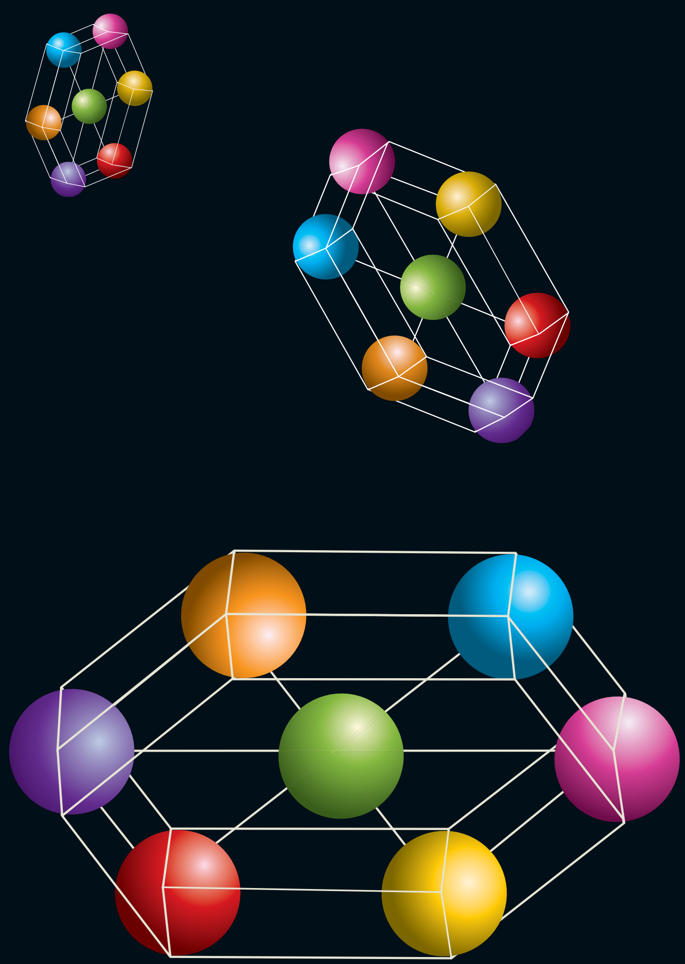
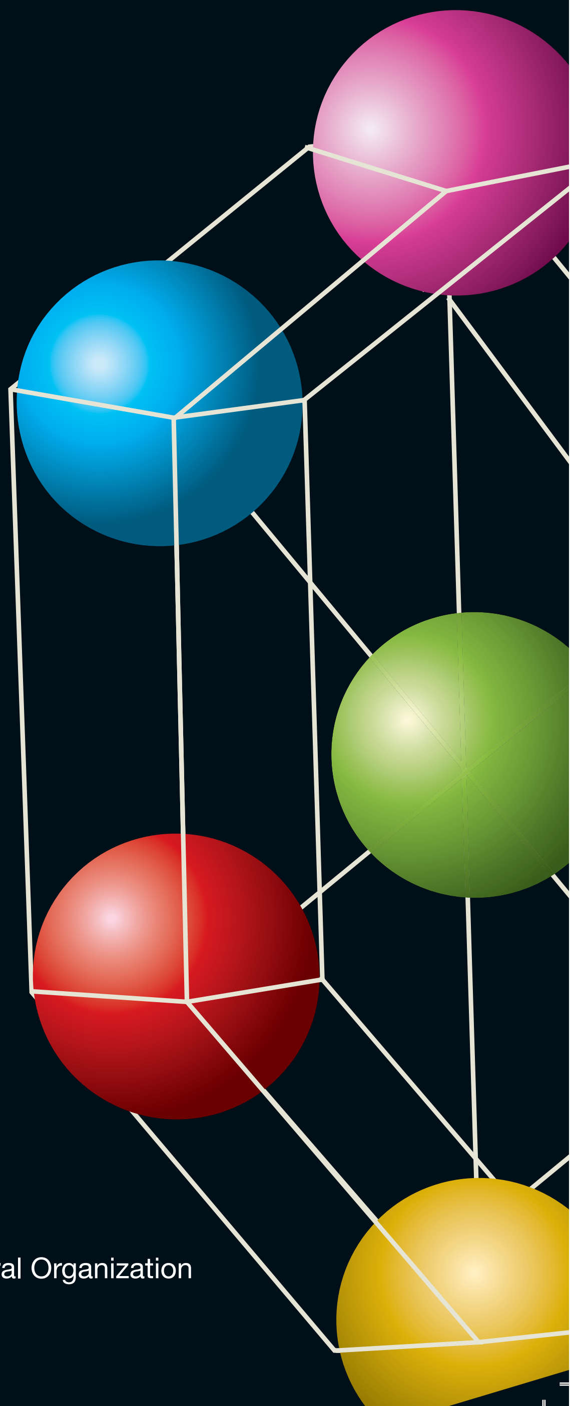
THE ETHICS AND POLITICS OF NANOTECHNOLOGY





United Nations Educational, Scientific and Cultural Organization

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United Nations Educational, Scientific and Cultural Organization

Table of Contents

1 INTRODUCTION

Nanotechnology could become the most influential force to take hold of the technology industry since the rise of the Internet. Nanotechnology could increase the speed of memory chips, remove pollution particles in water and air and find cancer cells quicker. Nanotechnology could prove beyond our control, and spell the end of our very existence as human beings. Nanotechnology could alleviate world hunger, clean the environment, cure cancer, guarantee biblical life spans or concoct super-weapons of untold horror. Nanotechnology could be the new asbestos. Nanotechnology could spur economic development through spin-offs of the research. Nanotechnology could harm the opportunities of the poor in developing countries. Nanotechnology could make the molecules in ice cream more uniform in size. Nanotechnology could enable a digital camera to work in the dark. Nanotechnology could clean up toxic waste on the atomic level. Nanotechnology could change the world from the bottom up. Nanotechnology could become an instrument of terrorism. Nanotechnology could lead to the next industrial revolution. Nanotechnology could transform the food industry. Nanotechnology could repair the ozone layer. Nanotechnology could change everything.

These are all *bona fides* lines culled from the headlines that start 'Nanotechnology could…'. What are we to make of this incredibly contradictory welter of promises and warnings? How can one thing hold so much potential, even taking into account the hyperbolic enthusiasm of public relations experts and journalists? Despite these wild promises, there is in fact something specific to nanotechnology, and there are a handful of very specific concerns that should occupy citizens, politicians, scientists and businesspeople interested in this area. In order to assess the ethical, legal and political aspects of nanotechnology it is essential to separate the tractable potential of nanotechnology from the imponderable possibilities. This document outlines what the science of nanotechnology is, and presents some of the ethical, legal and political issues that face the international community in the near future.

1.1 UNESCO AND NANOTECHNOLOGY

The development of science and technology is changing human existence significantly. Technology is making life safer and less burdensome. Medical science has greatly improved the health of citizens. Medical technology has contributed to improvements in public health. Information technology has increased the possibilities and extent of communication among human beings. Ecological sciences have developed more sustainable ways of production and consumption. Life sciences are inventing new products and new medications. Nanotechnology intersects with all of these fields, and raises many of the same ethical questions. For example, science can benefit human beings, but where do the benefits currently go? Science and technology are often well developed and promoted in more developed countries using resources from less developed countries, but the results and products generally do not return to these less developed countries. Science and technology have also become fundamentally international activities. Medical research, for example, is executed in all parts of the world in large-scale multicentre trials. Citizens in developing countries are subjects in research projects coordinated in developed countries. However, it is clear that the same ethical standards are not always used in all countries. In order to avoid differential treatment in ethics of science and technology, there is a growing need for international action in this area of ethics.

These considerations have stimulated the Member States of UNESCO to give priority to ethics in its work programme. Since the 1970s, UNESCO has occasionally paid attention to the ethical dimensions of the life sciences, and in particular genetics. In 1993, the Member States established the International Bioethics Committee (IBC). This committee unites 36 experts from all disciplines and all regions of the world, in order to provide recommendations concerning difficult bioethical issues. At the request of the Member States, it assisted in the drafting of normative standards that can provide a framework of bioethical principles for all countries. In 1997, the General Conference of UNESCO adopted the *Universal Declaration on the Human Genome and Human Rights*, followed in 2003 by the adoption of the *International Declaration on Human Genetic Data*. Because of the growing importance of global bioethics, the Member States of UNESCO have recently (October 2005) adopted the *Universal Declaration on Bioethics and Human Rights*. The creation of normative standards in itself will not be sufficient. In order to apply the standards and make them work in practical settings, activities of capacity-building have been initiated, for example promotion of ethics teaching, establishment of ethics committees, and exchange of experiences in ethics.

The increasing awareness of ethical problems in relation to science and technology was also manifested in the establishment by the Member States of UNESCO in 1998 of the World Commission on the Ethics of Scientific Knowledge and Technology (COMEST). This international committee of 18 experts advises the organization as regards other areas of applied ethics such as science ethics, environmental ethics and technology ethics. COMEST is specifically mandated (1) to be an intellectual forum for the exchange of ideas and experience, (2) to detect on that basis the early signs of risk situations, (3) to perform the role of adviser to decision-makers in this respect, and (4) to promote dialogue between scientific communities, decision-makers and the public at large. On the basis of its mandate, COMEST has analyzed information technology, water use and hydrological technologies, energy and space technology. The IBC has similar functions, but is focused on bioethics. The IBC promotes reflection on the ethical and legal issues raised by research in the life sciences and their applications, as well as encourages the exchange of ideas and information, particularly through education.

