting it, and processing it to perform a new function. It is a process that is inefficient in terms of the basic material (as the spoil heaps around any mine will demonstrate) and of energy. A typical semiconductor production plant consumes 30-50 MW of energy, enough to power a small city, while a typical server farm of the type used by Google or Amazon consumes 20-30MW. By way of comparison, performing far more advanced functions with the human brain consumes only some hundred watts.

In almost every area of technology, nature has evolved a solution far more advanced than humanity has managed. Whether in producing self healing, shock resistant but rigid materials such as bone, performing efficient conversion of sunlight into energy such as photosynthesis, or long life data storage with built-in error correction mechanisms such as DNA, our engineered equivalents are inferior in just about every way.

But our view of the world is changing. After twenty-thousand years of trying to tame nature, the combination of life sciences, nanotechnology and computing is enabling scientists and engineers to understand and even begin to copy many processes found in the natural world.

Combining Technologies

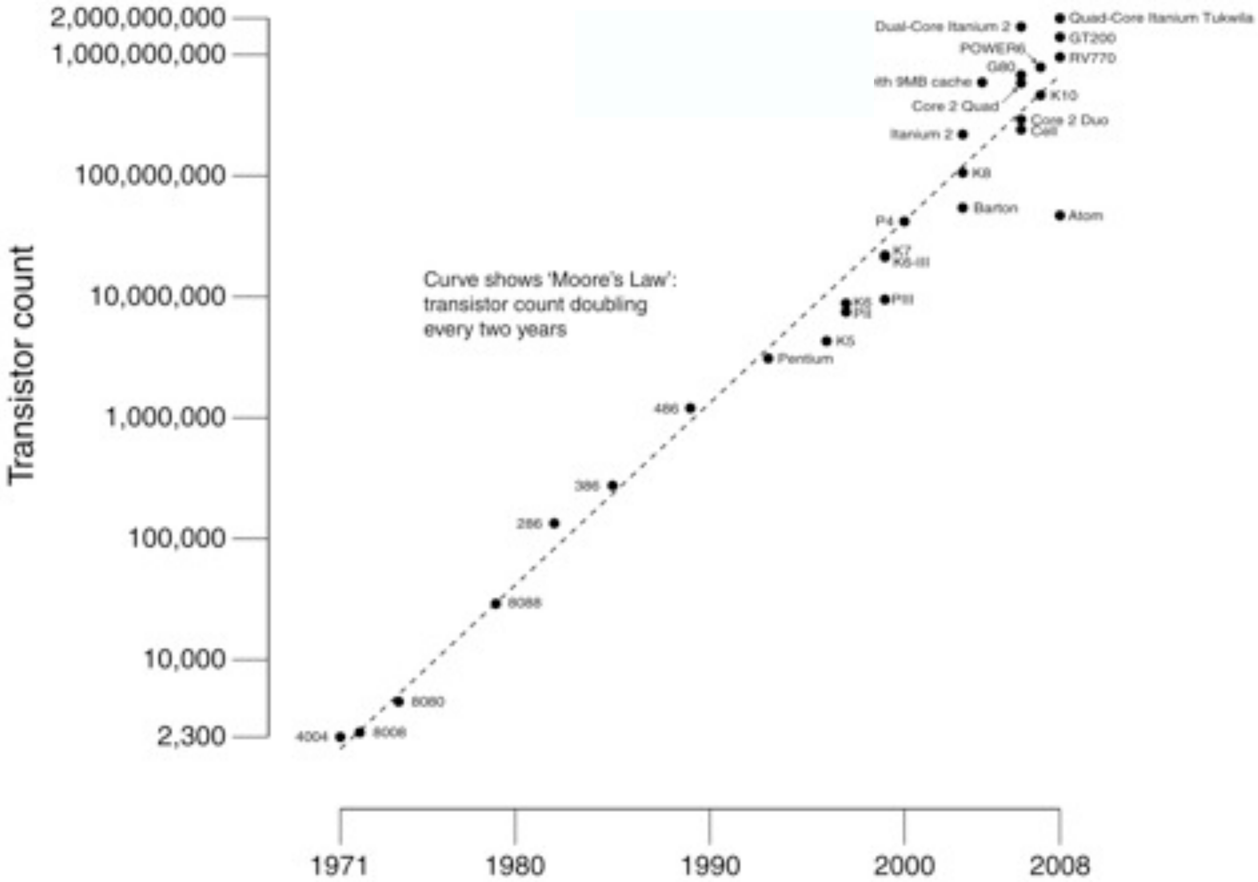
Thirty years ago the biggest problem in science was the acquisition of data. The lab notebook was an indispensable tool as readings had to be checked at regular intervals. Data was recorded by multi-pen chart recorders and experimental settings had to be adjusted and recorded by hand. Acquiring the data for a single experiment could take days or weeks. Results could be disseminated via scientific journals whose peer-review process often took a year, and researchers commonly waited a month for reprints to arrive.

