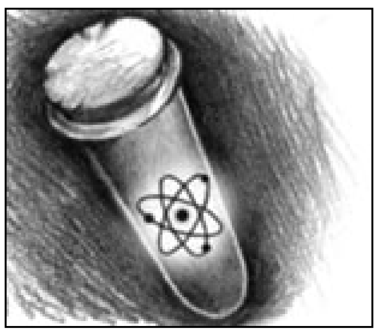
The Little Big Down: A Small Introduction to Nano-scale Technologies



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> “There isn't any human artifact that we manufacture that won't eventually be dependent on the kinds of discoveries being made in laboratories now...The long-term consequences of [nanotechnology] are going to be truly transforming. The trouble is, you can't predict the details of what that world will be like.” – **Thomas Theis**, head of physical science research at IBM Corporation, *The Washington Post*, February 22, 2004.

What is nanotechnology and why does it matter to civil society? From several different vantage points, nanotechnology – a set of techniques used to manipulate matter at the scale of atoms and molecules – looms as the highest, widest and most powerful technological wave the world has ever faced. The turbulence that will accompany the nano-wave has breathtaking societal implications, especially for poor and marginalized communities. It will upend markets for labour and raw materials and change the way we live, eat, work, wage war and define life. Some predict that nanotechnology will trigger a new economic and cultural utopia combining material abundance, sustainable development and profit. But history suggests a different scenario. In recent decades we have witnessed the privatization of science and a staggering concentration of corporate power that has undermined democracy and dissent throughout the world. Nano-scale manipulations offer unprecedented potential for sweeping monopoly control of elements and processes fundamental to life and material resources. In short, nano-scale technologies are poised to become the operative strategy for corporate control of industrial manufacturing, food, agriculture and health in the 21st century.

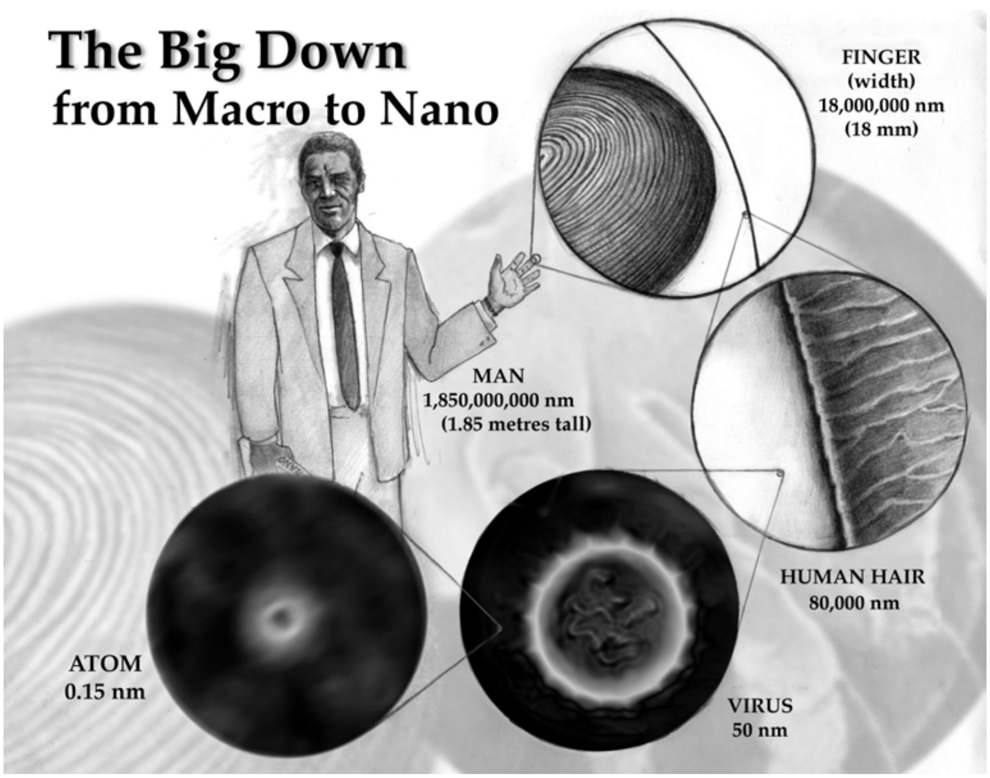
Investment in nanotechnology around the world – by both the private and public sectors – adds up to between 5 and 6 billion (US) dollars a year. Virtually all Fortune 500 companies are investing in nanotech research and development along with hundreds of small start-up companies. Europe, Japan and the US account for most of the government investment, with Japan investing slightly more than the other two major players. In the US, the level of government spending on nanotech is now over $800 million per year, making it the biggest publicly-funded science endeavour since the Apollo moon shot. (The Department of Defense gets the bulk of the US government’s money earmarked for nanotech.) At least 35 countries have some kind of national nanotech research programme: Korea is spending close to $200 million a year and both Taiwan and China are spending over a hundred million annually.[1] A well-worn statistic from the US National Science Foundation (NSF) forecasts that the global market for nanotech’s processes and products will reach one trillion dollars by 2015. Because nanotech breakthroughs are coming even faster than predicted, the NSF recently revised their prediction and now says the one trillion-dollar wave will come ashore sometime in 2011 or 2012.