This document responds to the ethical mandate of UNESCO. First of all, ethical issues in relation to nanotechnology should be identified and analyzed so that the general public, specialized groups and decision-makers can be made aware of the implications of the new technology. Since nanotechnology is developing quickly, an anticipatory approach to ethical issues is necessary. Instead of waiting for public concerns and moral discussions to emerge, IBC and COMEST are designed to continuously monitor the possible benefits and harms of new and emerging technologies such as nanotechnology. This is also the contribution that UNESCO can make: from a global perspective and at an international level, to promote the dialogue among all stakeholders and to provide recommendations to decision-makers who will be challenged by the moral issues of evolving and emerging technologies.

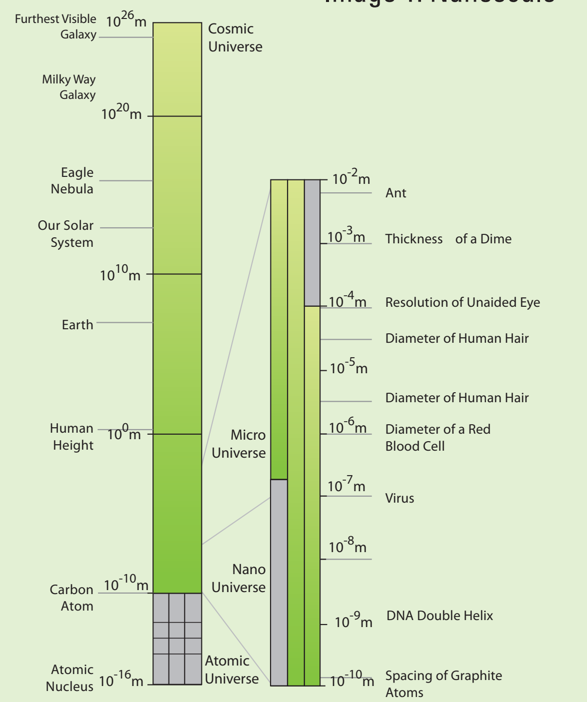
1.2 WHAT IS NANOTECHNOLOGY?

There are currently dozens of different definitions of what nanotechnology is or could be; and it is important to realize that none has been agreed upon. Definitions are also political and ethical—they can determine what people will pay attention to, worry about, ignore or investigate. The fact that there are many definitions is a good indication that nanotechnology (like other emerging sciences such as biotechnology) will likely confuse the settled categories of pure and applied research, and of publicly and privately funded research. Different disciplinary backgrounds and different national scientific establishments will bring different concerns and ideas to bear on what nanotechnology will become.

To begin with, is it nanoscience or nanotechnology? Throughout this document, the word 'nanotechnology' is used to mean both basic and applied scientific research. Many things we might want to characterize as 'basic' nonetheless require tools, practices, materials and techniques that are fundamentally technological to begin with (computers and software, complex microscopes and tools for physical and chemical measurement and manipulation). Similarly, many activities we might call engineering, because they involve the creation of devices or machines, are seen today by scientists as 'fundamental research' into the mechanics of nature. Hence in nanotechnology, science and technology are tightly interconnected and dependent on one another.

When it comes to nanotechnology, the familiar distinction between 'applied' and 'basic' research is also troublesome. It encourages people to confuse the *actual research of scientists and engineers* with the

Image 1: Nanoscale[1]



projected outcomes of observers, advocates, financiers and enthusiastic scientists. Very often, when people speak of nanotechnology, they confuse the proposed outcomes–the potential benefits and potential risks–of nanotechnology with the current state of the art in labs and corporations. The proposed outcomes of science are the stuff of social policy–they are and should be the subject of debate amongst all citizens of all nations, not just scientists or politicians. They are neither inevitable nor determined by basic research, but are constrained by it. Scientists' duty as citizens should be to challenge and critique unrealistic or dangerous outcomes–not simply to propose rosy ones. Existing research in nanotechnology should be at the centre of social policy as part of a system of checks and balances, not as the foundation for that policy.

So what is nanotechnology? Perhaps the simplest and broadest definition is that nanotechnology is research conducted at the nanoscale (10^{-9} metres, or one billionth of a metre. For reference, a human hair is roughly 20,000 nm in diameter). How small is the nanoscale? (See Image 1) Molecules, viruses and atoms are objects that range from less than 1 nm (atoms) to about 100 nanometers (large molecules like DNA). They are too small to see with the eye, or even with microscopes that use visible light. Hence the importance of new visualization technologies like the scanning tunneling microscope and the atomic force microscope, not only for seeing but also manipulating things at this small scale.

Such a definition is clearly too broad, however. Chemistry, physics and biology have worked with objects that are at the nanoscale for at least 100 years, and have debated their structure, composition and even existence for much longer. A more specific definition, for instance, would be one such as that often used by the US National Nanotechnology Initiative (Box 1). Most of what we know about how atoms, molecules and the physical world behave is based on research at larger scales (think of the physics of a baseball or the hardness of a diamond). At the nanoscale, however, properties can be observed to be quite different. For instance, a chunk of gold appears yellow to the human eye in natural light, but tiny nano-particles of gold (floating in water, for instance) can appear to be red because they reflect only the red light in the spectrum; similarly the electrical conductivity of carbon in the form of 'nanotubes' is much higher than carbon in the form of diamonds, due to it having a different structure at the molecular (nanoscale) level. These new properties, as the definition implies, might be exploited for novel applications–and this is at the heart of much of the enthusiasm about nanotechnology.

Box 1

The official definition of the US National Nanotechnology Initiative is that nanotechnology involves 'research and technology development at the atomic, molecular, or macromolecular levels, in the length scale of approximately 1 to 100 nm range, to provide a fundamental understanding of phenomena and materials at the nanoscale and to create and use structures, devices, and systems that have novel properties and functions because of their small and/or intermediate size'.

Definitions vary around the world, depending on national strengths. China, Japan and Korea emphasize the focus on materials and especially electronics, while researchers in Africa and Latin America often emphasize the materials in the context of medicine and environmental science. The Royal Society of the UK makes the distinction between 'nanoscience' and 'nanotechnology' where the former includes the 'study and manipulation' of nanoscale particles, and the latter the 'design, characterization and production' of 'structures, devices and systems' at the nanoscale.

1 Adapted from http://invsee.asu.edu/nmodules/sizescalemod/unit3.htm

The fact that gold reflects red light at the nanoscale is exploited in the design of experimental systems that kill cancerous cells with normal visible light, but leave normal cells unharmed.

There is a yet more specific set of definitions that have been proposed for nanotechnology, and these relate to the role of *control* at the nanoscale. Understanding and observing new properties of nanoscale objects is only useful (in an engineering sense) if they can be manipulated and exploited by creating novel combinations of molecules, new machines and devices or, in the most speculative case, tiny factories. Often this definition of nanotechnology goes by the name of 'molecular manufacturing' and has long been one of the most enticing aspects for science fiction writers of the last two decades. By defining it in this manner, the *proposed outcomes* of nanotechnology are significantly narrower—engineers and scientists imaging ways of constructing all kinds of products and materials 'from the bottom up'—meaning that they are created atom by atom using nanoscale factories. The advantage of this approach would be a nearly infinite flexibility to create any substance, object, device, machine or material through atom by atom construction. The alternative 'top-down' approach—the one we use today—uses natural and man-made substances that are then joined or constructed using a process specific to the product. No scientists working today have created such 'bottom-up' machines, few are even working in this area, but the debates about the theoretical possibility of such a manufacturing process have nonetheless been conducted very publicly and in the absence of any significant experimental work.[2] The possibility, and the threat, of molecular manufacturing are extremely peripheral to the other near-term issues addressed in the third part of this document.

The definition of nanotechnology as the manufacturing of nanoscale devices, rather than just the study of objects at the nanoscale has led some scientists to propose yet another definition—or re-definition in this case.[3] The study of 'nano-bio-technology' redefines the ubiquitous nano-sized objects of biology and chemistry (molecules) as tiny machines. So for instance, the molecule ATP, which is an essential component in the cell cycle of all living things, has come to be called a 'nano-motor'. So has the actin of the molecular duo, actin/mycin, which are responsible for the electrical stimulus that causes a heart to beat.[4] The redefinition of biology and chemistry as nano-bio-technology may seem like simply a craven attempt to garner attention for traditional science—but the same distinction applies here as above: If these tiny biological motors and machines are being harnessed and manipulated to do hitherto unknown or inconceivable things—if DNA is being used as a pair of tweezers, or the molecule 'prestin' is used to rotate a tiny gear—then the crucial component of the definition is not just the study, but the *exploitation* of molecular motors, molecules and the machines of life.

Finally, there is yet another definition of nanotechnology, namely that of the National Science Foundation's 'Nano-Bio-Info-Cogno (NBIC) Convergence'.[5] This definition proposes that nanotechnology represents a new kind of science that emerges at the nexus of biology, information technology and cognitive science at the nanoscale. This definition is in some ways the most radical, in that it is meant to capture the way nanotechnology will be used to 'improve human performance'. While it is true that many of the issues that are raised by studying and exploiting objects at the nanoscale require expertise in several fields, there are as yet very few scientists or laboratories capable of working at this 'convergence'.