In the 21st Century we have so much data the challenge is extracting the information from it that provides an insight. Information technology has allowed the automation of factories and laboratories, with automated gene sequencers and analytical labs work 24/7 churning our exabytes of data. And this data can be shared much quicker via the internet.

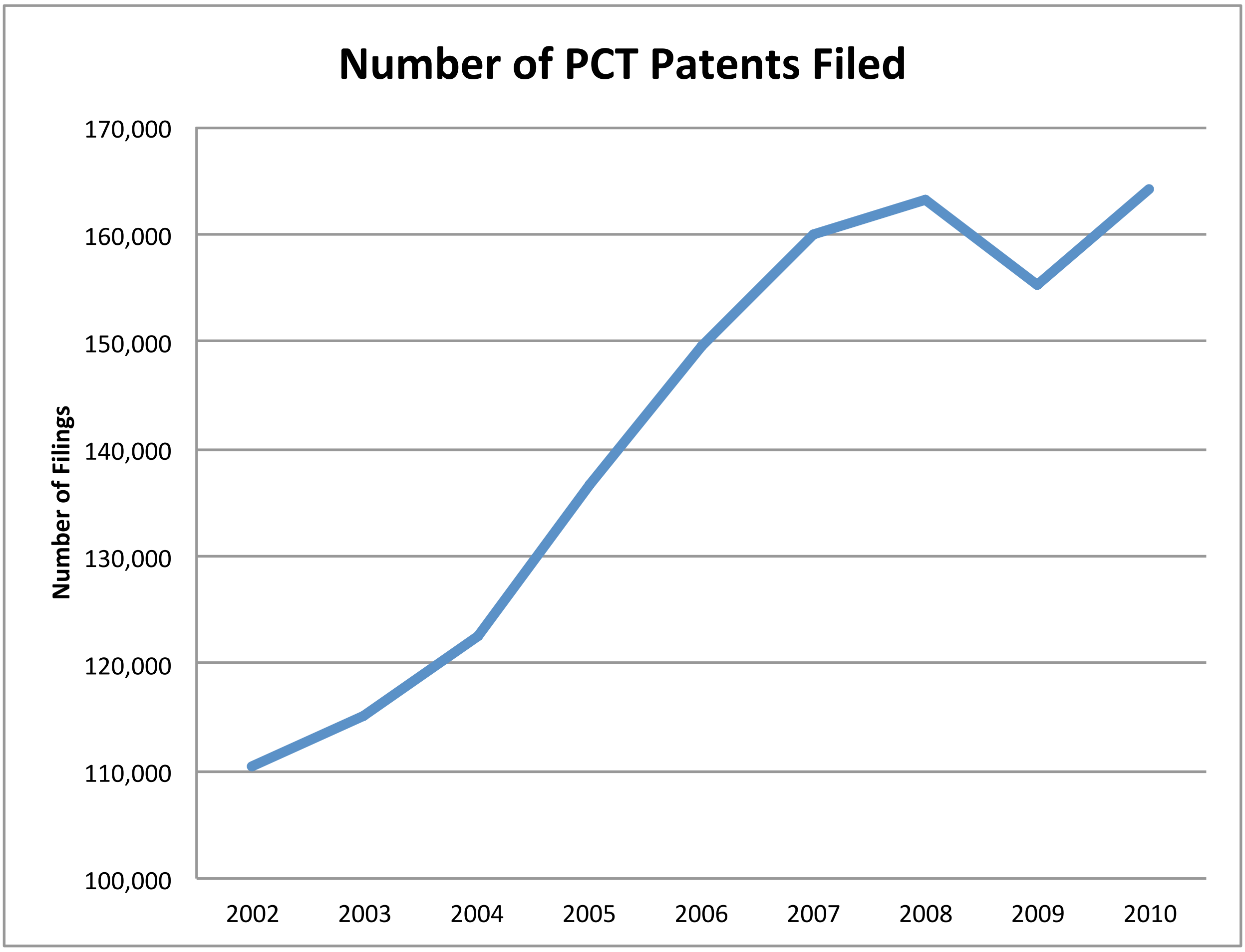
In a typical example of how information sharing can rapidly accelerate scientific discovery, online gamers took just three weeks to decipher the structure of a retrovirus protein that has stumped HIV researchers for over a decade[4].

