Nanotechnology – a Key Technology for the Future of Europe

Ottilia Saxl. July 2005

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‘Nanotechnology – a Key Technology for the Future of Europe’

“We take what we want from life, and then we pay for it” *Proverb*

The ***Millennium Ecosystem Assessment (MA) Synthesis Report*** * published on 30th March and drawn up by 1,300 researchers from 95 nations over four years, states: “Rising human population has polluted or overexploited two-thirds of the ecological systems on which life depends, ranging from clean air to fresh water, in the past 50 years. Human activity is putting such strain on the natural functions of Earth that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted."

“To give all 10 billion people on the planet (by 2050) the level of energy prosperity we in the developed world are used to… we would need to generate 60 terawatts…the equivalent of 900 barrels of oil per day...”
- Richard E Smalley, 1996 Nobel Laureate in Chemistry[1]

0 Introduction

Taking the findings of the Millennium Ecosystem Synthesis report[2] as a starting point, and drawing on the EU documents, ‘Towards a European Strategy for Nanotechnology’[3] and ‘Converging Technologies – Shaping the Future of European Societies’[4], this report identifies, in relation to European strengths, where nanotechnology research should be focused over the coming decade. The goal of this research is to discover new nanotechnologies that will ameliorate, or provide sustainable alternatives to some of the human activities that are most severely affecting the ecological balance of the planet.

In order that research can be turned into applications, there has to be an opportunity for developers to make a profit. This will in turn depend on legislation / fiscal pressures driving the take-up of radical, new, planet-friendly developments, thus providing the impetus for industry to quickly bring urgently needed new products and processes to the market place.

Europe has been seeking a means to unify its disparate cultures and communities. Success in safeguarding the future can only be achieved through a coherent, EU-wide vision, and if sufficient support for this vision can be gained, it may be the unifying goal that politicians makers are seeking.

[1] ‘Future Global Energy Prosperity: The Terawatt Challenge’. Richard E. Smalley 2nd Dec 2004. See: http://cohesion.rice.edu/NaturalSciences/Smalley/emplibrary/120204%20MRS%20Boston.pdf
[2] ‘Ecosystems and Human Well-Being’ Synthesis, Millennium Ecosystem Assessment, Island Press, Washington DC, 2005
[3] ‘Towards a European Strategy for Nanotechnology’, European Commission Communication, 2004
[4] ‘Converging Technologies – Shaping the Future of European Societies’. Rapporteur, Alfred Noordman. European Commission, 2004

This report comes with a caveat, which is that technology alone will not provide a solution to the planet's serious ills. The solution is down to each of us, as individuals, to take the necessary action before it is too late.

0.1 Background

Investment in nanoscale research has grown from around €1 billion p.a. in 2000 and is expected to reach €10 billion p.a. worldwide by 2006. The use of nanotechnology is accelerating, and a prediction made in the USA in 2000 that one trillion dollars in products worldwide would be affected by nanotechnology in 2015 has now been brought forward by five years to 2010.

According to 'Towards a European Strategy for Nanotechnology', nanotechnology has important implications for most, if not all industrial sectors. It particularly highlights medicine, information, energy, materials, manufacturing, instrumentation, food, water, the environment and security as key areas.

New products based on nanotechnology increasingly emulate nature, and this requires a profound understanding of how nature works at the nanoscale. To achieve this, research teams need to be multidisciplinary; and physicists, chemists, biologists and engineers are increasingly working together to find innovative solutions to what might have previously been considered intransigent problems. These scientists and engineers are also engaging actively with other disciplines, such as the humanities, to ensure that new scientific advances are socially acceptable and people friendly. Some of the potential of this important convergence of disciplines has been explored in another Commission publication entitled 'Converging Technologies – Shaping the Future of European Societies'.

A key conclusion is that the new products and processes resulting from the convergence of technologies with other disciplines, especially cognitive science, will become increasingly intuitive, and appear seamless with the ambient environment. This offers the possibility that new technology might offer an acceptably advanced standard of living in the future, by substituting for resource intensive activities; for example, high quality virtual meetings, virtual holidays, remote health monitoring and therapy, and intuitive and interactive access to ubiquitous information.

A driver of the report was to make a European response to an earlier US study[5] that examined the potential for converging technologies, main for medical and military applications, such as enhancement and repair of the faculties, and the ability of science to offer individuals the opportunity to improve their body performance beyond the accepted norm. By contrast, the Europe view of converging technologies is in a people-friendly light, exploring how they may result in more intuitive and inclusive technology-based new products and processes, with the potential for seamless integration into everyday living. At the same time, the report did caution on the need to be alive to the possibility of machine-dependence, and the opportunity posed for malevolent manipulation.

[5] "Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Sciences", M. Roco and C. Montemagno eds. NSF/DOC sponsored report, Arlington. 2002

0.2 Report Context

Although the objective of this report is to provide a vision for nanotechnology research in Europe, the context of the report must be global. As postulated in the Chaos Theory (where the fluttering of a butterfly's wings in one corner of the globe may dramatically influence the weather in another), actions each of us take in today's world, no matter how seemingly trivial, may have a profound effect on the life of a distant neighbour.

The report considers nanotechnology as a possible route to identifying solutions to the new and disturbing challenges highlighted in the Millennium Ecosystem Assessment Synthesis Report. These challenges relate to alleviating the actions of humankind, which are leading to the destabilization and possible collapse of the life-support systems on the planet.

Industrialization has led to the generation of huge 'wealth' for western society, based on asset-stripping the natural world, and exacerbating the divide between the rich and poor nations. See Figure 1. The rate of consumption and waste has increased so dramatically and is now so vast that it is threatening the very existence of all humankind on the planet. It is no exaggeration to say, that in order to ensure a future for the human race, dramatic actions need to be taken, as the various systems of nature that have operated until now to preserve equilibrium, are reaching the point of critical failure.

African Voices in Europe

Agriculture, Energy and Poverty. Across the globe 1.2 billion people live in absolute poverty. Of these, almost 300 million live in sub-Saharan Africa. The majority of these people are small-scale farmers who depend either entirely, or to a large extent, on agriculture and the management of natural resources for their livelihoods. Policy developments in Europe have a large 'footprint' throughout the world, but the impact of such policies on the poorest farmers in the developing world is often overlooked.

In the coming decade, two key policy areas concerned with sustainable development will have a massive impact on the poor in developing countries - food and household energy. These issues will become increasingly significant to the European public, as concern grows about the origins and quality of food, the impact of globalised production systems on the environment, and about fossil-fuel driven climate change.

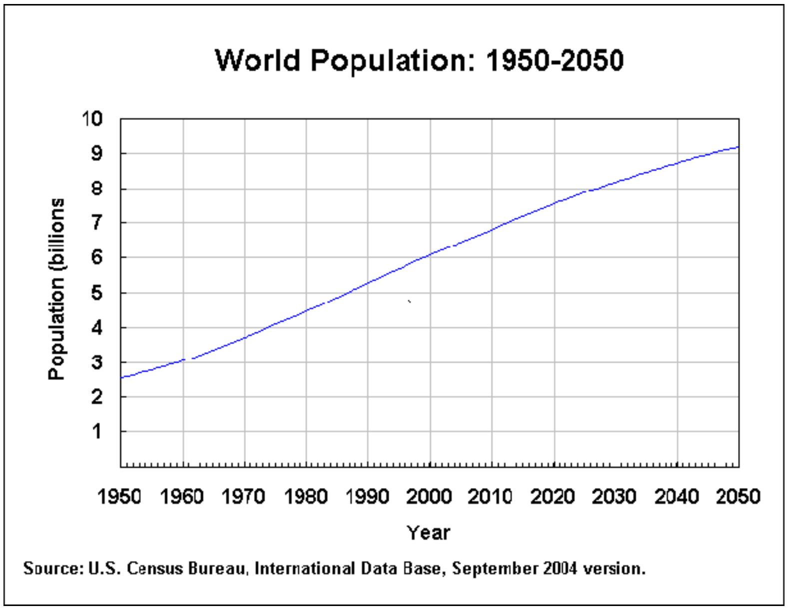
http://www.itdg.org/?id=africanvoices

Fig 1. Europe's responsibilities to Africa

By 2010 the population is expected to reach 7 billion. See Figure 2. To provide anything remotely approaching the present standard of consumption of the approximately 1 billion inhabitants of the industrialised nations is taxing the planet's resources to breaking point.

It can be concluded that the present emphasis by the EU and its component countries on 'growth' and 'competitiveness' is now inappropriate. Prevention of collapse of the ecosystem has now become the overwhelming issue, and depends on the immediate creation and implementation of a totally new strategy on which the society of the future can be based, and which must be in equilibrium with the natural world.

New technologies, including nanotechnology, may provide a part of the answer on how to create alternative lifestyles for the population that will be in harmony with the planet. The EU can play an important role in this, by putting the planet centre stage in the next Framework Programme for Research.



http://www.census.gov/ipc/www/img/worldpop.gif

Fig 2. World Population 1950 - 2050

0.3 What is Nanotechnology?

Nanoscience is a catchall term for research into matter ***at the scale where its properties are defined.*** Nanotechnology is the application of new techniques and knowledge of material behaviour at the nanoscale.

Nature is the ultimate nanotechnologist. The world is composed of atoms and molecules from which nature has built up complex inanimate and animate systems. Rocks, the sea, the air we breathe are all ultimately made of atoms and molecules, and all living things are systems whose working is defined entirely at the nanoscale. Nature even produces nanopowders and nanoparticles every time there is explosive volcanic activity, and milder manifestations are the clay and dust that are products of the wear and tear of the earth and its inhabitants.