Different groups define nanotechnology differently, depending on what they hope it will achieve—whether that relates to the body and human medicine, the environment, new materials or new biological objects. These definitions also vary according to the interests of nations and social actors interested in nanotechnology. Because there is still a gulf between the *proposed outcomes* and the *actual research* that has been conducted, the definition is hotly contested—and is an important aspect of the ethi-

2 The exception to this is the creation of quantum and molecular computers, but these machines do not manufacture anything, nor are they yet considered reliable or robust enough to be of much practical use. They demonstrate the possibility of using nanoscale objects as semiconductors and transistors for calculation and memory storage.

3 Whitesides, G. M. 2001. The once and future nanomachine. *Scientific American*, Vol. 285, No. 3, September, pp. 78-83.

4 Goodsell, D. S. 2004. *Bionanotechnology: Lessons from Nature*. Hoboken, NJ, Wiley-Liss.

5 Roco, M. C. and Bainbridge, W. S. 2003. *Converging Technologies for Improving Human Performance: Nanotechnology, biotechnology, information technology and cognitive science*. Boston, Mass., Kluwer Academic Publishers.

cal and political aspects of nanotechnology. From the perspective of UNESCO, even if nations are not actively pursuing research in nanotechnology, they should nonetheless have a stake in defining the proposed outcomes and actual course of research according to norms of equity, justice and fairness. In the absence of such a definition, nanotechnology will be defined by the corporations and nations that pursue their own interests most vigorously. At this early stage, citizens of every nation have a stake in understanding what nanotechnology is becoming and could be.

1.3 HISTORY

As with the definitions of nanotechnology, its history can be—and is—told in multiple ways, with various points of origin and important milestones.

Perhaps the most commonly discussed origin point is a lecture by the famous physicist Richard Feynman called 'There's Plenty of Room at the Bottom'[6] in which Feynman speculates about all the possible ways in which miniaturization, computer and information technologies and physics can be used to explore the sub-microscopic world. With bravado that was typical of Feynman, he laid out a series of things he thought should be easy to accomplish in the near future. Forty years later, many engineers and scientists are still excited by these predictions—but none of them have yet come true. A related work that is occasionally referenced from the same period is that of John von Neumann's 'General and Logical Theory of Automata' which similarly combined his knowledge of physics, engineering and information technology to propose the creation of autonomous machines—though in his case, not at the nanoscale.[7]

Neither Feynman nor von Neumann discussed these possibilities in terms of the word 'nanotechnology' however. The term was popularized in a book written by K. Eric Drexler—an inveterate nanotechnology visionary—in a book of 'future history' called *Engines of Creation*.[8] Drexler used the word to describe his vision of a world where molecular manufacturing would allow people to manufacture *anything* they might need—from automobiles to pieces of beef—simply by feeding waste material into a box that would use nanoscale assemblers to re-configure it into the necessary form (see Image 2). Drexler's book is more often remembered today for its dystopian, rather that its utopian promise: Drexler warned that as this technology developed it would be necessary to guard against the accidental release of autonomous self-replicating nano-machines that could—if they spun out of control and started to consume or transform

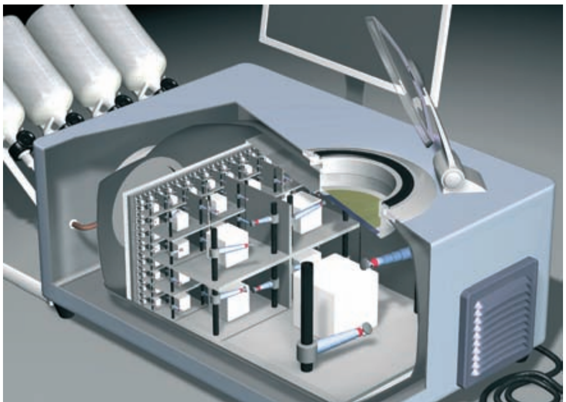


Image 2:
Desktop manufacturing[9]

Proposed desktop-scale molecular manufacturing applicance. Tiny machines join molecules, then larger and larger parts, in a convergent assembly process that makes products such as computers with a billion processors. (Parts shown as white cubes.)

[6] Feynman, R. 1960. There's plenty of room at the bottom. *Engineering and Science*, Vol. 23, No. 5, February, pp. 22-36.
[7] von Neumann, J. with Burks, A. W. 1966. *Theory of Self-Reproducing Automata*. Urbana, Ill., University of Illinois Press.
See also Jean-Pierre Dupuy's contribution to the recent EU Health and Environment report listed at the end of the document.
[8] Drexler, K. E. 1986. *Engines of Creation*. Garden City, NY, Anchor Press/Doubleday.
[9] Image credit: John Burch, Lizard Fire Studios, http://www.lizardfire.com

the natural and man-made world – turn the planet into a mass of uninhabitable 'grey goo'. Drexler has played an important role in generating both excitement and fear about nanotechnology over the years. He has founded an institute devoted to studying the potential scientific and social impacts of nanotechnology (the Foresight Institute) and written a book of theoretical engineering which claims to demonstrate the feasibility of molecular manufacturing.[10] At this point in time, however, there are no convincing experimental or engineering demonstrations of even very simple molecular control, and as a result, there has been a significant backlash against the idea of nanotechnology as molecular manufacturing, driven in part by the appearance of popular fiction scenarios that many scientists and engineers consider to be scientifically and socially infeasible. One of the other prominent scientists involved in the promotion of nanotechnology, Rice University's Richard Smalley, has accused Drexler of 'scaring our children' and promulgating a vision of the future based on poor scientific reasoning.[11] The marginalization and ostracism by the scientific community of the concept of molecular manufacturing has recently led Drexler to regret coining the term 'grey goo'.

Over the last 40 years, however, a significant number of real scientific and engineering breakthroughs have transformed older scientific questions into new nanotechnological ones. At the top of the list is the invention of the scanning tunneling and atomic force microscopes, which have allowed scientists to visualize, investigate, and ultimately probe and experiment with things at a scale never before possible. Between the late 1970s and 1983, Gerd Binnig and Heinrich Rohrer laid the groundwork for modern Scanning Tunneling Microscopes (STM) for which they shared the 1986 Nobel Prize with Ernst Ruska, who designed the first electron microscope. STM microscopes rely on the weird quantum property of 'quantum tunneling' to accurately probe and measure the configuration of electrons circling individual atoms. From this information, a computer can generate a visual representation of the atom (Image 3).

Just a few years later, Gerd Binnig was also involved in the invention of the atomic force microscope (AFM) at IBM in Zürich, Switzerland. The AFM has been commercially available to scientists only since about 1990 and works on a principle very similar to a classic gramophone, in which a cantilever with a fine point is dragged over a surface. Using a laser, the tiny nanoscale variations of the tip of the head as it bumps up and down over the atoms of a sample can be recorded and transformed into a digital image, as in the case of the STM.

These tools allowed engineers and scientists to create stunning images that display the configuration of atoms and molecules. However, it is not just the ability to see atoms that makes these tools so fascinating, but the ability to actually manipulate, move or arrange atoms into artificial configurations. One of the leaders in the use of such tools is Donald Eigler of IBM Research, Almaden in California. In 1989, Eigler demonstrated such a use of the STM by arranging several Xenon atoms in a vacuum to spell out 'IBM'. Later, Eigler and his students were able to use the STM to create a wide variety of images based on the manipulations of

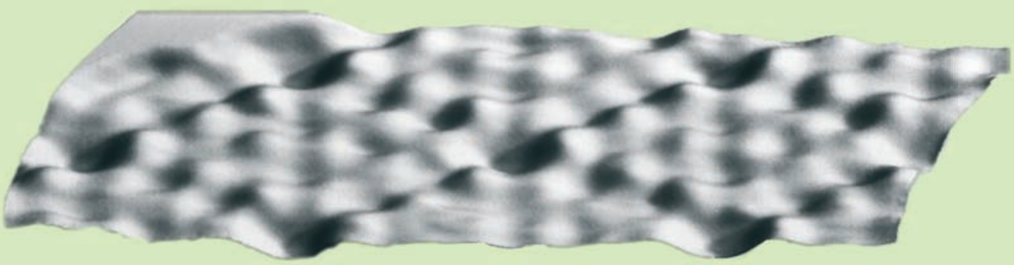


Image 3: Visualization of the atom[12]

[10] Drexler, K. E. 1992. *Nanosystems: Molecular machinery, manufacturing, and computation*. New York, Wiley.

[11] A public and slightly acrimonious debate was carried out in December of 2003 in *Chemical and Engineering News*, Vol. 81, No. 48, pp. 37-42.

[12] Figure reprinted with permission from Binnig, G. and Rohrer, H. 1987. Scanning tunneling microscopy: From birth to adolescence. *Reviews of Modern Physics*, Vol. 59, No. 3, p. 622. Copyright 1987 by the American Physical Society.

atoms and molecules, such as the 'quantum corral' (Image 4) which visually demonstrates the wave/particle duality of electrons at the atomic scale, and the creation of logic gates (gates like those used in computers to determine the logical functions AND, OR and NOT) using carbon monoxide atoms arranged precisely to 'fall' like dominoes, depending on the input to the gate.[13]

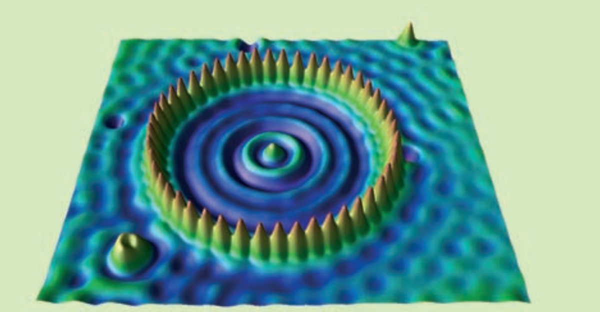


Image 4: Quantum corral

Another very significant scientific development that has contributed to the rising enthusiasm for nanotechnology was the discovery of 'buckyballs' or buckminsterfullerenes, which are soccer-ball-shaped molecules composed of 60 carbon atoms. Buckyballs (C_{60}) as well as other quasi-spherical carbon structures such as C_{70} and substituted derivatives are known collectively as fullerenes.