Unblocking The Technology Backlog

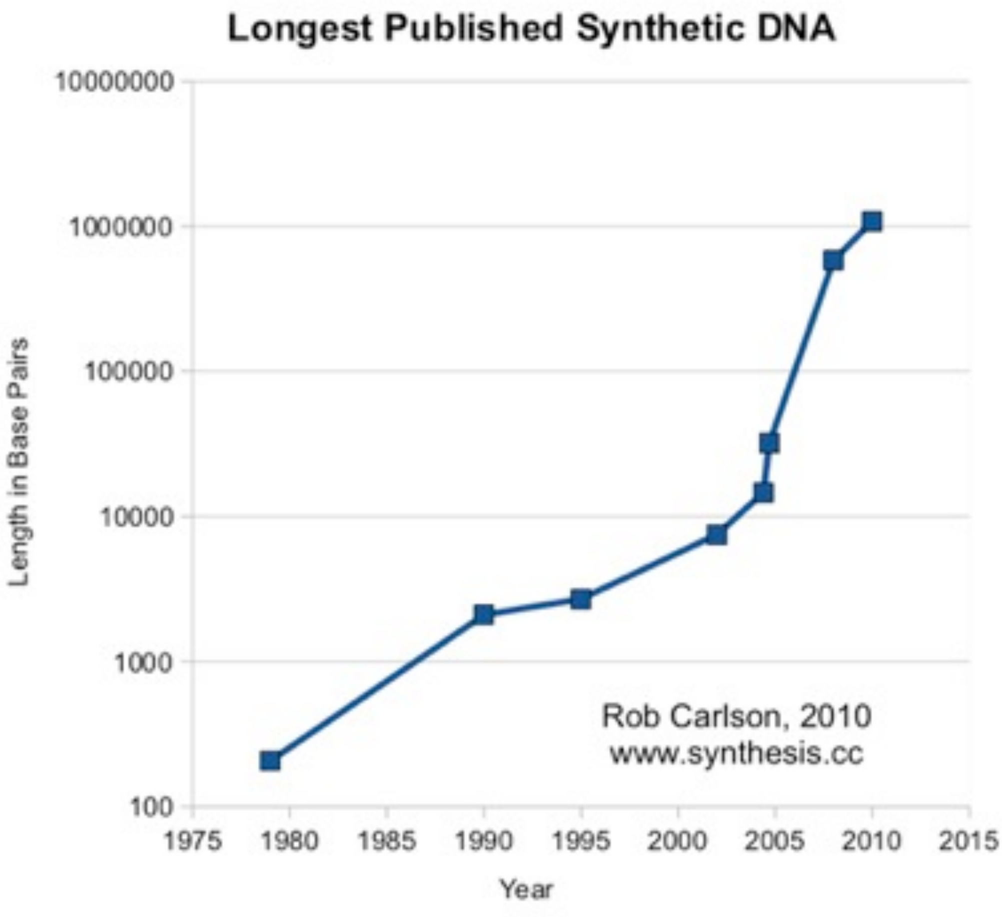
The interrelation between computing power and science many areas of technology are clear. With the result that knowledge is being generated at an ever increasing rate. The diffusion of new ideas is also unprecedented, and science is moving faster than ever before with the internet allowing the combined wisdom and expertise of the entire scientific community to be harnessed for the first time in history (as the population increases, so does the number of scientists and engineers, especially in Asia).