Many applications of nanotechnology are based on the fact that at the nanoscale, materials exhibit different properties to their bulk properties. In nanoparticle form, the surface-to-volume ratio increases, and the more surface that is exposed the more active the material becomes. For example, flour particles can be highly explosive, and hydrocarbons in a vapour of tiny droplets can be much more dangerous that when stored as liquid petrol.

One important objective of nanotechnology is to harness the new properties tiny particles exhibit by virtue of their high surface to volume ratio, or that can be imparted to them by chemically 'decorating' their surfaces with other molecules. These new properties can be incorporated into into larger devices and systems, such as new sensors that are able to rapidly detect and measure pollution in air or water or analyse blood. Nanosurfaces are also important when it is considered that most properties of material are resident ***in the surface layer***, and new materials can be made just by redesigning their physical and / or chemical structure ***at the surface.*** For example, only a small percentage of nanoparticulate clay minerals incorporated in the surface of a polymer can result in enhanced impermeability and heat resistance, enabling the development for example of new, lightweight, odour-resistant, stay-fresh packaging for food. Another application of a material in nanoparticulate form is nanosilver, which can be incorporated into textiles, coatings and wound dressings, providing remarkable anti-bacterial properties with many implications for healthcare.

Through understanding the properties of materials at the nanoscale, it is increasingly possible to design and make entirely ***new*** materials. The growth of civilisation has been founded on the innovative development and use of materials, from bronze to glass to tin to concrete to gunpowder – to name only a few. At first, serendipity led to the development of new materials, then an increasing knowledge of chemistry enabled a better understanding of the origins of their properties. Nanotechnology has taken this a step further and is leading to an even more profound comprehension of how materials derive their attributes, and the ability to design materials *de novo*. It is estimated that there may be of the order of 10^{22} materials possible, and nanotechnology is opening the door to the possibility of exploiting this treasure chest of almost infinite potential.

0.4 Future Nanotechnology Research

The promise of nanotechnology lies now in its potential to provide sustainable alternatives to some of the effects of the human activities that are most severely affecting the ecological balance of the planet, as well as offering new and satisfying lifestyles that are planet friendly.

Without doubt, the first hurdle is to overcome is a change in *mindset* of the population, and the EU and the politicians of individual countries need to provide a lead in this.

Today, the behaviour of the affluent citizens of Europe and elsewhere are mainly based on the 'acceptable' norms of

- ***excessive consumption***
- ***excessive waste, including food***
- ***unsustainable industrial growth***
- ***focus on 'improving the quality of life'***
- ***unsustainable air travel. See Figure 3***
- ***unsustainable employment***
- ***unfettered urbanization***
- ***the car as a symbol of success; with high consumption cars even more so.***
- ***sterilization of land (roads, housing). See Figure 4***
- ***transport of goods by road and air***
- ***the promotion of population increase***
- ***soil death through intensive farming***

- ***excessive and unnecessary imports and exports of foodstuffs***
- ***lack of strategic use of ITC***

It is critical to find ways and means to address those activities that are so seriously threatening the planet, now. Most can be simply and easily encapsulated in a few words, but their ramifications and consequences are huge.

GLOBAL AVIATION RECOVERY REACHES PRE 9/11 LEVELS

- ***After four years of gradual recovery the Worldwide number of flight volumes is now exceeding those of Q1, 2001***
- ***Year on year flight volumes have increased by 5%***
- ***Low-cost airlines and Asia-Pacific outpace global growth rates***
- ***160 potential airline start ups***

During April 2005, latest figures from OAG reveal, airlines will operate more than 2.27 million flights worldwide, 111,000 more compared to April last year and – most significantly – 45,000 more flights than in April 2001.

The statistics are provided in OAG's latest Quarterly Airline Traffic Statistics, a quarterly snapshot of airline activity around the world. OAG collates data from more than 1000 scheduled airlines, on a daily basis, to give an overview of anticipated travel demand versus historical trends.

Predictably, the biggest year-on-year growth is in China. Compared with April 2004, this month will see a 12% growth in flights to and from China, and a massive 20% increase in domestic flights, an additional 17,000 flights per month.

Worldwide, the growth figure is 5%. OAG reports a 7% increase in flights to, from & within Europe, and a 9% growth in the number of flights to, from and within Africa. A healthy 10% growth in the number of intra-Asian flights is balanced by a smaller 6% increase in the number of flights to and from the Asia-Pacific region. The Middle East continues to outperform the global trend, with an 8% increase in flights to and from the region, and a 6% "domestic" increase.

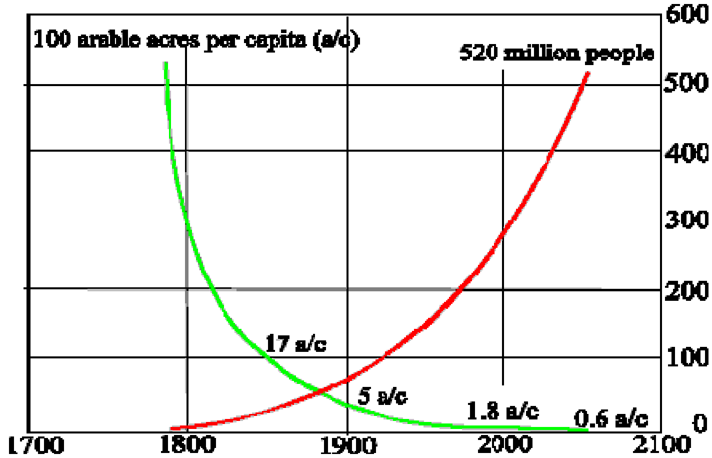
In North America, April 2005 sees a 5% increase in flights to and from the USA and Canada, and a 3% increase in domestic operations. The low-cost sector in North America has made significant gains since April 2001 rising from 12% of total market to 17%, representing today 147,000 out of the total of 838,000 flights. Worldwide the market share of low-cost carriers has doubled from 6% to 12% since April 2001.

http://www.oag.com/about_oag/company_info/press_releases/US/pr_QATS405.asp

Fig 3. Global Aviation Statistics. Press Release: OAG Worldwide, 11th April 2005

FOOD, LAND, POPULATION and the U.S. ECONOMY

by David Pimentel of Cornell University and
Mario Giampietro Istituto of Nazionale della Nutrizione, Rome



Executive Summary Released November 21, 1994 For copies of the full report contact: Carrying Capacity Network 2000 P Street, N.W., Suite 240 Washington, D.C. 20036 (202) 296-4548

The following are highlights of the study, "Food, Land, Population, and the U.S. Economy" by Drs. David Pimentel of Cornell University and Mario Giampietro of the Istituto Nazionale della Nutrizione, Rome. This comprehensive assessment of U.S. population growth and its impact on America's agricultural productivity was commissioned by Carrying Capacity Network (CCN), a non-profit organization in Washington, DC which focuses on the interrelated nature of the economy, population growth, and environmental degradation.

KEY FINDINGS

- At the present growth rate of 1.1% per year, the U.S. population will double to more than half a billion people within the next 60 years. It is estimated that approximately one acre of land is lost due to urbanization and highway construction alone for every person added to the U.S. population.
- This means that only 0.6 acres of farmland would be available to grow food for each American in 2050, as opposed to the 1.8 acres per capita available today. At least 1.2 acres per person is required in order to maintain current American dietary standards. Food prices are projected to increase 3 to 5-fold within this period.
- If present population growth, domestic food consumption and topsoil loss trends continue, the U.S. will most likely cease to be a food exporter by approximately 2025 because food grown in the U.S. will be needed for domestic purposes.
- Since food exports earn $40 billion for the U.S. annually, the loss of this income source would result in an even greater increase in America's trade deficit.
- Considering that America is the world's largest food exporter, the future survival of millions of people around the world may also come into question if food exports from the U.S. were to cease.

Figure 4. "Food, Land, Population, and the U.S. Economy" by Drs. David Pimentel of Cornell University and Mario Giampietro of the Istituto Nazionale della Nutrizione, Rome.

0.5 Biomimetics – the Route to Future NanoProducts

Traditional chemical techniques, allied with a better understanding of the processes involved, are being used a route to producing nanoparticles with specific applications, for example, in sensors, paints, coatings, cosmetics, drugs and as imaging contrast agents. Building nanoparticles into larger structures has proved much more difficult. The individual manipulation of atoms and molecules using man-made tools (such as microscopes) to make larger structures is incredibly time-consuming and inefficient. There is a solution, however, through emulating nature. Everything we see around us has been built by nature. Scientists are now concentrating on analysing how nature produces a useful structure or attribute - for example, the lightweight yet strong shell of the abalone, or the finely compartmentalised tiny glass skeleton of a diatom, to see if nature's techniques can be harnessed or copied, in the quest to produce better products.

To successfully emulate nature requires a profound understanding of how nature works at the nanoscale. To achieve this, research teams need to be multidisciplinary. For example, researchers at the University of Bonn have studied the way a lotus leaf repels water, which nature achieves through the presence of tiny pyramidal wax particles on the surface of the leaves. This repellency, called the Lotus Effect, has reached industrial application through the teams of scientists from different disciplines - physicists, chemists, biologists and engineers - working together to analyse and deconstruct nature's actions and translate them into a reproducible product.