Buckyballs are named after the famous architect and futurist Buckminster Fuller, whose geodesic domes share the characteristic soccer ball shape of the molecule. They are, like diamond and graphite, composed entirely of carbon, but their shape and molecular structure give them special properties. In a 1984 experiment, Professors Richard Smalley and Robert Curl, graduate students Jim Heath and Sean O'Brien of Rice University (USA), and Harold Kroto of the University of Sussex (UK), were the first to identify and characterize 'buckminsterfullerenes'. Buckyballs were first synthesized using a complicated device designed for vaporizing graphite and blowing through a tiny aperture, and characterized by Curl as having 60 carbon atoms arranged in alternating pentagons and hexagons. At the time, they did not call this work nanotechnology, but simply chemistry. The ability to synthesize these molecules soon drew attention to them as having significant and new properties that might be exploited. Smalley, Curl and Kroto were awarded the 1996 Nobel prize for their work.

In 1991, S. Iijima, then working at NEC in Japan, discovered another variation on buckyballs, called nanotubes. Nanotubes come in single- and multi-walled forms, and the single-walled form is essentially a long cylinder of carbon with half of a buckyball on either end (Image 5). Single-walled nanotubes (SWNTs) are more versatile than the buckyball form, and are estimated by some to be the strongest and most flexible material yet discovered. In addition, they have very high electrical conductivity (rivaling copper and gold, but in a much smaller wire), as well as high thermal conductivity. These properties have led to a proliferation of predictions, from the mundane (a new nanoscale wire for conducting energy and information) to the fantastic (an 'elevator to space'—a long thin 'cable' made of nanotubes that would lift a spaceship into space, rather than requiring a rocket to propel it).

One of the less glamorous disciplines to jump quickly into nanotechnology research has been the polymer sciences, which for over 60 years have

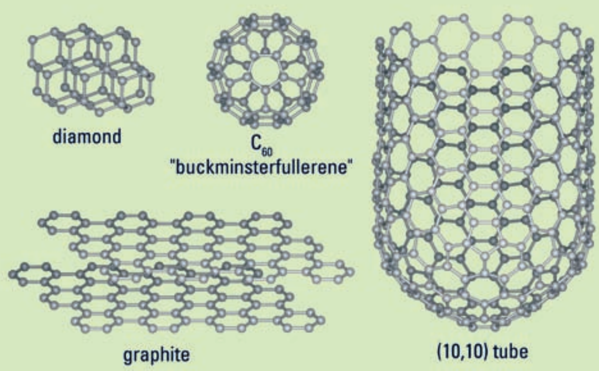


Image 5: Fullerenes[14]

[13] Image of quantum corral originally from Eigler, D. M. and Schweizer, E. K. 1990. Positioning single atoms with a scanning tunneling microscope. *Nature*, Vol. 344, 5 April, pp. 524-526.

[14] Image of carbon from http://cohesion.rice.edu/naturalsciences/smalley/emplibrary/allotropes.jpg

been experimenting with processes for making new materials, both natural and synthetic. It has been suggested that carbon nanotubes in particular will make exceptional materials for things like car bumpers or jet fighter wings, but the widespread experimentation on, distribution or exposure of these materials is currently limited by the difficulty of producing a large quantity of them. One of the early areas of commercial investment (and of potential regulatory and environmental concern) is the large scale production of SWNTs for use in experiments in universities and corporate labs. Mitsubishi Japan, for instance, has begun a significant effort to create larger volumes of fullerenes.[15]

The excitement about buckyballs and nanotubes has come primarily from chemists, chemical engineers and physicists. But electrical engineers and, in particular, engineers who create and refine semi-conductors and micro-electronics have been quickly approaching the nanoscale in their drive to miniaturize electronic devices and components. The humble transistor, which has been around since the late 1940s, has reached proportions so small that engineers are now facing the 'novel properties' that nanoscale materials begin to express. As these new properties appear, new kinds and configurations of materials become essential for smaller, faster, lower power devices. Perhaps the smallest such device that has been developed so far is the 'quantum dot' which is designed to confine a single electric charge that might be used as the basis for a computer. Quantum dots have been the subject of investigation and experiment since the early 1990s, but are not yet used in commercial computing devices. Quantum dots also have unique photophysical properties and are being investigated for use in biomedical imaging.

In addition to chemistry and electrical engineering, the fields of molecular biology and genetic engineering have become expert over the last 10 to 15 years at manipulating the basic components of cellular life at the molecular nanoscale. Techniques and tools that are available to biochemists and molecular biologists, like recombinant DNA and polymerase chain reaction (PCR) have vastly accelerated the kinds of manipulations and experiments that can be done on DNA, RNA and proteins. As mentioned earlier, some of this work is now being redefined as 'nanotechnology' because it is aimed at exploiting the properties of living organisms or molecules involved in organic life. Since about 2000, nano-bio-technology has begun to appear as a research field of its own.

It is only since about 1996 that the US government (and subsequently the Japanese and EU governments) began to seriously consider funding research under the label of nanotechnology. In 2001, the US government launched the National Nanotechnology Initiative – an interagency initiative designed to coordinate research amongst the various government agencies seeking to fund research and development in nanotechnology. The US National Science Foundation has been a leader in funding nanotechnology, and in particular through the creation of regional centres, focused on specific issues in nanotechnology. These 14 centres (as of 2005) are themselves charged with dispersing the funds to researchers, and coordinating projects and goals in their specific areas.

Following this initial surge of research money in the US, several other nations have begun funding nanotechnology-related research in earnest. Japan's Ministry of Education, Culture, Sports, Science and Technology has contributed some $250 million to research in various areas of nanotechnology. The UK Royal Society reports that the current level of EU research is about €1 billion, and that the United Kingdom is currently spending roughly £45 million annually. In addition, China, the Islamic Republic of Iran, Brazil and Israel have all made clear that national research priorities in science and technology include research into nanotechnology.

[15] See Tremblay, J.F. 2003. Fullerenes by the Ton: Mitsubishi's Frontier Carbon expects a big market for buckyballs. *Chemical and Engineering News*, Vol. 81, No. 32, pp. 13-14.

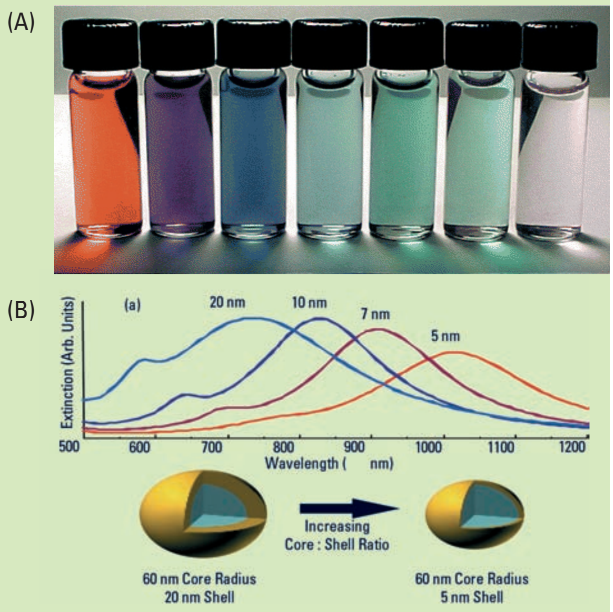
2 NANOTECHNOLOGY RESEARCH NOW

The array of nanotechnology research projects currently underway today is enormous. It is safe to say that, with the recent influx of funding and attention, there is nary a field of science that has not gotten into the game. Core fields like physics, chemistry, electrical engineering, molecular biology and computer science are the most well positioned to conduct research—but others like materials science, chemical engineering, environmental engineering, bio-engineering, medical research, optics and photonics all possess knowledge that contributes to the growth of nanotechnology—and especially to its practical realization. Even the social sciences and humanities have seen a surge of proposals and calls for research, largely in the areas of ethics and policy analysis.

Most current research in nanotechnology is not motivated by immediate practical applications—a great deal of it is exploratory and experimental, or devoted to the kind of characterization and careful investigation that forms the core of any science. While there is no shortage of proposals for possible future uses, nanotechnology as it stands in 2006 is in a state of transition—old disciplines are recognizing that there are a variety of new problems that overlap with neighbouring disciplines, and new tools and techniques are producing a generation of scientists who can research and understand phenomena their mentors could not.