[4] Fox News 19th September 2011 [U.S. Gamers Crack Puzzle in AIDS Research that Stumped Scientists for Years] (accessed 28/09/2011)



Source: World Intellectual Property Organization



Source: Rob Carlson, www.synthesis.cc

But the growth in new ideas has not been matched by a corresponding growth in the availability of capital to translate those ideas into products.

The combination of a perception that easy returns can be made from social media technologies, the ongoing financial crisis and an increasingly risk averse investment community has led to many emerging technologies finding it increasingly difficult to raise the capital required to spin out new companies. The reverse is true in areas such as clean tech and social media, where venture capital is attracted to businesses that require the minimum of start-up capital and which can scale to be a Facebook or Twitter within four or five years. When compared with life science businesses that can take a decade to reach maturity - even if the various regulatory hurdles in getting a new drug or medical device approved and on the market can be overcome - the choice is a simple one for most denizens of Silicon Valley. As Martin Weber, a partner at Holtzbrink Venture, explained to DowJones in August 2011[5], "The VC industry is not historically a very successful business and the few firms that do prosper are getting more and more deal flow. This is inevitably leading to concentration and the median deal size rising." Put simply, if you want to raise less than a few million euros then go elsewhere.

[5] Financial News 2nd August 2011 Europe suffers VC slump (accessed 25th September 2011)

The other main outlet for research-based technologies is through licensing of patents. In much of the world industry is preoccupied with weathering the financial storm and has little time for risky new ideas, however great the potential rewards may appear. Staying in business today always takes priority over new business tomorrow.

The end result is an increasing technology overhang, with too many new technologies chasing too little money, driving down valuations and resulting in potential entrepreneurs preferring the safety of the lab to the high risk world of technology entrepreneurship. Even in the boom years, spinning out a start up from a university can make large returns for the backers but relatively little for the technical founders.

A key component of realising the potential of emerging technologies is in finding new ways to finance early stage technology businesses. Could a proportion of the trillions of dollars which was spent in 2008 to rescue banks - something that merely maintained the economic status quo - have been put to better use in addressing the emerging technology overhang?

Chapter Three: From Take, Make Waste to Zero Waste

A New Industrial Revolution?

$$I = P \times A \times T$$

The last industrial revolution was characterised by a linear model of take, make, waste and this model has held for almost 300 years. Paul R. Erlich of Stamford developed the IPAT equation[6], an attempt to describe how our growing population, affluence, and technology contribute towards our environmental impact. The equation states that Human Impact (I) on the environment equals the product of P= Population, A= Affluence, and T= Technology.

This predicts that as both population and affluence increase, technology will multiply this effect. This held true until almost the end of the 20th century, but the 21st has been characterised buy an increasing awareness of sustainability which - although population, affluence and technology are still advancing - has seen a slight slowing of the environmental impact.

Although this is a simplistic view, it is a view held by many groups, and one which has contributed to public opinion in Europe and the US becoming increasingly concerned that technology is a tool whose effects are more negative than positive. In the case of GMOs the opposition was not to the technology itself, which simply allows it to be far more specific in doing something that plant breeders have done for millennia as they transformed low yielding wild grasses into rice and wheat. The opposition was almost entirely to the business model of companies such as Monsanto which saw genetic engineering as a way to 'own' certain crop species and use that to capture a large part of the market. Anti-capitalist rhetoric was mixed with technology, and the view that GMOs were a way of forcing people to eat something that is somehow dangerous and unnatural in order that large corporations could make profits became entrenched[7].

Once we start to look at bottom-up technologies, from biomimetics to nanotechnology, and from industrial biotechnology to regenerative medicine, it becomes clear that there is an option to further slow the growth in environmental impact and perhaps even reverse it. An increasing number of emerging technologies are being deployed with this aim in mind, whether the use of genetically modified organisms in bioreactors to transform waste into energy or chemicals, or the use of nanomaterials to enable lighter stronger materials for aircraft and automobiles, or the use of organic or plastic electronics for the production of low cost solar cells.