A similar example of multidisciplinarity can be demonstrated in the field of imaging-based medical diagnostics. In the 1980's, medical imaging techniques could only detect changes in the appearance of tissues when the symptoms were relatively advanced. Later, contrast agents were introduced into living tissue to more easily identify the locus of disease. Today, through the application of nanotechnology, both the imaging tools <u>and</u> the contrast agents (based on 'smart' nanoparticles called quantum dots) are being dramatically refined towards the end goal of detecting disease as early as possible, eventually at the level of a single cell. A key challenge of disease imaging has been to create research partnerships between the almost non-overlapping competencies of those developing the imaging technology and those developing the contrast agents, in a framework of life sciences applications.

> Fluorescent nanocrystals such as quantum dots are nanoparticles which, depending on their coating and their physical and chemical properties, can target a specific tissue or cell and be made to fluoresce for imaging purposes. They offer a more intense fluorescent light emission, longer fluorescence lifetimes, and a much broader spectrum of colours than conventional materials, and are expected to be particularly useful for imaging in living tissues.

Another example of nanotechnology enabling the emulation of nature is in energy collection and the development of novel solar cells. Some solar cells are based on an understanding of how plants photosythesize; i.e. convert sunlight to energy. This has led to the development of novel, polymer-based solar cells that are flexible, cheap to fabricate, with a good solar-to-light energy conversion efficiency that would be of great benefit the less developed regions of the world.

Today, life- and physical scientists and engineers are not only working together, but also engaging actively with other disciplines, such as the humanities, to ensure that new scientific advances are socially acceptable and people friendly. Some of the potential of this important convergence of disciplines has been explored in the EU report 'Converging Technologies – Shaping the Future Societies of Europe', cited previously.

1 Socio-Economic Challenges

Today, Europe is faced with the unexpected challenge of addressing potentially dislocating and disruptive global issues. These issues have paradoxically arisen as a result of the success of earlier policies, geared to enhancing industrial growth and competitiveness. Many citizens of the EU, and other countries in the world, are living in a time of unparalleled wealth and consumer power, which is leading to a drain in global resources and serious knock–on effects in terms of the ability of the planet to cope with their demands.

New research strategies are urgently needed to find technologies that are planet friendly and can also provide acceptable lifestyles for its citizens, in an era where resources can no longer continue to be used in a careless or profligate manner. This report examines how nanotechnology, as an enabling technology with huge potential, may provide some solutions as part of a package of research and other actions. The EU cannot solve the world's problems in isolation, but can lead by example.

Through the Lisbon Agreement of 2000, and other declarations, Europe set itself the goal of creating a dynamic, knowledge-based economy and society by 2020. In 'Towards a European Strategy for Nanotechnology', it was stated that nanotechnology, as part of an interdisciplinary approach, is expected to dramatically affect medicine, IT, energy production and storage, materials, manufacturing, instrumentation, food, water and the environment, and security.

These themes are still important areas for research, but the focus may be dramatically different to those envisaged by the architects of these declarations, whose objective was industrial and economic growth. Today, we must radically rethink what constitutes a successful society in world terms, and must expect, as a result, the reduction or even demise of some industries that are highly energy, water or mineral resource intensive. These may be as disparate as the aviation and aerospace industries, paper and bottle making industries, out-of-season food exporters and importers, exotic flowers producers and the fast food industry.

The main challenge Europe faces is, in essence, twofold. One is to create the means for its citizens to lead satisfactory and satisfying lifestyles that are ecologically friendly, - before it is too late, and circumstances inflict changes upon them (the least welcome scenario!), and two, to change the accepted norms of behaviour, and encourage the adoption and use of new, planet-friendly technologies. There is little doubt that technology in general, and nanotechnology in particular, can help make the necessary lifestyle changes much less painful, but cannot succeed in isolation. First and foremost, behavioural changes also need to be made, which perhaps, and unfortunately, can only be successfully driven by new legal and fiscal measures.

1.1 Nanotechnology and Future Socio-Economic Challenges

The planet is on an accelerating course to terminal ecological disaster. Nanotechnology is not the cure-all; only a complete attitude change now, by the populations of the world, led by the industrialized nations, will give any hope at all of passing a remotely habitable planet on to our children. However, nanotechnology is only part of the answer, as it may offer some solutions to finding a sustainable lifestyle for the future. What it won't do is reverse the damage to natural systems, once they begin to die.

Given that there are urgent issues of global importance to be addressed, especially in relation to energy, food and water, as a result of global warming and a massive reduction in available agricultural land, there follows a list of challenges, with indications of areas where nanotechnology may lead to solutions that have a more planet-friendly impact.

Note: In the list below, it is a 'given' that the nanotechnology-based products will be cheap to produce, less resource intensive and are 'smart', i.e. respond to the demands of their immediate environment

1.1.1 Energy

Reducing the demand for hydrocarbon-based non-renewable energy. According to Nobel Laureate Richard Smalley[6], *"Developing new sources of sustainable energy is the single most important problem facing humanity today"*. New techniques for renewable energy generation, energy conservation and storage are critical areas of research and development.

Nano: Bio-inspired, lightweight, efficient solar power collectors; flexible, lightweight, interactive displays for virtual meetings, conferences and even holidays / virtual newspapers; nanocomposites for energy efficient vehicles / engines; fuel cells; energy efficient, resource-saving building materials / lighting / glazing; 'clever', lightweight packaging; nano-enabled, local manufacturing (bottom-up manufacturing at point-of-use)[7].

1.1.2 Water

Husbanding water resources. With global warming, potable water is expected to become a more divisive issue than oil.

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6 Richard Smalley is widely known for the joint discovery and characterization of C60 (Buckminsterfullerene, a.k.a the "buckyball"), a soccerball-shaped molecule which, together with other fullerenes such as C70, now constitutes the third elemental form of carbon (after graphite and diamond).

7 Already the concept of local 'personal fabrication systems' is becoming a reality. First stage 'fab labs' are already available, as low cost manufacturing centres to be used by less developed countries to produce small parts that can be assembled into a larger whole. Apart from enabling poorer communities, the excitement of the Fab Lab is the elimination of transport costs of goods. In the pipeline are 'fab labs' based on inkjet printer technology that can act as a rapid prototyping machines, building up sophisticated three-dimensional artefacts from computer models by laying down layer by layer of nanoparticulate metals or other materials. See 'FAB The Coming Revolution in Your Desktop – from Personal Computers to Personal Fabrication' Neil Gershenfeld, Basic Books 2005

Nano: Self-calibrating nanosensors; point-of-sample, high-speed analytical techniques for measuring water quality; nano-based, filtration and purification techniques, using membranes systems. Stay-clean clothes / less water intensive manufacturing / food production.

Note: Carbon nanotubes have been found to trap bacteria in drinking water by making them stick together in clumps. They can then be sieved out and destroyed. See: New Scientist, Feb 19th 2005

1.1.3 Environment

Environmental monitoring. Obtaining quality data on the speed and levels of environmental pollution.
Nano: Self-calibrating, cheap, fast air and water pollution sensors that can detect a wide variety of organic and inorganic chemical species. Novel catalysts for extracting harmful exhaust chemicals from cars, aircraft and power stations.

1.1.4 Waste

Waste reduction is vital to saving energy and resources, including water.
Nano: Recyclable, minimalist 'smart' packaging that uses less resources but offers more attributes; able to monitor and identify contents, provide data on energy to produce and transport, and signals its location at any time. Important in the reduction of waste food. More for less – nano-enabled products require less energy and materials to produce.

1.1.5 Healthcare / Ageing population / Diseases of the Less Developed World

Resource-intensive, increased healthcare demands are imposing an intolerable strain on the economies of most countries.
Nano: Remote health monitoring / non-invasive diagnosis; fast analysis of genetic predispositions to illness leading to genome-based therapeutics. Nano-based imaging and drug targeting and delivery for early identification and minimally toxic treatment of disease. Regenerative medicine[8]. Drug / hormone delivery on a needs-basis using electronics-derived technology. Patient-friendly, 'smart' cochlear and retinal implants. Medical textiles, with health monitoring, transmission of information and therapeutic capabilities; nanostructured bandages that encourage cell growth; infection reduction, through anti-bacterial dressings, surfaces and textiles. Nano-enabled technologies for quality of life for the elderly or infirm (lightweight, flexible interactive displays / robot 'helpers') activated verbally, by minimal movement or even thought. Affordable diagnostics and treatments for the killers such as HIV Aids, TB and malaria.

1.1.6 Food

A recent (April 2005) Government study showed that one third of all food produced in the UK goes to waste, consuming huge resources of water and energy. Exporting and importing meat, fruit, vegetables and flowers out of season (or in season, to countries which already have similar products) result in pollution from air, sea and land transport, the excessive use of local precious water resources, and the transfer of pathogens, as well as contributing to the poverty of countries producing cash crops.
Nano: Less wasteful, feature-rich packaging, (able to detect pesticides, deterioration, inform on provenance etc); antibacterial packaging and food preparation surfaces e.g. using nanoparticulate silver;

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[8] Regeneration of organ function through using 'nanoscaffolding', with cell-friendly surfaces, and using nanomaterials that diffuse chemicals that facilitate cell growth and differentiation. These can be implanted into the body, and provide a structure around which cells will grow to form a new, fully integrated organ or tissues. See the Vision Paper of the European Nanomedicine Platform, published September 2005

1.1.7 Animal Welfare

'A civilisation is judged by how it treats its animals.' Mahatma Gandhi.
Nano: Advanced computer-based modelling of nanoparticle behaviour in living systems and the environment to eliminating animal-based testing; cell-based toxicological and efficacy tests for new drugs and nanoparticles (more relevant than animal-based testing) leading to the use of the patient's own cells - the 'personalised medicine' revolution.