To take just one example of such work, consider the attempt to use nanotechnology in cancer therapy. Researchers at various universities and medical centres around the world make use of 'gold nanoshells' and normal visible light in order to kill cancer cells. 'Nanoshells' are tiny beads of glass coated with gold in different thicknesses. The optical absorption of gold (the property that causes it to look yellow in daylight) can be varied with the thickness of this shell, so that only certain wavelengths of light are absorbed and certain wavelengths reflected. Researchers then attach antibodies to these shells that are specific to cancer cells, so that when the shells are injected into a mouse body, they attach themselves only to the cancer cells, and not the normal cells. When the specific wavelength of light is then shone through the body (ultraviolet light in the form of a low power laser), this causes the gold nanoshells—and only the gold nanoshells—to heat up to a temperature at which they kill the surrounding cancer cells. (See Image 6)

Image 6: Nanoshells[16]



Gold nanoshells consist of a dielectric core nanoparticle surrounded by a thin metal shell. By varying the relative dimensions of the core and shell constituents, one can design particles to either absorb or scatter light over the visible and much of the infrared regions of the electromagnetic spectrum. (A) These vials contain suspensions of either gold colloid (*far left* with its characteristic red color) or gold nanoshells with varying core shell dimensions. (B) The optical properties of nanoshells are predicted by Mie scattering theory. For a core of a given size, forming thinner shells pushes the optical resonance to longer wavelengths.

[16] Figure is from West, J. L. and Halas, N. J. 2003. Engineered nanomaterials for biophotonics applications: Improving sensing, imaging, and therapeutics. *Annual Review of Biomedical Engineering*, Vol. 5, pp. 285–92.

Box 2 Recent Commercial Nanotechnology Products

- Cerax nanowax for snow skis
- Franz Ziener waterproof ski jacket (NanoTex)
- Wrinkle and stain resistant nano-care clothing
- L'Oréal deep penetrating skin cream
- Kodak's OLED (organic light emitting diodes) camera
- Performance sunglassed nanofilm anti-reflective coating
- Z-COTE sunscreen
- Babolat nanotube tennis racket
- InMat's nanotech tennis balls
- Shockjock Aerogel footwarmers
- Simmons washable bed mattress (NanoTex)
- Maruman & Co. golf clubs using 'titanium fullerenes'
- Nanodynamics golfballs
- Bionova 'personalized skin care'
- Nucryst wound dressings for burn victims, coated with 'nanosilver'
- Envirosystems EcoTrue nanoemulsive 'military grade' disinfectant
- BASF's Mincor superhydrophic spray for coating building materials to make them water-resistant
- Nanofilm's ClarityDefender window spray
- Flex Power joint and muscle pain cream (using '90 nm liposomes')
- 3M dental adhesive (nanohydroxyapatite)

Despite such promising and innovative uses, the drive for university scientists and engineers to find practical applications and to make partnerships and collaborations with industry and government remains extremely strong. And it necessarily gives current nanotechnology research a business and consumer market orientation.

While only a handful of products have been developed to date (see Box 2 from Forbes' 2003 and 2004 'Top 10' lists), it is nonetheless important to understand the significance of this 'rush to commercialization'. For if the use of nanomaterials and nanoscale production processes does reach commercial maturity quickly, it can potentially generate new ethical and political issues as well as activate older ones. Many corporations are concerned about the public reception of new products and the public understanding and perception of nanotechnology. Their reasons are self-interested of course – they hope to build successful products – but they are also based on the recent experience of the backlash against genetically modified foods and organisms (GM/GMO). Because of the status of science today – in the wake of nuclear power, Chernobyl and Bhopal, the GM foods debate, BSE in the UK and EU, and the tremendous rise in tort litigation in the US – nanotechnologists are hyper-aware of the need to study both potential uses and potential harms well in advance of their commercialization. This recognition and precautionary direction to corporate research is novel.

The international implications of this are clear – as in the case of GM foods, lack of knowledge about the health and safety effects of nanotechnology can result in restrictions, outright bans, and complex international conflict over production and transport of such materials. In addition to calls from non-governmental, civil society and international observers for more research, many corporations see a need for increased research in the areas of safety, toxicity, health and environmental effects and, to some extent, ethical and political issues related to the production of nanotechnology. The adoption of voluntary standards, the creation of international standards, and the creation of international best practices for production and engineering of nanoscale materials are all the subject of corporate concern – but the institutional and organizational framework for addressing these concerns across competing interests is not yet well developed. This is a role that UNESCO and UNESCO's Member States can clearly play – facilitating the development of both required and voluntary standards for commercial production, and encouraging the promulgation of ethical standards for commercial as well as traditional university research practices.

3 ETHICAL, LEGAL and POLITICAL IMPLICATIONS of NANOTECHNOLOGY

Just as nanotechnology covers a broad range of scientific and technical fields, the ethical, political and legal implications will as well. There are a number of areas where nanotech will intersect with existing policy issues or old ethical dilemmas – and a few that may be new.

3.1 INTERNATIONAL ASPECTS OF NANOTECHNOLOGY

Research into nanotechnology is currently taking place in both developed and developing nations around the world, but the level of financing and investment, access to scientific and technical infrastructure and materials, and cooperation across sectors varies a great deal. As with previous advances in science and technology, developing nations risk being distanced by a 'knowledge divide' if they cannot find ways to participate on equal footing with other countries. But there is increasing evidence that the nature of this divide will look different today than it might have 15 years ago. Researchers are much more likely to have ready access to publications via the Internet, and with the changing economic fortunes of China, Brazil and India, researchers in the US and the EU are far more likely to travel to, interact with and form collaborations with scientists in these nations. As a result, nanotechnology stands to be a much more international scientific project than, for instance, research into biotechnology was in the 1980s and 1990s. Different national interests may clash as a result, but it is clear that the nature of the 'knowledge divide' will look different.

It is quite possible that inequalities of access to research may be greater *within* nations, than between them. The communication between experts and elites of different countries at the highest levels of research and development has become easier and more common – but the communication between the experts and elites of a nation and the poorer and less well educated has grown less common and incentives to do so have dwindled. There is therefore a need for scientists and experts in the international community to find ways of mending the 'knowledge gap' within their own countries as well as between nations.

Related to the question of a knowledge gap is the degree to which the *kinds* and *direction* of nanotechnology research will benefit all nations equally. As a 2005 *PloS Medicine*[17] article outlines, there are a number of areas that could benefit the poorest nations far more than any commercial development would – areas such as energy storage and conversion, water treatment, and health and disease diagnosis and treatment. The article goes so far as to suggest that the top ten applications of nanotechnology for developing nations could also address the UN's 'Millennium Development Goals' (see Image 7).

However, by what mechanisms should such research be promoted? How can scientists in universities and corporations be given incentives (above and beyond mere commercial viability) to pursue these goals? International cooperation can help to guide the work of university and corporate scientists towards research in the areas of greatest need and impact. Many of these areas have strong commercial and development possibilities, but not without the commitment of nations and private actors, first, to encourage such research and, second, to make use of it in the various infrastructures of developing nations.

[17] Salamanca-Buentello, F., Persad, D. L., Court, E. B., Martin, D. K., Daar, A. S. and Singer, P. A. 2005. Nanotechnology and the developing world. *PLoS Medicine*, Vol. 2, No. 5, e97, p. 302.

Image 7: Top Ten Applications of Nanotechnology and the UN Millennium Development Goals (MDGs)

Ranking (Score)	Applications of Nanotechnology	Examples	Comparison with the MDs
1 (766)[a]	Energy storage, production, and conversion	Novel hydrogen storage systems based on carbon nanotubes and other lightweight nanomaterials Photovoltaic cells and organic light-emitting devices based on quanum dots Carbon nanotubes in composite film coatings for solar cells Nanocatalysts for hydrogen generation Hybrid protein-polymer biomimetic membranes	VII
2 (706)	Agricultural productivity enhancement	Nanoporous zeolites for slow-release and efficient dosage of water and fertilizers for plants, and of nutrients and drugs for livestock Nanocapsules for herbicide delivery Nanosensors for soil quality and for plant health monitoring Nanomagnets for removal of soil contaminants	I, IV, V, VII
3 (682)	Water treatment and remediation	Nanomembranes for water purification, desalination, and detoxification Nanosensors for the detection of contaminants and pathogens Nanoporous zeolites, nanoporous polymers, and attapulgite clays for water purification Magnetic nanoparticles for water treatment and remediation TiO_2 nanoparticles for the catalytic degradation of water pollutants	I, IV, V, VII
4 (606)	Disease diagnosis and screening	Nanoliter systems (Lab-on-a-chip) Nanosensor arrays based on carbon nanotubes Quantum dots for disease diagnosis Magnetic nanoparticles as nanosensors Antibody-dendrimer conjugates for diagnosis of HIV-1 and cancer Nanowire and nanobelt nanosensors for disease diagnosis Nanoparticles as medical image enhancers	IV, V, VI
5 (558)	Drug delivery systems	Nanocapsules, liposomes, dendrimers, buckyballs, nanobiomagnets, and attapulgite clays for slow and sustained drug release systems	IV, V, VI
6 (472)	Food processing and storage	Nanocomposites for plastic film coatings used in food packaging Antimicrobial nanoemulsions for applications in decontamination of food equipment, packaging, or food Nanotechnology-based antigen detecting biosensors for identification of pathogen contamination	I, IV, V
7 (410)	Air pollution and remediation	TiO_2 nanoparticle-based photocatalytic degradation of air pollutants in self-cleaning systems Nanocatalysts for more efficient, cheaper, and better-controlled catalytic converters Nanosensors for detection of toxic materials and leaks. Gas separation nanodevices	IV, V, VII
8 (366)	Construction	Nanomolecular structures to make asphalt and concrete more robust to water seepage Heat-resistant nanomaterials to block ultraviolet and infrared radiation Nanomaterials for cheaper and durable housing, surfaces, coatings, glues, concrete, and heat and light exclusion Self-cleaning surfaces (e.g. windows, mirrors, toilets) with bioactive coatings	VII
9 (321)	Health monitoring	Nanotubes and nanoparticles for glucose, CO2, and cholesterol sensors and for in-situ monitoring of homeostasis	IV, V, VI
10 (258)	Vector and pest detection and control	Nanosensors for pest detection Nanoparticles for new pesticides, insecticides, and insect repellents	IV, V, VI