The awareness of the environmental impact of technology coincided with the birth of nanotechnology. Up to this point many technologies had been developed and deployed simply because they were either useful or increased labour productivity. Little or no thought was given to the impact of any technology, from steam power through to the internal combustion engine,

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[6] Ehrlich, Paul R. and John P. Holdren. “Impact of Population Growth.” Science 171 (1971)

[7] As a result of the GMO furore many companies making use of emerging technologies, from nanotechnologies to biorefineries, are now much more sensitive to the opinion of environmental organisations, the general public and its ultimate effect on policy and regulation than in the past.

or from mechanised agriculture to genetically modified crops as long as profits were increased by the application of technology.

Nanotechnology was something rather different. Coinciding with the widespread availability of internet access and the rise of social networks, it was the first wave of new technologies to be subjected to an intense and critical examination both by scientists and the wider public. Nanomaterials such as nanoparticles and carbon nanotubes were not immediately deployed widely as a number of questions about their safety and ultimate fate were being asked by environmental groups. Even researchers, forearmed with the knowledge of 20th century technologies, wondered whether carbon nanotubes, with their long thin fibrous structure could possibly produce the same effects as asbestos fibres, responsible for hundreds of thousands of premature deaths.

The internet enables a widespread debate to take place about the pros and cons of this new technology. As a result, almost everyone – from philosophers to environmental groups to the general public – became involved to some extent in the decision-making process. The level and extent of involvement was unheard of just a decade earlier when GMOs were first deployed.

As a result, we are moving toward a more sustainable and responsible use of technology. The combination of viewing technology in a fresh way and the raft of emerging technologies allows us to look at the IPAT equation in a different way.

The Challenge Of Communicating Technology

It seems strange that while almost every government is concerned about a lack of innovation there are very few effective measures to stimulate the translation of scientific research into useful technologies. This represents a failure of policy on a global scale. Unless this technology overhang is addressed we risk being unable to take the measures needed to deal with emerging global risks.

While the technologies exist, the political will to use them does not. Many governments, especially in Europe, are still deeply suspicious of new emerging technologies, and see this area as a long term one which can be kept ticking over while more pressing matters are addressed. Banks are bailed out, economic stimuli announced, while science budgets are trimmed, storing up problems for future governments while allowing current incumbents to nibble away at deficits. Recent events in the global economy have revealed a generation of weak leaders who prefer tinkering at the margins to fixing the root of problems. The era of bold initiatives such as putting a man on the moon or eradicating smallpox seems to be over and big ideas are now left to business or philanthropists to execute.

Even so, the challenge is still one of communication, something the scientific community is not renowned for. Policy makers engaged in firefighting the latest bout of global financial Armageddon have no time or inclination to read *Nature* or to give time to researchers talking about technology. The current generation of global leaders, especially in the Western democracies, have backgrounds almost exclusively in law, politics or economics, and the same is true of their advisors. Although science and technology underpin economic growth (and the worlds stock markets) as well as improving quality of life, the meme of the IPAT equation requires that technology be thought of, against all evidence, to be something negative, and political expediency requires that sensitive issues such as GMOs, safety of nanomaterials and the use of embryonic stem cells in regenerative medicine be kept at arm's length or kicked into the long grass of committees and enquiries.

While science and technology have been held accountable for much environmental damage, they are only one component of the massive change in the 20th century. Tigers have not become an endangered species because of improved hunting weapons, but because the population of India has increased by almost a billion in the last 70 years, resulting in a massive loss of tiger habitat. Although technological progress resulted in environmental degradation, technology is playing a growing part in reversing that trend, whether biorefineries creating alternatives to oil-based chemicals or nanotechnology creating lightweight cheap solar cells.

Perhaps the most visible impact of technology improving quality of life is in healthcare. Many diseases which carried a death sentence 30 years ago are now manageable (albeit chronic) conditions. Anyone entering an operating theatre a hundred years ago had a slim chance of emerging alive, something we now take for granted.