1.1.8 Agriculture

Diminishing food and water resources are putting pressure on remaining agricultural land. A recent study has shown that soil-dwelling bacteria are critical to equilibrating the oxygen / carbon dioxide balance in terms of the speed of response.
Nano: Nanosensors for monitoring soil health.

1.1.9 Lifestyle

Intuitive, pervasive ITC as the basis of acceptable, inclusive, new planet-friendly lifestyles.
Nano: Nanomaterials for flexible, cheap, low power, paper-like displays for creating virtual environments, providing free ubiquitous access to information, entertainment, education; on textiles, domestic goods. Inclusive.

1.2 Ethical Issues

Ethical issues regarding nanotechnology relate mainly to military and medical applications. Military applications, in the US in particular, are absorbing a high proportion of funding for nanotechnology research. In 2005, the USA Department of Defense received $276 million, 28% of the overall US nanotechnology research budget. The USA has also placed a clear emphasis on nano as part of converging technologies for the improvement of human performance, with military applications in mind, and several conferences and workshops have been held on this theme[9]. There is a very thin line which divides the potential of nanotechnology for better medical treatment, life extension, or the improvement of human performance, which has more sinister connotations.

The EU is supportive of the many benefits offered by nanomedicine, but is also alive to the many ethical issues it raises. In the communication 'Towards a European Strategy for Nanotechnology', it is made clear in the introduction that "Ethical principles must be adhered to…" and "Dialogue with the public is essential to focus attention on issues of real concern…". This is also addressed in the Vision Document of the European Nanomedicine Technology Platform, due to be launched in September 2005, where many opportunities for new medical treatments through the application of nanotechnology are outlined. In this document there is a full chapter on Nanomedicine and Ethics[10].

Finally, the European Commission is keen to involve many stakeholders, not only scientific experts, but also those from the humanities and members of the public, in its new projects

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[9] 'Converging Technologies for Human Performance Enhancement', 2002 See: http://wtec.org/ConvergingTechnologies/

[10] See Appendix 2: Ethical Issues in Nanotechnology, with especial reference to Nanomedicine.

and programmes, to ensure that benefits accrue to society as a whole, and questions of ethics are openly debated and addressed.

2 The NanoScience and NanoTechnology Base of Europe

2.1 EU Funding

Funding levels for research is often equated with leadership in the field, though this may not be the case for nanotechnology. It is difficult to obtain more than a general idea of the funding for nanotechnology globally. Fig 5 shows approximate spending levels worldwide. Europe, Japan and the US are spending roughly similar amounts. Figure 6 shows spending levels across Europe, by country.

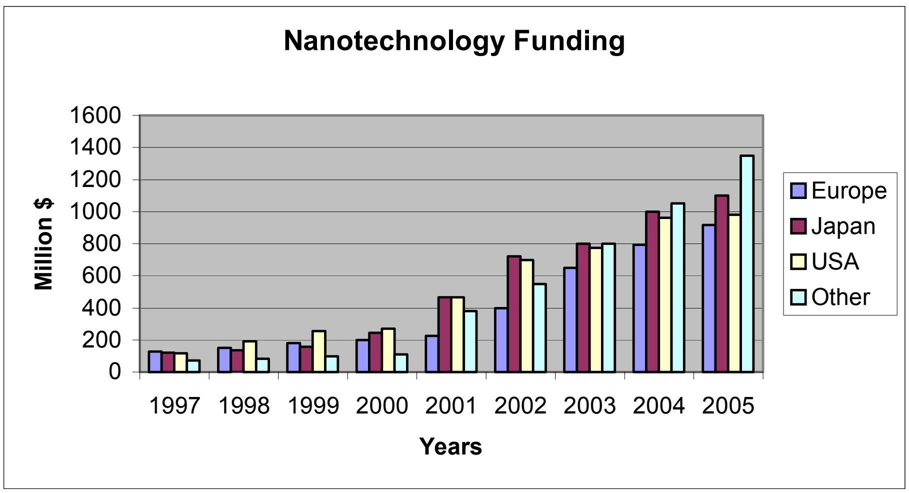

Fig 5. Global Nanotechnology Funding

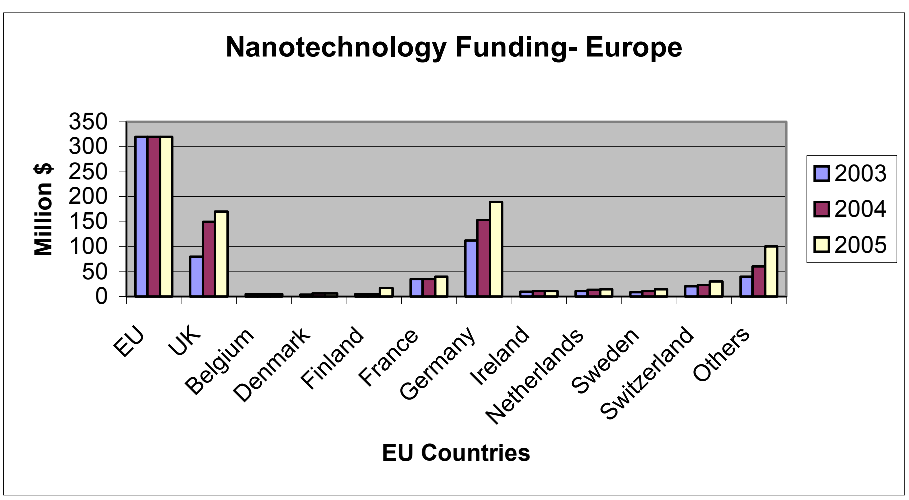

Fig 6: Nanotechnology R&D spending in the EU member countries

2.1.1 Valuing the Spend on Nanotechnology, by Country

The actual value of the spend, or investment in nanotechnology, depends on several factors:

- The scale of indigenous industry that will benefit from nanotechnology, and thus speed up the commercialization process through existing routes to market. *e.g. , in Finland, nanotechnology development is focussed on the electronics, forestry products and environmental industries.*

- The extent to which industry views nanotechnology as critical to future success. *e.g., several major German companies such as BASF, Siemens, Beiersdorf and Henkel, have embraced nanotechnology early, as they believe it offers many benefits for their future competivity.*

- The 'value' per euro spent on research. *e.g., in countries such as China, Korea and India, there is the combination of an industrialized society but low wages. Each euro spent on nanotechnology research buys more in terms of human resources than in the West, perhaps by as much as a factor of 10.*

- Strategy. *e.g., goal setting by governments. The US National Nanotechnology Initiative set clear goal-oriented outcomes for their research programme.*

- Military uses. e.g., f*unding for military research is by far and away the largest sectoral spend on nanotechnology in the US.*

2.3 European Strengths

Europe has recognised strengths in specific areas of nanotechnology research[11], in nanomaterials, nanoelectronics and ITC research (including quantum computing); photovoltaics and nano-based sensors. It is also recognised as having strengths in nanomedicine generally, including diagnostics (in-vitro and in-vivo), regenerative medicine and targeted drug delivery; and this is complemented by an acknowledged nanotoxicology research capability. Europe also boasts a strong industrial base in instrumentation.

Europe also has several unique advantages. Firstly, the cultural differences amongst its citizens form an asset in terms of an imaginative approach to research; and EU policies and support for researchers to gain experience of work in different countries and companies have enhanced the ability of its scientists to work in transnational and transdisciplinary teams. If, as is postulated, biomimetics is the route to disruptive new products and processes based on nanotechnology and other disciplines, then this ability to work in teams is of great importance to Europe if it is to succeed in researching and applying biomimetics-inspired technologies.

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[11] 'Nanotechnology in Europe', TTC 2005

Secondly, an influx of well-qualified mathematicians and physicists from the New Accession countries has filled a recognised vacuum in the European research base, and is adding fundamental skills to the various research groups.

Thirdly, the EU and national strategies to encourage scientists to commercialize the results of their research have resulted in a burgeoning of nanocompanies that have been formed across Europe. See Figure 7. This is an encouraging trend, as historically, Europe has failed to capitalise on the results of its research. In the USA at present, there is some disquiet in some quarters about changes to the SBIR (Small Business Innovation Research) program which has made some observers anxious that the commercialization of nanotechnology (a high risk area) through the formation of new start ups, may diminish as a result.