What are the implications of the nano-wave? We can guess what the implications of this next technological wave will be – at least in general terms – by surfing through the history of technological change over the last half-millennium. Though it may seem counter-intuitive, history shows that technological waves, at least initially, further destabilize the lives of the poor and vulnerable.[2] It’s not surprising, really: those with wealth and power are usually able to see (and control) the approaching technological wave and prepare themselves to ride its crest. The rich have the economic flexibility to remain buoyant while those barely keeping their heads above water get washed away along with obsolete parts of the old economy. The wave creates economic opportunities for the rich, but the poor get swamped by the sudden demand for new technical skills and different raw materials.

Revolutionary Wave Effects: "The new wealth that accumulates at one end is often more than counterbalanced by the poverty that spreads at the other end...the rich get richer with arrogance and the poor get poorer through no fault of their own."[3] **Carlota Perez**, Visiting Senior Research Fellow, Cambridge University

Consider one example in just one sector: the potential of nano-scale innovations to affect the market for rubber. Researchers are designing nano-scale particles to strengthen and extend the life of automobile tyres as well as new nanomaterials that could be used as a substitute for natural rubber. If nano-designed tyres and other products such as medical gloves require little or no rubber in the future, it will mean less demand for natural rubber, with potentially devastating impacts on rubber tappers and plantation workers worldwide, especially in Malaysia and Thailand, the world's top producers of natural rubber. The point is not that the status quo should be preserved but that the nano-wave will bring monumental socio-economic disruptions for which society is ill-prepared. While there could be environmental gains from replacing some conventional materials with new nanomaterials, potential benefits won't stop the poor from being swept away in the ensuing tide.

What *is* a nano, anyway? "Nano" is a measurement not an object. Unlike "biotechnology," where the word itself lets you know that *bios* (life) is being manipulated by human art (*techne*), "nanotechnology" indicates only the scale of the art. A "nanometer" (nm) equals one billionth of a meter. The youngest and healthiest eyes can't see things much smaller than a millimeter in size and a nanometer is a million times smaller than that. Even most microscopes can't see things on the nano-scale. It takes ten atoms of hydrogen lined up side-by-side to equal one nanometer. A DNA molecule is about 2.5 nm wide. A red blood cell is gargantuan in comparison: about 2,000 times bigger than DNA or about 5,000 nm in diameter.



Nanotech's "raw materials" are not wood or rubber or steel. They are the diverse chemical elements of the Periodic Table, which are the stuff that makes up *everything*, including wood and rubber and steel, as well as DNA. Being able to make precise manipulations at the nano-scale – at the scale of atoms and molecules – opens up a world of possible applications across all sectors of the economy: computers can get smaller and faster; drugs can permeate the body more completely and can target specific cells; catalysts (used to speed up chemical reactions, including oil-refining processes) can be made more reactive; sensors can monitor everything – from crops to cows to crooks to chemical warfare agents to customers – with much greater precision; materials can be stronger, lighter and "smarter."