Sustainable and Responsible Innovation

The ideal of the sustainable and responsible use of emerging technologies is to use technology to reduce our environmental impact while still allowing for an increasing - and increasingly affluent - population. This requires a shift in our thinking from a linear take, make, waste model to a cyclical one where no waste is produced. It also requires a shift in focus from labour productivity to resource productivity. If technology can help us achieve this then the IPAT equation starts to look more like this

$$I = (P \times A) / T$$

The environmental impact is now the product of population and affluence, but now mitigated by technology. Technology actually reduces environmental impact rather than increases it.

It is possible? Ray Anderson, the CEO of US carpet tile manufacturer Interface read Paul Hawken's book *The Ecology of Commerce* in 1994 and realised that his business actions were harming the world his grandchildren would inherit. As a result, Anderson changed the corporate culture and managed to

- cut greenhouse gas emissions by 82 percent
- cut fossil fuel consumption by 60 percent
- cut waste by 66 percent
- cut water use by 75 percent

The strategy also allowed Interface to invent and patent new machines, materials, and manufacturing processes while increasing sales by 66 percent, doubling earnings and raising profit margins.

The same idea is taking hold in the semiconductor industry, a major user of both energy and water. AU Optronics new plant in Taiwan has been built to minimise environmental impact, and the economic benefits accrue from reduced use of water and energy. IEEE Spectrum reports that "the company hopes to influence both its own suppliers and its customers to create a 'virtuous cycle' of new ideas and methods.[8]"

The widely held view, especially in government, is that to ensure sustainable and responsible innovation more targets and regulation are required to force companies to comply. A recent example of the futility of this approach is the 2008-9 financial crisis in the banking industry, one of the most regulated and supervised sectors in the world of commerce. A combination of unwillingness and inability to see the unfolding crisis led to the deepest recession since the 1920s. What we can learn from the example of Interface and an increasing number of companies is that once the idea begins to take hold that sustainability is not merely about changing your corporate branding to a flower and then carrying on business as normal. It is, rather, a matter of exploiting emerging technologies in a way that reduces consumption while increasing profits. At that point the first dominos in the corporate world will begin to fall.

So the companies that embrace emerging technologies to reduce environmental impact will be the once with long-term sustainable future and the ability to become the titans of the 21st century. Those who do not will lose market share to those who do, and increasingly fall foul of government regulators.

A typical application of an emerging technology comes from work on synthetic biology at UC Davis. The project, supported by the Japanese chemical company Asahi Kasei is creating cyanobacteria, or blue-green algae, that convert carbon dioxide in the air into complex hydrocarbons, all powered by sunlight[9]. Complex hydrocarbons which form the basis of most of the chemical industry are commonly known as crude oil. While the work will be slow to yield hydrocarbons in large quantities at a cost comparable with pumping crude oil out of the ground, it is a good example of an emerging technology which will both ease pressure on global resources and disrupt a number of existing businesses.

Making Technology Relevant

The past 10 years of nanotechnology have been characterised by the attempted pushing of technology into a technology agnostic industry. While emerging technologies do confer immense advantages over time, it is the applications of these technologies rather than the technologies themselves that gain acceptance.

[8] IEEE Spectrum September 2011 How a Taiwanese Fab Went Green (accessed 1/10/2011)

[9] UC Davis press release 13th September 2011 'Synthetic biology' could replace oil for chemical industry (accessed 1/10/20110

The same is true with governments and international organisations. Most international organisations were conceived in the immediate aftermath of the Second World War when television was a rarity. As recent events such as the 'Arab Spring' have shown, many governments and organisations have yet to come to terms with relatively consumer-friendly technologies such as social media and mobile telecoms. It would be unrealistic to expect this type of institution to engage on areas of emerging technology such as nanotechnology and industrial biotechnology - which are so far removed from the perception of these organisations as to be invisible.

As nanotechnology and life sciences are poised to be to be as influential as oil and chemicals were to the early 20th century, and the global population becomes interconnected in a way undreamt of by even the best science fiction writers, our relationship with technology will change at a rapid pace. The difficulty that both policy makers and the general public have with technology results from a lack of knowledge and a lack of control.