[a] The maximum total score an application could receive was 819. DOI: 10.1371/journal.pmed.0020097.t001

3.2 TOXICITY AND ENVIRONMENTAL IMPLICATIONS OF NANOTECHNOLOGY

The most pressing near-term issues related to nanotechnology are toxicity and exposure to humans and the environment. This is more properly a safety and health issue—not an ethical or political issue—but because of nanotechnology's perceived novelty, there are heightened concerns that nanotechnology might pose new forms of hazard or exposure risks, and therefore new questions about how to deal with them. Most corporations and many researchers address this area through 'risk management'—a highly technical form of assessment that is necessarily narrow in scope. While this approach has the benefit of accurately stating the risks (and occasionally the benefits) of newly created substances, materials and devices, it does not address any wider issues of the ethical or political meaning of this risk—such as who will bear it, how it will be distributed internationally, and who will be given the power to make decisions based on these analyses.

To date, there have been a handful of studies about these risks. Several recent reports (listed at the end of this document) go into greater detail on the current state of research. There are two concerns: the hazardousness of nanoparticles and the exposure risk. The first concerns the biological and chemical effects of nanoparticles on human bodies or natural ecosystems; the second concerns the issue of leakage, spillage, circulation, and concentration of nanoparticles that would cause a hazard to bodies or ecosystems.

Defined as 'nanoparticles' there are only a couple of novel substances that might conceivably be in wide circulation in the near future. The most obvious are carbon-based nanostructures such as buckyballs, single-walled and multi-walled carbon nanotubes. Other substances such as titanium dioxide, zinc oxide, or gold nanoparticles are also likely to be (or already are) in use in diverse settings. It is best to distinguish between three types of nanoparticles: 'engineered' nanoparticles (such as buckyballs and gold nanoshells), 'incidental' nanoparticles (such as those found in welding fumes, cooking and diesel exhaust), and 'naturally occurring' nanoparticles (salt spray

Box 3 Recommendations from the European Commission's Health and Consumer Protection Directorate General

1. Develop a new nomenclature for nanomaterials.
2. Assign new Chemical Abstracts Service Registry Number (CASRN) to new nanoparticles.
3. Advance science by collecting data and performing analysis on new nanoparticles.
4. Develop new measuring instruments.
5. Develop standardized risk-assessment methods.
6. Promote best practices in risk assessment.
7. Create institutions to monitor development of nanotechnology.
8. Establish dialogue with the public and with industry.
9. Develop guidelines and standards for production, handling, commercialization and risk assessment of nanomaterials.
10. Revisit existing regulations and change them where appropriate to reflect specificities of nanotechnology.
11. Maximize the containment of existing free nanoparticles.
12. Strive for the elimination or minimization of the release of nanoparticles into the environment where possible.

from the ocean, or forest-fire combustion). Only 'engineered' nanoparticles constitute an entirely new class of particles and, to date, buckyballs are the only engineered nanoparticles that have been seriously studied, whereas 'incidental' nanoparticles (often referred to as 'ultrafine particulate matter') such as auto exhaust have clearly been more extensively studied. The handful of studies on the toxicity of fullerenes so far suggest that they are indeed hazardous—but also that they can be engineered to be less so, in particular by conjugating other chemicals to the surface of buckyballs, thus changing their chemical properties.[18] Such findings suggest that the proper question for regulators and policy makers to ask of nanotechnology is not 'Is it safe?' but 'How can we make nanotechnology safer?' International cooperation and coordination can play a role in setting minimum ethical norms for the creation and testing of such substances: Scientists should be expected not only to announce the discovery or creation of such nanoparticles, but the requirements necessary to make them safe, or safer than other materials that achieve the same purposes.

Environmental and ecological impacts can also be extremely complicated to assess. Because of the natural complexity of ecological cycles, and the impossibility of directly experimenting with the natural environment, knowledge about the hazard and exposure risks of nanoparticles to an ecology is slim. As in many other cases, however, the most pressing issue may not be determining the exact toxicity of nanoparticles, but creating new and enforcing old regulations on the industries who create and process these new materials. In many countries oversight of some of the most clearly hazardous chemicals, such as arsenic and mercury, is weak—and if nanoparticles are shown to be less toxic than such substances, the challenge to regulators will be significant. Corporations who practise green chemistry and who develop processes for recycling and reusing waste products will naturally create fewer exposure risks than those that do not; but creating incentives for practices that are more costly is a political problem much older than nanotechnology.

Both the EU and the US possess established regulatory systems through which hazard and exposure risks of nanotechnology might be assessed. The European Commission has already published a preliminary report on the potential process by which these risks can be dealt with. In addition, the new Registration, Evaluation and Authorisation of Chemicals (REACH) regulation in the EU will have far-reaching effects on the chemical industry with unknown consequences for manufacturers of nanoparticles.[19]

The US Environmental Protection Agency (US EPA), the Food and Drug Administration, the Occupational Safety and Health Administration, and the National Institute of Occupational Safety and Health have also begun to inquire into the need to change

[18] Several studies have been done on the toxicity of fullerenes, including one that has demonstrated oxidative damage to the brain in the largemouth bass (Oberdörster, E. 2004. Manufactured nanomaterials [fullerenes, C 60] induce oxidative stress in brain of juvenile largemouth bass. *Environmental Health Perspectives*, Vol. 112, No. 10, pp. 1058-62) and one that measures the cytotoxicity of buckyballs in rats (Colvin, V. L. 2003. The potential environmental impact of engineered nanomaterials. *Nature Biotechnology*, Vol. 21, No. 10, pp. 1166-1170).

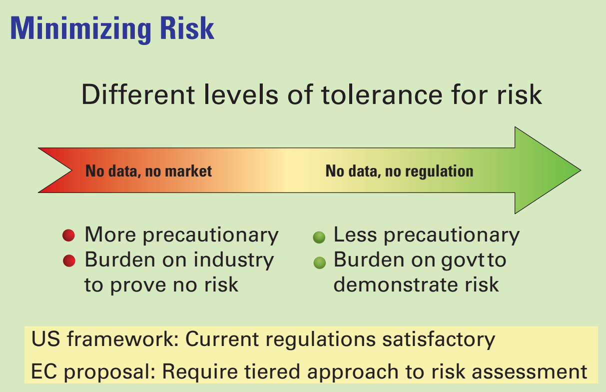
[19] http://europa.eu.int/comm/enterprise/reach/overview.htm (Accessed 17 January 2006.)

existing processes to accommodate nanotechnology. In particular, the US EPA is evaluating its first 'pre-manufacturing notice' from a company seeking regulatory approval for carbon nanotubes. In addition to the regulatory mandates of these agencies, several are also funding intramural and/or extramural research projects targeted at understanding hazard and exposure risks posed by engineered nanomaterials.

The UK Royal Society has recently published a report as well, and recommends a two- to five-year window within which corporations and universities are urged to investigate and understand the toxicity and design processes for managing it, before the government should undertake any new regulation in nanotechnology.

An issue that is clearly related to toxicity is that of consumer awareness, labeling and the promotion of standards and regulation of nanoparticles. One of the core questions concerning the production of any kind of scientific or technical object today is the degree of trust and reliability that consumers and citizens put in the information they are given. Genetically modified foods have been an obvious example, and a frightening one, for most corporations interested in investing in nanotechnology. The decision by some corporations to create and distribute GM foods without either seeking public approval or openly labeling the foods as such created a substantial backlash, and opened up discussions about the labeling of food products and the reliability of government and corporate oversight and assurance of the safety of GM foods.

Image 8: Attitudes towards risk[20]



Nanotechnology faces similar issues, especially if scenarios like the 'grey goo' story are used for emotional or persuasive purposes. Even in the absence of such alarmism, however, the normal course of health and safety reporting produces so many conflicting and often incomprehensible warnings and approvals that it will be difficult to effectively communicate the precise risks of nanoparticles, whatever they are. To further complicate matters, there is as yet no consensus on whether nanoparticles or nanomaterials should be treated as something entirely new, or as a subset of existing materials, for the purposes of regulation or labeling. The standards bodies that oversee materials, from national standards organizations to the International Organization for Standardization (ISO), will be faced with the challenge of determining what, if anything, makes nanoparticles novel substances distinct from larger structures of the same chemical composition. Only then will it be easier for regulators to know if they should refine existing systems of regulation, or create new ones.

If it is true that familiar materials behave differently in the nanoscale size range, it is possible that existing regimes for assessing risk will not capture these potentially new dangers. The recommendations of the european experts address some of these issues (Box 3) by calling for new standards, tools, nomenclatures, and systems of measurement specific to the nanoscale and the new kinds of nanoparticles. International organizations can play a role in both facilitating such developments and encouraging their widespread use and adoption not only in the US and Europe, but more importantly in developing nations like China, India, Brazil and the Islamic Republic of Iran, as they begin to develop both nanotechnology research programmes and forms of regulation.