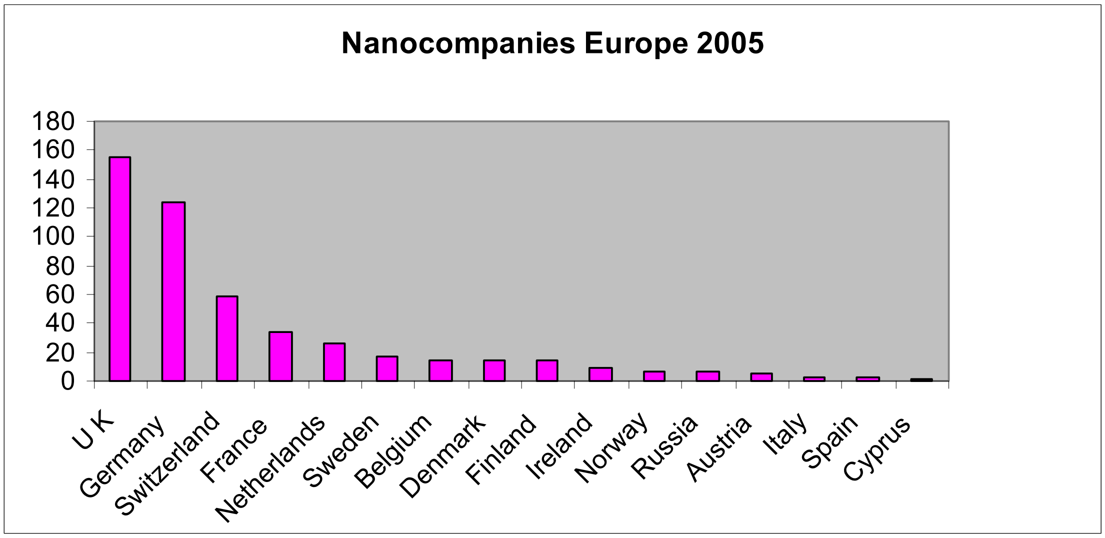


Figure 7. Nanocompanies in Europe. Source: Institute of Nanotechnology

Fourthly, and importantly, Europe has embraced the development of environmentally friendly technologies, perhaps faster than most of its industrial neighbours. The challenge is now to commit much further to research in this vital future area, and thereby gain world leadership.

Finally, Europe has also shown interest in the development of technologies for the less-advantaged regions, but needs to accelerate a programme of further research aimed at developing affordable, effective technologies, now. A recent paper by Fabio Salamanca-Buentello et all[12] lists ten nanotechnologies considered in a survey of leading nanotechnologists to be the most important to the developing world. These are:

- Energy storage, production and conversion
- Agricultural productivity enhancement
- Water treatment and remediation
- Disease diagnosis and screening
- Drug delivery systems

[12] 'Nanotechnology and the Developing World, F. Salamanca-Buentello et al, April 205, www.plosmedicine.org

- Food processing and storage
- Air pollution and remediation
- Construction
- Health monitoring
- Vector and pest detection and control

They may not be everyone's top 10 but they do indicate the potential for nanotechnology in solving some of the crises in the less developed world, allied with a policy of reduction of asset stripping by the affluent nations.

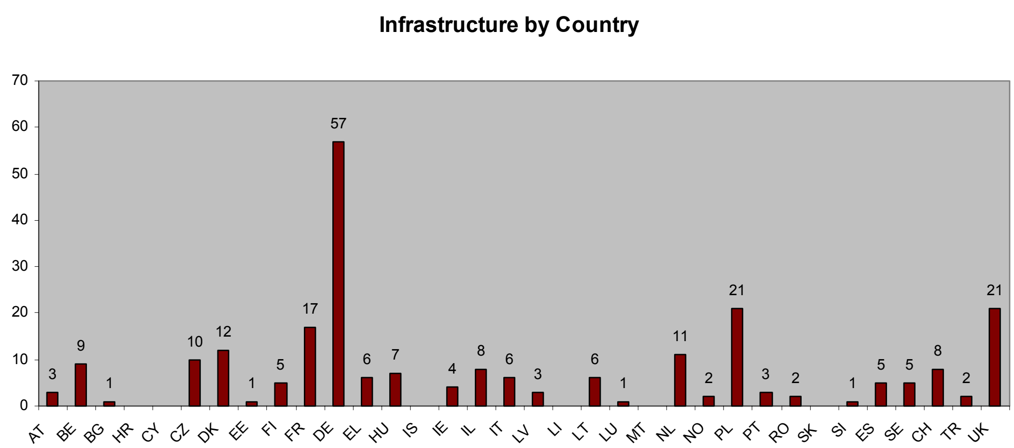
2.2 Infrastructure

The comment is made in the EU's 'Towards a European Strategy for Nanotechnology', that "the EU…lacks world class infrastructure… that muster the necessary critical mass". Nanoforum, the EU-funded European Nanotechnology Information network has produced a report on 'Nanotechnology Infrastructure in Europe'[13], which includes information on the level and focus of infrastructure facilities across Europe. Figure 7 shows the number and general focus of facilities by country.

If it is believed that smaller, lighter, faster and better performing technology can bring solutions to some at least of the current industrial and environmental problems, it is important to develop a world class infrastructure at European level to cluster the specialists, engineers, researchers who will create the technologies of the future.

In order for Europe to maximise the potential for nanotechnology in the key areas of energy efficient systems for heating and cooling, manufacturing and transport; better medical technologies and the provision of clean water, coherent research and development programmes are needed underpinned by necessary infrastructure. In Europe, this is in the main fragmented, often unnecessarily duplicated and dispersed throughout European nations and regions.

Furthermore, as biomimetics, or the emulation of nature, is the most likely route to these new products and processes, the nanotechnology infrastructure and facilities Europe needs to be able to cope with the complex demands of organic and inorganic chemistry, electronics and life science research.



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[13] 'Nanotechnology Infrastructure in Europe', Nanoforum, 2005. www.nanoforum.org

Figure 7. N&N infrastructure in the EU and associated states (by country). A total of 236 centres with extensive fabrication and/or analytical facilities were identified. Source: Nanoforum

In the light of meeting important new goals, decisions as to whom or what should comprise a strategic European infrastructure network, and the capabilities required of each node needs to be urgently assessed, and the necessary investment made.

2.3 Global Perspective – Overarching Drivers

The serious issues of global warming, threats to water and food resources, and the challenges of healthcare in affluent and poor societies that are confronting society are global in nature. They demand a global response. There are two extreme scenarios in terms of public acceptance of the severity of the crisis. One is a reluctance by populations (and even governments) to change ingrained habits of consumption, or make any 'sacrifices'; the other (less likely) is that policies promoting lifestyle changes and the application of planet-friendly technologies are eagerly embraced, and lead to uniting different cultures in a common goal.

Across the world, there are many research groups and facilities. It is likely there is considerable duplication of research, and lack of communication across national boundaries may be resulting in a slower-than-need-be progress. It is vital that the EU takes a lead through its FP7 and FP8 programmes by focusing on goal-oriented research in relation to these global issues, and actively seeking international partnerships, where possible, to short-circuit the realisation of these goals.

Areas where nanotechnology may be relevant to identifying solutions are listed in Section 1 above.

3 Regulation

With any new technology, there are always vociferous exponents and vociferous detractors. Nanotechnology is no exception, especially as it is appears to be the next wave technology following hard on the heels of genetically modified organisms, and given the negative connotation of GMO's, in the public mind, nanotechnology, although there is no connection, may also be perceived in a negative way. It is likely nanotechnology will offer many benefits to society, so efforts need to be made to promote these benefits, as well as addressing concerns.

It has been recognized there may be environmental and health dangers associated with uncontrolled or unregulated release of some nanoparticles into the environment, including carbon nanotubes. This release could occur during development, manufacture, incorporation, use or disposal of products. The dangers of 'designer' nanoparticles has also thrown into high relief the dangers of other nanoparticles, created by nature, or as by-products of existing industrial and other processes. The latter includes combustion products of aircraft and car engines, and fine metal dusts or exhaust products resulting from some manufacturing processes, which may cause damage to health or the environment.

Debating the risks of nanotechnology is fraught with problems, particularly as nanotechnology is an all-embracing term, and does not apply to a *single* technology or application. So far, risks seem to be associated only with nanoparticles, which also offer many opportunities. For example, medical research is presently excited by the possibility of using fluorescent nanoparticles, called quantum dots, as unique disease markers, helping differentiate between malignant and non- malignant growths, and also in the detection and treatment of disease at the very earliest stage. However, the toxicity of these nanoparticles is incompletely understood, and work is needed to determine how these particles can be safely used in achieving important diagnostic and therapeutic goals. Europe is fortunate in having notable strengths in this area, but new research is needed both into modelling nanoparticle behaviour, and cell, rather than animal-based testing, as the only practical way forward.

The public needs to be informed about the benefits of nanotechnology, as well as the risks, and reassured that the risks will be well researched and regulated. Scientists have too often, and to their cost, ignored the importance of the need to inform and engage with the public. The UK Government understood at any early stage that action was necessary, and commissioned the Royal Society and the Royal Academy of Engineering (cited above) to investigate the potential benefits of nanotechnology, the likely risks, and what if any actions should be taken regarding each.

A survey, commissioned as part of the above report, found that the public held both positive and negative views about nanotechnology. They were excited by the idea of new advances particularly in medicine and in the creation of new materials; they had a sense that the developments were part of natural progress; and had the hope that they would improve the quality of life. Concerns were expressed about financial implications; the impact on society; the reliability of new applications; long-term side effects and whether the technologies could be controlled. The issue of the governance of nanotechnologies was also raised, as to which institutions could be trusted to ensure that nanotechnologies would be socially beneficial. Comparisons were made with earlier issues with genetically modified organisms and nuclear power.

Based on the survey and a wide dialogue with many stakeholders, the RA / RAE report made several recommendations. These included a more sustained and extensive programme of research into public attitudes, a debate about the future of nanotechnologies should be undertaken now, to inform key decisions, and that there should be public dialogue around the development of nanotechnologies. It emphasized that governance would also be an appropriate subject for early dialogue. The complete report can be accessed at www.nanotech.org

3.1 Possible Regulatory Framework

A key recommendation of the RA / RAE report was to put in place a regulatory framework early enough to ensure public confidence. The report made several further comments regarding the focus of regulation. For example, it noted that little risk is expected when the nanoparticles are fixed in a material, but where there risks of release during disposal, destruction or recycling of the product exist, and suggested that producers publish procedures outlining how these materials will be managed to minimise possible human and environmental exposure as a result. Similarly, it accepted that some manufactured nanoparticles will be more toxic per unit of mass than larger particles of the same chemical.