In order to have a meaningful discussion about emerging technologies, the arguments much be couched in terms organisations understand. For organisations ranging from the United Nations to the World Economic Forum, technology is not a part of the agenda, whereas population growth, famine, international relations and financial instability is. While much effort is put into managing various crises, almost no effort is put into proactively averting them.

The UN has calculated that the price of fighting the 2011 drought and famine in East Africa will be almost $2 billion. This allows technology to be placed into a context where it can be made relevant. The UN understands famine, drought relief, and their associated costs.

In 2004, the UNCCD estimated that some six million hectares of productive land was being lost every year since 1990, due to land degradation. This in turn had caused income losses worldwide of US$ 42 billion per year[10]. With two-thirds of arable land expected to be lost in Africa by 2025, land degradation currently leads to the loss of an average of more than 3 percent annually of agriculture GDP in the Sub-Saharan Africa region. In Ethiopia, GDP loss from reduced agricultural productivity is estimated at $130 million per year.[11] While part of the problem is political instability and population pressure combining to prevent previously nomadic peoples following the best yields, lack of knowledge about good husbandry and the technology to implement it are also major factors.

The losses can be even greater if wars are fought over resources, whether energy, water or food, with the international community picking up the bill for dealing with millions of refugees and other victims.

The lack of use of technology for risk mitigation does not only cause human misery, it also causes tangible and quantifiable losses for national economies and companies. Many technologies exist which could potentially mitigate the effect of oil spills from deep water drilling or oil transportation. They are, however, not yet developed. The cost of doing so, estimated to be

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[10] UN Convention to Combat Desertification June 2004 Ten years on: UN marks World Day to Combat Desertification (accessed 1/10/2011)

[11] United Nations Economic and Social Council October 2007 Drought and Desertification (accessed 1/10/2011)

several hundred million dollars, is almost insignificant when compared with billions wiped off stock prices, the bill for environmental clean up, and many other non-insured losses.

The future should be one where technologies are developed that allow us to carry on current human activities in an increasingly safe and resource-productive manner. Governments which have proactively supported new and sustainable technologies such as wind in Denmark, solar in China or biofuels in Brazil are now seeing the economic benefits. The mitigation of risk by spending millions now instead of billions later is beginning to make both social and economic sense, especially given the certainty over the problems that population growth and increasing affluence will create.

But for emerging technologies to find a place on the agenda of international organisations, the discussion must not be about the technologies themselves, but about the risk that they can prevent or mitigate. In this sense, responsible development of emerging technologies can be seen as a form of insurance.

Chapter Four: Using Emerging Technologies For Good

Information And Regulation

Recent emerging technologies such as GMOs and nanotechnology have been dealt with crudely by governments and regulatory agencies. Attempts at regulation and addressing public safety concerns have concentrated on the underlying technologies rather than the end use. As a result there is a blanket ban on GMOs across much of Europe, and there have been numerous attempts to either regulate the whole of nanotechnology or force researchers to consider the ethical impact of their work. It is an approach every bit as absurd as suggesting to the pioneers of quantum physics that they should predict the future applications of their work in electronics, communication and nuclear weapons before being allowed to embark on their research.

These crude attempts stem from a mixture of scare stories in newspapers (bad news sells newspapers) and a lack of understanding among policy makers coupled with poor communication skills among the scientific community. This is perhaps a situation that cannot be changed easily, but there is another factor at work, one that could make government attempts at regulation of technologies impossible -- the internet.

The internet does not just speed the flow of information between researchers, it also allows groups to collaborate in new ways and over large distances. The progression over the past decade from Usenet newsgroups through Yahoo groups and now to Facebook has been rapid. New methods of collaboration are constantly springing up, whether for sales or research. The effect of this is that disruptive innovation no longer needs to be gestated in a Bell, Sony or IBM lab. As communication and chemical and biological modelling tools become more efficient and widespread, the proportion of time spent at a lab bench is dwindling. Less time in the lab means lower capital costs, resulting in smaller groups being able to have the research impact that was once the preserve of top tier universities and large corporations.