There is a political and cultural component to this problem—that is, the attitudes that politicians and citizens have towards risk and regulation. Image 8 illustrates the spectrum of attitudes that might be taken on these issues, with the more precautionary style of EU regulation on the left, and the market- and corporation-friendly style of the US on the right. The precautionary style takes the lack of data on the safety or efficacy of nanotechnology to

[20] Figure provided by Kristen Kulinowski of the Center for Biological and Environmental Nanotechnology. All rights reserved.

be a caution against marketing products, while the market-friendly style takes the lack of data to mean no additional regulations are necessary before going to market.[21]

What makes this divergence of styles particularly alarming is that globalization has rendered the efficacy of national regulation and safety assurance both more political and more difficult.

3.3 BEYOND RISK ASSESSMENT

Issues of safety, toxicity and environmental impact are clearly important issues, about which more research and more international oversight is needed. They are, however, relatively narrow technical problems that are best dealt with through the use of sophisticated techniques of risk analysis, scientific experimentation, and the legal re-evaluation of existing regulatory systems.

There are, however, a number of other issues that cannot be strictly accounted for through the technical mindset of risk analysis. These broader ethical and political issues include those of intellectual property, secrecy and legitimacy of scientific results, the potential for a knowledge divide based both on funding and on the legal implications of intellectual property. At a very broad level, the question concerns whether nanotechnology as a science will look like, and proceed like, the traditional science of the past, or whether it will be transformed by new political, social and legal pressures into something that is no longer so familiar.

Recent research in biotechnology and genetically modified foods represents a certain 'loss of innocence' with respect to the purity and disinterestedness of science. The overt regulation and social direction of basic scientific research no longer seems to be taboo for many nations—and the case of nanotechnology may represent one of the first where scientists themselves are no longer capable of autonomously directing scientific research due to the growth of external pressures, not only commercial, but from civil society and State actors as well. The outcome of such new interaction is far from clear.

3.4 SCIENCE ETHICS

One of the most troubling issues that nanotechnology raises is that concerning the very structure of science itself, and is not restricted only to nanotechnology. The danger concerns the legitimacy of scientific results, as well as the public trust in those results and the use and abuse of them by governments, corporations or nonprofit entities. Science in the twentieth century has increasingly come under new forms of scrutiny and new pressures that guide the creation, publication and sharing of scientific information. One of these is clearly the expanding system of intellectual property rights and rewards; another is the increasing public scrutiny of scientific research, and the demands that it be made accountable to the public; a third is the use and abuse of scientific information by governments in the context of increased secrecy and novel anti-terrorism efforts. Taken together, these pressures can have negative effects on the kind and quality of science performed, and can introduce incentives that are contrary to the values of objectivity and disinterestedness.

Furthermore, in large part due to the ever-increasing globalization of scientific research and the expansion of networks that contribute to it and feed off it, the question of who will benefit or who will suffer from these potential threats is newly unclear. Good science requires strong infrastructures for managing it; and the lack of these infrastructures in developing countries could leave them without the best and most reliable scientific knowledge

[21] For the precautionary style see also the report produced by COMEST: *The Precautionary Principle*. UNESCO, 2005.

and practices, either because they cannot afford to pay for premium scientific information or because they cannot access scientific data and material that is digitally archived. Both the digital divide and issues of the political control of networks by particular nations could have an impact on what forms of knowledge about nanotechnology will circulate globally.

As in the case of hazard and exposure risks, the biggest problem surrounding our knowledge of the risks and benefits of intellectual property is that we don't have much. There is almost no evidence available that proves the (economic) effectiveness of increased patent or copyright protection, nor any that proves decreased protection is beneficial. One can, however, look to other areas of science and intellectual property, for guidance with respect to nanotechnology.

Three kinds of controversies have bedeviled the use of intellectual property in science and in science-based commerce recently: an over-liberal granting of patents, which can lead to increased litigation costs and extremely complex systems of cross-licensing and patent trading amongst corporations and governments; new database laws, which effectively give single corporations rights over facts – something the intellectual property systems of the world have long been explicitly opposed to, and which can curtail even the most innocuous basic research by introducing prohibitive costs; and the rise of so-called 'business-method' patents in information technology.

Business-method patents are a good example of overzealous expansionism in intellectual property. Business-method patents essentially give broad rights to corporations who perform established processes using computer technology (two famous examples are patents on online auctions and patents on online shopping). Such a patent land-grab may also face nanotechnology precisely because it is defined as 'exploiting novel properties' of well known materials.

The danger created by excessive patenting in nanotechnology is that of the 'patent thicket' or the 'tragedy of the anti-commons'. Patents on basic nanoparticles and processes using nanoparticles could end up being so finely and acutely propertized that the ability to create a novel material – for instance a water filtration system that uses carbon nanotubes to produce clean drinking water – could face nearly unnavigable complexity in terms of competing and overlapping patent claims. It introduces a need for legal expertise even before research can begin, and places not only commercial interests at risk, but those of universities and academic centres as well. Rather than producing incentives for more rewards, it introduces anxiety concerning the legality and liability of using what might be perceived as products of nature, or natural processes. The chilling effect could drive all but the richest away from some kinds of research.

Such chilling effects are all the more pronounced when what is protected is scientific information – not necessarily processes or devices – such as the use of gene sequences, information contained in a database or other kinds of essential but intangible inputs to the scientific process. In this case, even the use of information about nanoscale products could require licensing fees and contracts. The fact that developing nations may have, or design, their own intellectual property laws within country does not exclude them from such problems. International organizations like the World Intellectual Property Organization, the World Trade Organization, and industry groups whose sole commercial revenue comes from exploiting intellectual property (such as the motion picture and recording industries) have fought hard over the last ten years to harmonize and strengthen intellectual property laws in nearly every corner of the globe.

The solution to this problem is to encourage – and amongst national governments, to require – open access to publicly funded research results and materials. The current trend towards ever increasing protection of intellectual property will at best introduce significant transaction costs because of the complexity it introduces, and at worst actually stifle the ability of scientists to independently investigate and verify scientific questions. Incentives are easy to create, but intellectual property deadlocks are very difficult to untangle. The patent system is a poor substitute for peer review and replication, and yet the incentives force scientists in the direction of novel and patentable research rather than reliably reproducible results, or clear and broad experimental evidence which may have little practical applications. There is a great need for widespread dissemination of open access repositories containing publicly funded research – not only in electronic form, but in print form in countries where access to the Internet may be intermittent or unreliable. There is also a great need for the dissemination of new norms for publicly funded scientists – norms that encourage scientists to make their work public first, and seek intellectual property protection second. Only by encouraging scientists to work in the global public interest can a system of open, reliable, and replicable science be maintained.

A second pressure on science comes from increasing public scrutiny on the research and results of science. A number of high-profile events – from the Asilomar controversy over the invention of recombinant DNA, through the disasters at Chernobyl and Bhopal, and the crisis over BSE to the public controversy in Europe of GM foods have made both governments and publics wary of trusting the statements of scientists. However, by the same token, scientific research has become increasingly responsive to social and public demands – two good examples are the pressure that AIDS activists have exerted on medical science to increase research on that disease, and the success of environmentalists in creating and sustaining wildlife habitats alongside fishing or agricultural needs. These new modes of interaction between scientists and the public are often mediated by the interests of large corporations. In the case of nanotechnology, in particular, there is a greater sense than ever before that the public need be involved earlier and more often, in order to avoid the kind of backlash that accompanied the introduction of GM foods.

International institutions such as UNESCO can serve as effective mediators or facilitators of this dialogue between the public and scientists. If nanotechnology research is to be socially directed towards solving the problems that are most urgent for the largest number of people, then there is a need for people and institutions who can connect scientists, funders and entrepreneurs in search of problems with local experts and experts in areas other than nanotechnology (for instance, in environmental remediation or in the areas of water and/or energy policy in developing nations).

A third pressure is much less certain: that from secrecy and the threat of terrorism. Two kinds of concerns are at issue here. The first is the concern that nanotechnology research, even basic research, may be used to contribute to the creation of new and nefarious kinds of weapons by terrorists, or that such weapons created by national governments may end up in the hands of terrorists. This concern drives the pressure to classify or make secret much research in nanotechnology (as well as in biotechnology or chemistry). The second concern is the opposite: that national governments are abusing the threat of terrorism to classify research, or more likely, to dismiss scientific results it finds out of sync with its political goals. The issue here concerns not so much the particular goals of national governments as the legitimacy of scientific results along with the effective separation of science and government interests. The less separate the two are the less likely even top-notch science will appear legitimate and disinterested to national or international publics. Again, international organizations can play a role here in helping define new norms of scientific conduct – norms that balance the manifest need for openness in science with the political pressures to keep potentially dangerous information from spreading.

3.5 DISTRACTIONS — ETHICAL ISSUES THAT AREN'T

Two recent discussions surrounding nanotechnology have received a lot of attention when it comes to ethical or social implications and risks: the so-called 'grey-goo' scenario, and the concerns about 'post-humanism'. The grey-goo scenario is based on the fear that nanotechnological devices will either be programmed to self-replicate, or that they will 'evolve' into devices capable of self-replicating, and that should they proceed to do so, they may destroy the natural world. Currently there are no nanotechnological objects capable of self-replication (unless one includes objects such as DNA and viruses under the definition of nanotechnology, which muddies the discussion further). Yet philosophers, ethicists and many scientists frequently speak as if such objects exist now, or will in the very near future. Often such claims depend on some form of 'technological determinism' in which advocates or opponents presume that technology develops autonomously, and is beyond human, social, or governmental control. In the absence of experimental science, the debate is quickly polarized: one must be either for or against nanotechnology.