The following recommendations were made:

- the UK Health and Safety Executive carry out a review of the adequacy of existing regulation to assess and control workplace exposure to nanoparticles and nanotubes, including those relating to accidental release.
- in the meantime lower occupational exposure levels for chemicals when produced in this size range should be set; that chemicals produced in the form of nanoparticles and nanotubes should be treated as new chemicals under these regulatory frameworks,
- the annual production thresholds that trigger testing and the testing methodologies relating to substances in these sizes, should be reviewed as more toxicological evidence becomes available
- the ingredients lists for consumer products should identify the fact that manufactured nanoparticles have been added.

Finally, the report acknowledged that almost no information exists about the effect of nanoparticles on species other than humans or about how they behave in the air, water or soil, or about their ability to accumulate in food chains. Until more is known, the release of nanoparticles and nanotubes to the environment needs to be avoided as far as possible. The report specifically recommended…. that 'factories and research laboratories treat manufactured nanoparticles and nanotubes as if they were hazardous …, and that the use of free nanoparticles in environmental applications …be prohibited'.

Since the report was published, the UK Government, co-ordinated by DEFRA, has embarked on an exercise to identify producers of nanoparticles in the UK, the levels and composition of imported nanoparticles, and all products in the UK marketplace containing nanoparticles. There have also been several research and information networks created to identify potential risks to health and the environment.

4 Economic Efficiency, and Competitiveness in a World Market

Planet friendly technologies may not appear at first to be attractive to investors, but can become attractive when their use is driven by legislation or tax incentives. Here, communication between politics, research and industry is essential for defining the goals of the technologies of the future. Europe's legislators can direct investment, and thus encourage industry to research the kinds of new products and processes needed for the 21st century applications discussed in Section 1.

4.1 Supporting / encouraging / developing start ups

The commercialisation of nanotechnologies to date seems to be following a unique path. Firstly, as many aspects of a large company's product portfolio could be influenced by nanotechnology, deciding where to place research investment is a difficult decision, so instead many companies have turned to technology-watching. Research breakthoughs in nanotechnology often have more than one application in more than one industry. This is now a win-win situation, and new nanotechnology companies are often able to license different aspects of their technology to several different companies without any conflict of interest. For example, the University of Bonn, which specialises in the 'Lotus Effect' (liquid

/ dirt repellency technology) offers this expertise to many major clients including BASF (self-cleaning shoes), Creavis (plastics), ITV Consortium (textiles), BYK Chemie (additives), Liqui Moly (car care), ERLUS (ceramics), Tiger ISPO (coatings, paints), Ferro (inorganic coatings), Schoeller Hoesch (paper and fleece).

Unlike in the past, many breakthrough nanotechnologies are being developed by small companies, and this may continue to be the case. In order to get to the market, nanotechnological research and development is only likely to succeed if two conditions are met: One, is that multidisciplinary groups or partnerships need to be created. For example, a company able to create nanoparticle 'labels' which fluoresce in the presence of diseased cells needs to partner with a medical imaging company. The partnership will also need to include companies involve din measurement, data processing, image analysis and visualisation techniques in order to bring a product successfully to market. Two; small companies often have no route to market, so must partner with a large company already established in the field. The above example also illustrates this, as the nanoparticle company will partner with the larger established imaging business in order to short circuit the time to market.

4.2 Dealing with generic nanotechnologies

As hinted above, small nanotechnology companies often hold intellectual property that underpins a spectrum of applications that could be wide ranging in their application. For example, a small Oxford company, Oxonica, has applications for its techniques in nanoparticle design in areas a diverse as sunscreens and cosmetics, contrast agents for medical imaging, anti-counterfeiting technology and fuel additives, and they partner with a variety of unrelated industries to commercialize each application.

It is soon obvious which nanotechnologies are winners, in terms of their broad and disruptive applications. These companies / organizations are the 'nanotechnology' jewels in the crown of whichever country possesses them, and require to be carefully nurtured and developed, and Europe requires special initiatives to ensure the survival and success of the companies with such valuable technologies.

4.3 Licensing and Patenting

Licensing and patenting issues often slow down or impede the development and application of new nanotechnologies, and a better alternative to the present international patent system is sought, especially given the new goals of nanoscience, which must be quickly turned into nanotechnologies. It is suggested that since nearly all nano-related research and development is taking place within basic research, problems may arise in relation to the sharing of new knowledge between competing organizations. This is because intellectual property rights and particularly the international patent system are only relevant to technical *solutions*, which are impossible to develop without the basic research.

Consequently, new approaches to IPR may be necessary, with mechanisms for assessing intellectual and financial rights, in relation to sharing scientific and technical knowledge, and aimed at shortening the distance and time between basic and applied science.

5 Military Nanotechnology[14]

A major issue to be considered is how nanotechnologies may affect the military and the future arms race. Converging technologies (as described in Section 0.2) for augmenting human performance has obvious attractions, such as improving stamina, strength and the ability to deal with multiple situations and process information more effectively.

History also shows us that technology advances have lead to the military developing smaller, more mobile and more powerful weapons, surveillance systems and other military equipment. While these may be developed under the auspices of safeguarding freedom and ensuring security, such devices if they continue to follow current trends could give rise to an arms race similar to that of nuclear weapons.

To prevent an escalation there must be internationally agreed regulations. For instance, nanotechnology could one day make surveillance devices and weapons that are virtually undetectable and have advanced remote control capabilities, which raises issues of where the dividing line lies between ensuring security and infringing human rights. As a result, unilateral actions of one country on another could become more targeted and more difficult for the international community to police. Safe-guarding these technologies will be crucial- preventing their sale or distribution to, or theft by, other organisations.

At present the main country publicly declaring that it is developing military uses of nanotechnologies is the US. In 2001 the US invested 125 million USD in nanotechnology initiatives for the Department of Defense (DoD). The proposed budget for 2005 includes 276 million USD for the DoD and 1 million USD for homeland security (together this is approximately 28% of the total nanotechnology budget). For example, the Institute of Soldier Nanotechnologies (ISN) at MIT was established in 2002 with a five-year 50 million USD contract from the US military and is looking at producing a battle-suit that provides improved protection, monitors vital signs and (at the same time) is lighter than conventional equipment.

The UK Ministry of Defence (MOD) is also funding some military aspects of nanotechnology including new structural materials, electronic devices and quantum interference, however this is on a much smaller scale (approximately £1.5 million per annum). This research is mainly carried out through the Defence Evaluation and Research Agency (DERA) and its Corporate Research Programme, although the MOD recognises that close collaboration with academic research is essential to keep abreast of developments in nanotechnology that could have applications in defence.

Sweden is investing 11 million euros over 5 years in nanotechnology research for military purposes through FOI (the Swedish Defence Research Agency). The funding is divided between 7 research projects (involving universities, major defence companies and some

[14] Source: nanoforum. www.nanoforum.org

high-tech start-up companies) and focussed during the first two years on feasibility studies before entering an application-oriented phase.

The EU has recently published a call for proposals and supporting activities in the scope of the preparatory action on "the enhancement of the European industrial potential in the field of security research". While this does not specifically mention nanotechnologies, many of the areas have implicit nanotechnology connections (such as sensors, tracking devices) under the project themes of "Improving situation awareness" and "Protecting against terrorism (including bio-terrorism and incidents with biological, chemical and other substances)". There is a budget of 65 million euros from 2004-2006, which is a precursor to a much larger Security Research Programme that will start in 2007.

6 Forward Look: Long Term Challenges and Visions

6.1 Why nano now?

Why has nanotechnology sprung into prominence now? It is because scientific advances (such as the scanning probe microscope) of the last thirty years have gradually enabled us to 'see' atoms and molecules, and manipulate them in a controlled fashion. This has led not only to a more profound understanding of the properties of materials, but even more importantly, to the ability design materials with new properties, and even create entirely new materials hitherto unknown in nature, such as carbon nanotubes.

A new man-made nanomaterial, carbon nanotubes (hollow cylinders of carbon atoms), was first isolated in 1991, and with every passing year, new applications have been discovered. These applications relate to the structural rigidity, flexibility and strength of the nanotubes. They are 10 times stronger than steel but only 1/6th of the weight; they can be conductors or semiconductors, they possess an intrinsic superconductivity, are ideal thermal conductors and also behave as field emitters. It is not difficult to conceive of some of the many tremendous opportunities they, and other applications of nanotechnology, present.

6.2 Why nanotechnology is so important

Nanotechnology has been moving up the research agendas of the industrialized nations since the nineteen eighties and nineteen nineties. In the early days, nanotechnology research was driven by the needs in particular of the electronic industry, which viewed tolerances at the nanoscale as essential to making better quality products. This industry also realised from their research and development activities, that new properties of materials were emerging at the nanoscale that they could harness in their quest to squeeze more information processing and storage into smaller and smaller volumes.

This early knowledge and application of nanotechnology for electronics became the foundation for later work across many discplines and sectors. The dawning of realisation that that the world operates at the nanoscale, and that by using new technology the natural world could be observed, and more importantly, emulated, has led governments to embrace nanotechnology and its multivariate opportunities with energy. Figure 5 illustrates the escalation in national funding for nanotechology since 1998. The marked increase in 2000 represents the time that the US National Science Foundation announced the National Nanotechnology Initiative, and since then different countries have followed by ploughing millions of euros into research and development. About a billion euros is being spent worldwide in 2005.