From a government perspective much of this is invisible. There is nothing and no one to regulate, and the technologies and their exploitation can easily move outside national regulatory environments. Banning or refusing to fund research in one country is now as ineffective as making the sharing of music files illegal. Adding restrictions to the use of technologies simply results in them moving to another home, and even technologies with a global impact such as geoengineering are well within the scope of a philanthropic billionaire.

In a paper published by the World Economic Forum, Rethinking the Role of Technology Innovation in an Increasingly Interdependent, Complex and Resource-constrained World[12], we argue that there is a need to ensure that governments, businesses and other stakeholder organisations are equipped to make the most effective use of science and technology innovation in addressing the global challenges of the 21st Century. The paper calls for the creation of a new institution, an authoritative and neutral source of intelligence on emerging technologies and the opportunities and challenges they raise.

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[12] http://www.scribd.com/doc/47096457/Building-a-Sustainable-Future or http://www.forumblog.org/blog/2011/01/addressing-global-risks-requires-more-sophisticated-thinking-on-new-technologies-andrew-maynard-tim-.html (accessed 28/09/2011)

Providing Real Solutions To Global Risks

While there is little doubt that many emerging technologies will have the ability to address a number of the problems faced by humanity over the next forty years, the challenge is to enable them to be deployed effectively. This requires three interlocking steps:

Defining the problem

Often global problems are couched in general terms and there is little appreciation of the issues surrounding the problem. Providing solar power to rural Africa is pointless without the provision of methods to store the power generated. Removal of heavy metals from drinking water will fail if the technology needs power or regular maintenance, and the technology must be in every case appropriate to the end users. While this is obvious to those engaged in development work, it is something often overlooked by technology providers.

Engaging public opinion and policy makers

As in the case of genetically modified crops, it is easy for public opinion and subsequently policy to turn against an entire area of technology. While questions may be asked about the business model of some of the early exploitation of GMOs, there is no little doubt that it is a technology which can be both sustainable and profitable. However, as a result of early negative publicity it is still taboo across much of the European Union. While nanotechnology has so far avoided this fate due in part to its wide range of potential applications getting on the wrong side of public opinion can make emerging technologies almost impossible for European governments to fund and deploy.

Making the application of technology economically attractive

While much of the discussion over risk and emerging technologies has involved international organisations and governments, they are rarely the source of much innovation or agents of change (other than through tax or regulation). For technologies to be effectively deployed there has to be an economic case to involve companies. As pressure for increased sustainability and escalating resource prices are now inescapable, this provides the market for emerging technologies. The EU making the move to a bio-based society with the aim of creating an overarching framework for policies to help ensure sustainable use of biological resources, availability of food and biomass[13]. Moving from a fossil-based to a bio-based economy requires support for the competitiveness of the bio-based industries, the real work will be done by companies, whether existing multinationals or new ones, that are able to take advantage of new technologies.

[13] European Comission 2011 European Strategy and Action Plan towards a sustainable bio based economy by 2020 (accessed 1/10/2011)

Conclusion: We Have The Tools, Let's Use Them Wisely

Humans have a natural irrepressible curiosity, and we have spent our entire history attempting to make sense of the world around us through superstition, organised religion and (finally) science. The process has been random, with many scientific discoveries being made by chance. The path from discovery to application has been one strewn with hazards raging from lack of capital to ridicule.

As we enter the third millennium, the converging factors of science and information technologies allow us to escape the random process of discovery and application, our control over materials and the interconnected world. Through nanotechnology and life sciences we are finally allowing scientists and engineers to dream about a perfect material for an application, whether data or energy storage, and set about using the entire panoply of scientific tools, from supercomputing to genetic engineering, to build that perfect material, just as nature has always done.The impact of this change of thinking cannot be overestimated. The harnessing of materials properties on the nanoscale will create a shift in the way we approach resources every bit as significant as the transition from hunter gatherers to farmers.

But our interconnected world allows us to go even further. The increased pace of scientific innovation and the ability to share it is only one part of the impact. Perhaps more significant is the increasing ability to use social networks to harness the entire scientific community and coordinate science on a global basis to address the major risks we face. By doing this effectively, the global scientific community has the potential to have an even bigger impact on the global economy than the world financial community.