'Grey goo' is a distraction because it forces the discussion of ethical and social issues to revolve around the technical risks and possibilities of future research rather than the real system for research oversight and regulation that exists today. The solutions for guarding against grey goo are as hypothetical as the scenario itself, and this distracts attention away from the current practices of science and technology and the need for careful oversight and deliberation that attends to current problems and practices, not imagined future scenarios.

A similar distraction is created by discussions of 'post-humanism'. In this debate, a variety of proposed uses for nanotechnology to enhance, repair, replace, or augment human characteristics are introduced. Such enhancements run the gamut from nanoscale sensors that might be added to the retina that improve sight to cochlear implants that improve hearing to performance enhancement technologies for athletes to new forms of plastic surgery.

Discussions of post-humanism encounter the opposite problem from those of the 'grey-goo' scenario: They assume that the ethical dilemmas that nanotechnology will create await us in the future and that we must prepare for them, whereas they are in fact issues that already face us today, such as performance enhancing drugs in sports, genetic screening for human characteristics, or privacy concerns over the handling of information technologies that we carry on our bodies. If anything, nanotechnology should provide an occasion to renew our focus on these concerns and try to achieve real answers to both present and future issues of this sort. UNESCO has already published analyses that would apply (for example, *Human Cloning: Ethical issues)* with only minor modification to issues of human enhancement through nanotechnology.

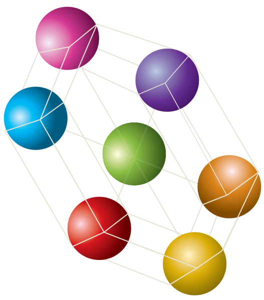
If policy-makers, elected and appointed officials, non-governmental and advocacy organizations can be convinced to look beyond these two distractions, a number of other pressing issues present themselves as being in need of serious discussion and creative forms of policy and regulatory oversight. These include toxicity and environmental hazard and exposure risks; labeling, consumer awareness and product regulation; intellectual property, secrecy, and the reliability and legitimacy of international scientific research; the potential for international scientific and technical divides and, most importantly, the promotion of uses for nanotechnology that help solve the most pressing needs for the greatest number of people.

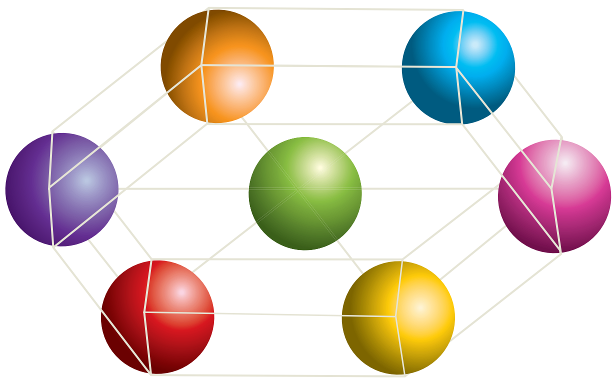
Many of these issues overlap with other existing ethical and political discussions – they should be made to build on existing debates rather than start from scratch. For example, intellectual property issues are already widely discussed in the contexts of biotechnology and information technology; likewise, medical ethics discussions already concern issues of enhancement, medical risk, and the use of human subjects. Although nanotechnology is new and exciting, the ethical and political issues it raises are not radically different from the ones we face already – but it may provide a chance to address them with more success than ever before.

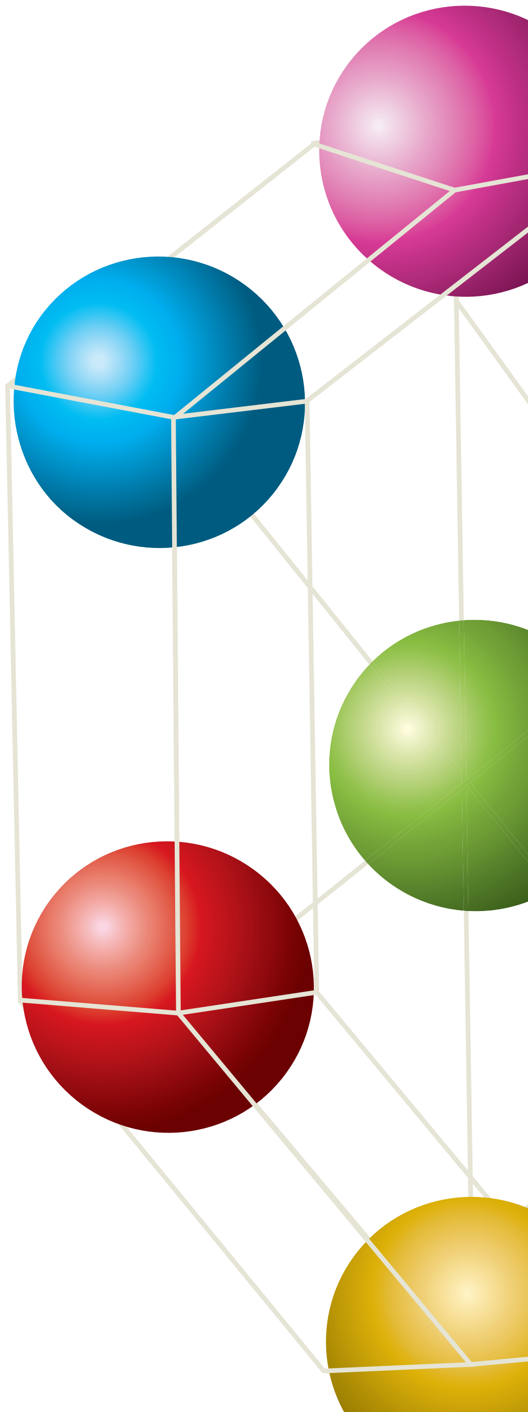
4 CONCLUSION

NANOTECHNOLOGY is at a crossroads. The emergence of consensus concerning the direction, safety, desirability and funding of nanotechnology will depend on how it is defined, and on who will be included as a result. It is safe to say that, as our world comes to depend more and more on science and technology, and as public awareness of the dangers and possibilities continues to increase, the involvement of all manner of participants will move further 'upstream'—into the heart of scientific work itself.

Furthermore, the broad attention and enthusiastic concern of a variety of groups—from governments to non-profit organizations, and from corporations to activist groups—will require concerted coordination as well. It is clear that there are already enough people interested in doing something that the need to create new institutes, agencies or isolated groups is diminishing as the need to strengthen existing ones grows.







5 APPENDIX
Index of reports on nanotechnology

This index contains a list of the most recent reports that have been released covering nanotechnology, its implications and the social, political or ethical issues.

- **UK Royal Society and Royal Academy of Engineers Report**
  'Nanoscience and nanotechnologies: opportunities and uncertainties'
  http://www.nanotec.org.uk
- **The Action Group on Erosion, Technology and Concentration (ETC)**
  'The Big Down'
  http://www.etcgroup.org/documents/TheBigDown.pdf

  'Down on the Farm'
  http://www.etcgroup.org/documents/ETC_DOTFarm2004.pdf
  http://www.etcgroup.org/article.asp?newsid=485
- **Demos**
  'See Through Science'
  http://www.demos.co.uk/catalogue/paddlingupstream
- **European Commission Community Health and Consumer Protection**
  'Nanotechnologies: A preliminary risk analysis'
  1-2 March, 2004
  http://europa.eu.int/comm/health/ph_risk/events_risk_en.htm
- **Swiss Re Report**
  'Nanotechnology – small matter, many unknowns'
  http://www.swissre.com/INTERNET/pwswpspr.nsf/alldocbyidkeylu/ULUR-5YAFFS
- **NSF/Meridian Institute International**
  '"Nanodialogues" on Risk, Nanotechnology and the Poor and Regulation'
  http://www.nanodialogues.org
- **NSF NBIC Report**
  'Converging Technologies for Improving Human Performance'
  http://www.wtec.org/ConvergingTechnologies
- **National Research Council**
  'Small Wonders, Endless Frontiers, a Review of the National Nanotechnology Initiative' *(2002)*
  http://www.nap.edu/openbook/0309084547/html/1.html
- **UK Nanojury 2005**
  http://www.nanojury.org
- **Woodrow Wilson Report**
  'Nanotechnology and Regulation: The case of the TSCA'
  http://nanotechcongress.com/Nanotech-Regulation.pdf

Division of Ethics of Science and Technology of UNESCO

The Division of Ethics of Science and Technology reflects the priority UNESCO gives to ethics of science and technology, with emphasis on bioethics. One objective of the medium-term strategy of the Organization is to ‘promote principles and ethical norms to guide scientific and technological development and social transformation’.

Activities of the Division include providing support for Member States of UNESCO that are planning to develop activities in the field of ethics of science and technology, such as teaching programmes, national ethics committees, conferences and UNESCO Chairs.

The Division also ensures the executive secretariat for three international ethics bodies, namely the World Commission on the Ethics of Scientific Knowledge and Technology (COMEST), the International Bioethics Committee (IBC) and the Intergovernmental Bioethics Committee (IGBC).

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