As always, innovation is driven by financial gain, underpinned by consumerism, legislation and contingency, such as war or plague. The automotive and aerospace industries, in parallel with the military are ealy adopters. Gradually, and surprisingly slowly, the pharma and medical giants have woken up to the opportunities offered by nanoscience and nanotechnology. Today, inappropriately, military funding for nanotechnology is outstripping any other. Inappropriately, because it is hard to identify the threat. While industrial companies are seeking ways of using nanotechnology to make better products (e.g. nanocoatings that repel dirt and provide scratch resistance for windscreens, windows and even spectacle lenses), it is more difficult to comprehend what drives the military research.

6.3 A Forward Look

Nanotechnology is one highly important facet of a spectrum of technologies that may offer some solutions to creating a sustainable future. Its key selling point has been heralded as offering benefits for the environment through ‘more for less’; the concept of being able to fit more features into smaller, smarter products. This should translate into products that use less resources (reducing waste and pollution) to produce, and are more energy efficient. The message is that technology may help us to make the necessary fundamental changes in our lifestyles that the future demands. Nanotechnology, in conjunction with other technologies, may provide alternatives to activities that are resource intensive; and also may offer new opportunities for a satisfying way of life in this futureworld, without jeopardizing our environment.

The application of nanotechnology is not without its downsides, in terms of our incomplete knowledge. Although we are able to make totally new, nano-derived materials, especially nanoparticles and carbon nanotubes*, how they will behave in living systems and in the environment is incompletely understood. Some new nanoparticles appear to offer huge benefits for healthcare – in the targeting of drugs to the disease site, and as contrast agents in the early identification and treatment of disease. It is therefore critical to understand how these nanoparticles work, and what their long-term effects in the body might be, so their benefits can be fully realised.

6.4 A Day in a Life in 2025

Rogerio wakes to the sound of a gentle alarm. Even though it is November, the house is pleasantly warm as it has been constructed from energy-efficient nanocomposite materials, specially designed to keep the atmosphere warm in winter and cool in summer. The windows have a nanocoating that allows in filtered light and retains heat; it is also dirt repellent, so they never need washing. Rogerio hates window-cleaning.

He calls out 'News, please' and one wall of his bedroom suddenly becomes illuminated, and shows scenes, with a commentary, on the latest happenings in the world. He calls 'weather in Stockholm, please' and the image changes to show a weather map, with the forecast for the day. He then says, 'Fine, thanks', and the screen reverts to bland wallpaper once again.

Rogerio then gets up, and goes to the bathroom. His water is constantly recycled, using nanofilters. He washes, and brushes his teeth with a toothpaste which incorporates hydroxyapatite and other nanoparticles. As a result, his teeth are perfect, with no fillings or decay. Rogerio, though, is not completely perfect, he was in an accident as a child, and as a result his hearing was damaged; but thanks to nanotechnology, he now has a tiny cochlear implant that requires no external power source. It was fitted several years ago, almost painlessly, and cost him about the price of a new shirt. The quality of the sound means he feels that he has no impediment at all to his faculties. This technology is available cheaply, all across the world, as are many medical advances based on nanotechnology

During the day, Rogerio is a busy executive, working for a well-known bank. He takes care of his health, and knows that he has a genetic propensity for heart disease (he checked his genome himself using a cheap, palm-sized instrument) so he ensures he monitors all his 'vital' systems every morning. In the bathroom, he grasps on a small 'handle' for a few minutes, and in a few seconds, his pulse rate, blood pressure and cholesterol level are displayed on the bathroom mirror. If he wants to know anything more such as his blood sugar level, he will need to wait a little longer; but he doesn't bother. Everything seems to be fine.

After washing, Rogerio puts on his clothes, which are treated to stay fresh and clean, and crease-free. This makes them much more energy-efficient – and he looks very smart. His breakfast usually consists of fruit, bread, porridge and yoghurt – these are 'nutrigenomic' foods; specially modified to provide the optimum kind of nutrition that keeps his heart in good order, and helps his general well-being.

Ahead is a busy day. Rogerio decides to start work. He could use his bedroom as an office, but prefers to move into another room. As he opens the door, already he can see some of his colleagues are at work, in this virtual office. The closest person geographically actually lives four hundred kilometres away. He knows he has a series of meetings arranged for today with clients from across the world. Travel is not the norm any more, and it is simple to meet by means of virtual reality. The technology makes it so natural that people have been known to forget they are conversing with a hologram, and try to shake hands or pat each other on the back. As the day progresses he communicates with his work colleagues, who live in many different places, but they are all so comfortable with the technology they feel they actually are in the same room. They even eat a virtual lunch together!

Rogerio remembers the days when people travelled by car or aeroplane, until droughts, fires, famines, plagues and hurricanes became so frequent that the scientific evidence for an imminent, irreversible ecological global disaster could no longer be ignored. Governments had to then make some very hard-hitting decisions to ensure the survival of the planet, and the continuation of the human race. Travel was forbidden, except in emergency, new forms of energy use were enforced through legislation, such as the adoption of renewable energy technologies (mainly solar), and energy saving was a priority.

The aviation and automotive industries completely slumped. A revolution in manufacturing occurred, as the transport of non-essential goods became impossible. Instead, local ‘desktop’ manufacturing units became the norm, creating products by building them up using something similar to inkjet technology, but in 3-D.

The health of the population began to be monitored remotely, and most patients could be treated early, in their homes, saving energy and other resources. Technology enabled disease to be identified at the level of a few cells, and treated in situ. In extreme cases, patients could go to small, local surgical units that contained all the latest equipment. At this time, funding had been made available to implement long-awaited cures for the diseases of the less developed world (which had existed for some time, but had not been deemed economical by their developers). Industry, including the food industry, had been thrown into turmoil. Food had to be grown and consumed locally, so new flavours were created to provide variety in taste; and many foods were scientifically modified to provide health benefits and prevent the manifestation of genetically inherited diseases. These were specially grown in isolated units.

At leisure, Rogerio occasionally reflected that life in 2025 was actually not too bad. His home was comfortable, he could communicate with any of his friends worldwide, and when he became bored, he could transform his surrounding environment, using a few spoken commands, into a beach paradise; only lacking the real sea. He did prefer, though, just to go a walk outside, and marvel at the miracle of nature. The tarmac of many roads, drives and gardens had been torn up, and the underlying soil painstakingly nursed back to health - a desperate attempt to regenerate the precious bacteria, providers of a healthy atmosphere on which all life depended.

Farming and agriculture had also changed dramatically. Gone were the killer fertilizers and pesticides; although some growers were licensed to produce special foods that could counteract some inherited diseases. People were lucky, also, in that science had discovered a way of encouraging the body to regenerate its own tissues and organs, that transplants were not required, even in severe cases of organ failure.

It was fortunate, he thought, that some nations, especially Europe, had seen the wisdom twenty years ago, of encouraging new research and development in the technologies that people now needed. Surprisingly, also, the bank had done rather well out of the new world order. The use and development of these new technologies had been enforced by law, and this meant a new role for the bank in providing finance. By law also, banks today had to use a high proportion of their surplus to support projects in specified regions of the world at very low interest rates. Not popular to begin with, but the benefits were now apparent. However, it had been sad to see so many businesses such as those involved in import and export of out-of-season fruits, flowers and vegetable, and those needing a high energy input such as glass factories, go to the wall.

Rogerio mused that life was generally good. Surprisingly, people understood they had been saved from the brink of extinction - there was still a long way to go to be sure, and all the indicators of climate change were currently monitored, almost obsessively, using nanosensors. It was interesting to see, though, how attitudes to waste and recycling had changed; small plots of land were again being nurtured in the quest for good food; less travel had meant more social interaction, and the cheapness, ubiquity and user-friendliness of information and communications technology meant that education and entertainment were available on demand. Technology had certainly made this new era so much better than he'd ever hoped.

There had been a bit of a backlash against all the military spending, though, especially when people realised that the battle that needed to be waged was a joint one, of survival, not one against an imaginary enemy.

The day over, Rogerio reached for a bottle of homemade wine his neighbour had recently given him. He opened it. 'Surprisingly good', he thought; 'a bit like life is just now'.
He'd better be careful not to break the bottle, though; glass bottles and jars were extortionately expensive nowadays.

Conclusion

A major change is immediately necessary to the whole concept of industrial growth, upon which our present existence is predicated. The Lisbon Agenda is not attacking this issue sufficiently strongly, only hinting at sustainability. Far more is required in terms of a vision and a strategy for Europe (and the planet's) future. The reason for this is that our environment is so affected by the activities of mankind that we are reaching the point of ecological catastrophe. A key issue now, is how to rein in the insatiable, and misplaced, drive for industrial growth that has been part of our daily life ever since mankind harnessed steam; and to try and undo some of the damages already inflicted by modern cities and civilisations.

It is possible that new technologies, including nanotechnology, allied to behavioural changes may offer a way forward that enables us all to lead satisfying lives without completely destroying the planet that sustains us.

Appendix 1: Analysis of Strengths, Weaknesses, Opportunities and Threats

<table>
<tr><th>STRENGTHS</th><th>WEAKNESSES</th></tr>
<tr><td>

In nanomaterials research and development
In biomimetics research (a major source of nanoinnovations)
In nanoelectronics and IT research, including quantum computing
In nanotoxicology research, both in-vitro and in-vivo
In nanophotovoltaics research
In nanosensor research and development
A strong industrial base in instrumentation
In nanomedicine generally –diagnostics (including imaging), tissue and organ regeneration and targeted drug delivery
In cultural differences resulting in imaginative approaches to research
In the ability to work in teams
From access to mathematics and physics expertise from what was the eastern bloc
Acceleration of new company formation underway
European openness in developing and adopting environmentally friendly technologies
Europe openness to developing technologies for the less-developed regions

</td><td>

Critical issues (ecological meltdown, poverty and disease) are not clearly addressed in the Lisbon Agenda or the proposed research framework programme of the EU
Lack of a planet friendly scorecard for research, regionally, nationally or at EU level.
No clear technology transfer routes to the less developed world
Fragmented research infrastructure across Europe, and lack of easy and affordable access by industry to state-of-the–art, well-managed, facilities
Nationally variable industry pull-through
Variable incentives / cultures for supporting start-ups
European funding slow and highly bureaucratic
No Europe-wide support for individual genius
Not enough synergy between regional, national and EU projects
Academic research often lags industry
Funding may be duplicated
Not sufficient balance between research and the implementation of practical and affordable solutions
Inappropriate new EU investment in military research
Lack of fiscal incentives for environmentally friendly technologies; also lack of legal incentives
Critically slow emergence of technology from the research base
Unnecessary and expensive sponsorship of research in non-indigenous and / or multinational companies (Who, overseas, sponsors European companies?)
Lack of skilled staff (including technicians)

</td></tr>
<tr><th>OPPORTUNITIES</th><th>THREATS</th></tr>
<tr><td>

The exploitation of planet and people friendly research
The development of widely applicable technologies (sensors, renewable energy, medicine etc)
The creation of new technologies (medical and non-medical) to support the ageing / disadvantaged / diseased
Reduction animal experimentation through cell-based toxicity testing
Critical niche opportunities in areas such as lab-on-a-chip, sensor technology

</td><td>

Brain drain in life sciences, electronics, software and engineering
Global dominance reached through the application of military-inspired research
Europe’s inability to effectively commercialise publicly funded research
Public backlash to nanotechnology
Too little, too late, of the technologies that matter

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Appendix 2: Ethical Issues in Nanotechnology, with especial reference to Nanomedicine

Nanotechnologies are said to offer great promise for medicine, but much of this lies in the future. In the largely exploratory and discovery phase, ethical and social assessment is necessarily preliminary. This future orientation has also made nanotechnologies vulnerable to the current *zeitgeist* of overclaiming in science, either the potential benefit or harm. Perhaps the first ethical issue is the frequent use of the word "will", about future outcomes which cannot be known. This sometimes seems to express an 'article of faith' about science which would present a problem if it generated a false impression of inevitability of future developments. Equally there is a need to be careful about placing premature weight on speculative concerns about nanotechnologies raised ahead of evidence.

Nanomedicine touches upon many issues already familiar in bioethics, and also some more particular questions. Before considering these, a more basic contextual question should be considered.

What drives nanotechnology?

It is a common misconception that technology is neutral. On the contrary, a technology reflects the values and goals of the society within which it emerges and, in turn, may alter the values and aspirations of that society. In a somewhat sceptical climate of public opinion, more sensitive areas of technology might be seen as a social contract. A technology would be welcomed if the values and goals of the inventor are close to those of wider society, and if the invention correctly anticipates what society wishes, as with the acceptance of the mobile phone. On the other hand, if the inventor is remote, the aims do not correlate with the values and goals of the society, or if the invention is unfamiliar or risky, there can be outright public rejection, for example, of importing unlabelled GM soya and maize products to the UK.

We should therefore ask - whose values will nanomedicine express? For developments that are novel, highly technical and unfamiliar, it is important to ask if these are a product of widely shared values, or only of a powerful elite. The kinds of values, ideologies and beliefs that may influence or drive nanomedicine include:

- Free, curiosity-driven research,
- Economic growth, jobs and competitiveness,
- Quality of life, as variously defined – e.g., personal affluence, consumer choice, environmental goals, social justice, global health and poverty, spiritual goals,
- Compassion, motivated by the desire to alleviate human suffering,
- Medical 'success' - seeking a technical solution to any condition, as an obligation,
- Different religious belief systems,
- Transhumanism, driving human evolution by physically changing humans.

Two critical areas about which world views make implicit or explicit assumptions are the concept of the human being and the notion of progress.

Nanomedicine and the nature of the human being

Many conceptual models of the human being exist. Depending on the context, we might be a bag of genes, a conscious mind, a spiritual and bodily being, a set of capacities restrained by natural form, and so on. Nanotechnologies provoke a possible conflict between holistic and functional views, and between what is considered fixed and what is changeable. Traditional presuppositions hold that there are moral or societal bounds which restrain what may be technically feasible in intervening in the human condition. These limits are drawn from the insights of religious and cultural traditions, philosophy and theology, the arts and humanities, and the social sciences. These are challenged by transhumanist belief that humans are destined to go beyond current limitations. If our humanity is not to be defined simply by technological feasibility, where do we draw lines to limit some technological possibilities or promote others? A related issue concerns the relationship between one's identity, one's body and external devices. How far should we develop devices promoting direct brain-machine interactions, or apply external or internal controls of the body or the brain?

Some raise a metaphysical question of whether to focus on functional enhancements, which misses the point about both what is wrong with human beings and what makes life worth living. Notions of improvement carry the danger of the stigmatisation of disability or what is perceived as defective. Beyond a certain basic point of physical survival and necessity, it is argued that what matters most to humans are not functional things but relational, aesthetic and creative aspects, and that our problems are less physical limitations than our moral, relational or spiritual failings.

Nanomedicine applied in non-medical contexts

Should a distinction be maintained between medical and non-medical interventions in the human person? Procedures developed in an acceptable medical context may pose serious ethical questions if applied non-medically. This distinction is recognised in the European Convention for Human Rights and Biomedicine which opposes sex selection in IVF except to avoid serious sex-related hereditary disease. Inevitably, there are grey areas, but if the broad distinction is valid, it implies that restrictions should be made to ensure that nanotechnologies, devised and permitted in a strict medical context, are not applied without limit to non-medical contexts.

For example, nanotechnology may assist the repair of sensory organs or provide intimate control from the brain to prosthetic limbs for accident victims or the disabled. Should these capabilities be used to enhance the capacities of the able bodied, for example to extend sight into the infrared for better night vision when driving? Again, if nanotechnology enables specific interventions in cell repair mechanisms, should this be used to seek to extend the human life span?

A related issue concerns surveillance and military uses. The same nanotechnology that enables small devices to be implanted in the body to monitor a range of medical indications, such as blood sugar levels in diabetics, could also lead to more problematical applications such as increased surveillance of citizens or military applications. Mechanisms are needed to identify such potential crossovers at an early stage.

Social issues relating to nanomedicine: What do we mean by progress?

A common view in scientific and political circles is a belief in "progress" through technology, to improve the human condition in its widest sense. It is confident of human skill and ingenuity to overcome any problems. The currently dominant economic model frames nanotechnologies in terms of their capacity for wealth generation. Another widely held view, however, sees intervention explicitly balanced by care for our fellow humans and attention to the impacts of our innovations on the environment. Interventions are made which respect certain limits defined by the human condition and our finite environment. Technology is not the sole engine of progress but a tool which remains at the service of humanity, not the other way round. Lastly, there are those for whom progress is entirely personal and not for the state to dictate.

At this stage nanomedicine is driven by a “technology push”, which has a social dimension. Functions and properties that can be measured or manipulated tend to put a steer on what applications are promoted. Prototypes produced in the laboratory co-produce ethics with the artefact. Thus there may already be implicit ethics in practices within the research community. What are the needs which nanobiotechnology is assumed to meet? Who should define these as needs, or judge whether the expense of research is better spent on other ends? This is especially relevant to high tech medicine in a global context of health needs which often require simpler solutions. How are such judgements to be made democratic accountable at a meaningful stage of development? Foresighting very uncertain technologies is notoriously difficult, and carries the risk that early public engagement may promote either public assurance or public panic over the wrong issues.

Special issues relating to nanomedicine

Lastly there are particular features of nanomedicine to consider. The reductionism that opens powerful therapeutic possibilities can also create potential for powerful harms, if the precision becomes wrongly applied or if it has more than just the desired effect. Small things may mislead by telling an incomplete story. The ability to intervene at a cellular or molecular level may fall foul of the complexity of the system. For example, nanomedicine may enable rapid read-outs of our whole genome or of our body's levels of everything imaginable, but what does all that information mean? What is now a well person, when we have so much unsuspected data about our bodies? This raises familiar issues about genetic information, but also how such extensive and possibly distressing information is handled. Going to the doctor for the right antibiotic for a chest infection may result in discovering a susceptibility to breast cancer.

The notion of bottom-up construction based on living systems, either by mimicking or by incorporating components from living systems may raise concerns about hybrid devices which interface human and machine, and what we should choose to build. The inherent reductionism can stimulate a practical approach which it assumes the right to tinker around at this reduced level, without knowing how the changed pieces fit together, having lost sight of the whole. The effect of nanoparticles on biological systems and human health raises important ethical questions on what constitutes acceptable and unacceptable risks where scientific data are available, and how precautionary we should be over uncertain risks which may take a long time to assess.

This brief survey is largely limited to asking questions which seek to map out some of the ethical and social topography of the uncharted lands which nanotechnologies may offer to medicine. How as societies we seek answers as these technologies emerge will be of crucial importance, so that the right benefits may be achieved with justice, and retaining our humanity in all its rich diversity.

Dr Donald Bruce.
Science, Technology and Religion Project,
Church of Scotland