"You would never have thought it possible to pick up an atom and actually move it a few atomic diameters away. It is equivalent to reaching out to the planets and being able to touch a planet and move it from one orbit to another." **Joseph Stroscio**, physicist, National Institute of Standards and Technology, Maryland, USA[4]

If nano can do all that, what's the problem? There are at least four problems and they're big ones.

Big Problem Number 1: Technological control at the nano-scale goes hand-in-hand with corporate control at the nano-scale. Remember that almost as soon as scientists figured out how to *manipulate* life through genetic engineering, corporations figured out how to *monopolize* it. In the same way, nano-scale patenting will accompany atom-level manipulations. A dangerous precedent was set back in the 1960s when Glenn Seaborg, the American who won a Nobel Prize for Physics in 1951, "invented" the chemical element *Americium* (element no. 95 on the periodic table) and acquired US patent #3,156,523 for it. Yesterday's patents on genetically modified organisms will facilitate today's patents on atomically modified organisms and materials. In essence, patenting at the nano-scale could mean monopolizing the basic elements that are the building blocks of the entire natural world. Civil society and governments must go beyond the demand for "No Patents on Life" to guard against exclusive monopolies on the nano-scale components that make up life and everything else in the universe.

"It is true that one cannot patent an element found in its natural form; however, if you create a purified form of it that has industrial uses – say, neon – you can certainly secure a patent." **Lila Feisee**, Biotechnology Industry Organization's Director for Government Relations and Intellectual Property[5]

"What is claimed is Element 95." – from **Glenn Seaborg's** patent, issued November 10, 1964 – the shortest patent claim on record

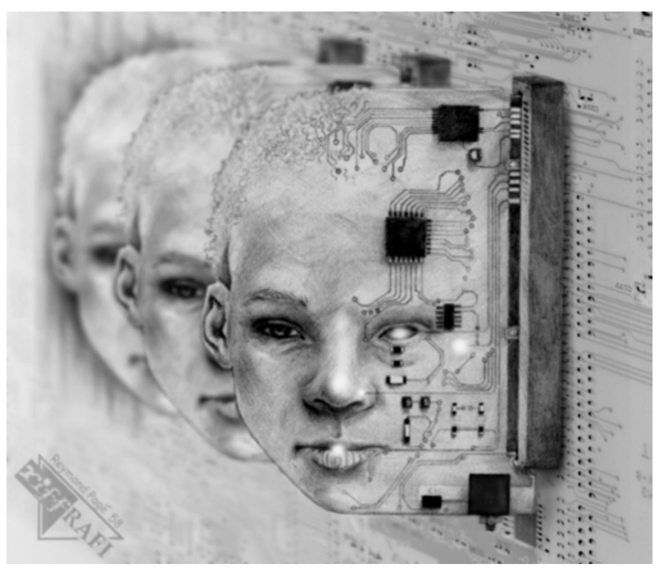
Big Problem Number 2: Convergence. Scientists and governments in the US and Europe have a strategy to merge the sciences based on the unity of nature and "material unity at the nano-scale." The logic behind the push to converge diverse technologies – such as informatics, biotechnology, nanotechnology and cognitive sciences – lies in the fact that the building blocks of all matter, fundamental to all sciences, originate at the nano-scale.[6] Since all materials and all processes operate from the bottom up (beginning with atoms that combine to form molecules and all larger structures), proponents of convergence believe they can control events on the macro-scale by manipulating events at the nano-scale. For example, at the nano-scale, scientists can already artificially synthesize DNA molecules. DNA controls the formation of proteins, which may ultimately determine the health and behaviour of the entire organism. The behaviours of individual organisms determine collective behaviour to a large extent and hence the behaviour of society itself. According to this hierarchical and reductionist view, every substance, as well as every biological or cultural system, is the result of molecular processes operating on different levels.

Atomic Coup Goes BANG! Nanotechnology enables the control of matter through the manipulation of Atoms. Convergence happens when Nanotech merges with Biotechnology (enabling the control of life through the manipulation of Genes) and with Information Technology (enabling the control of knowledge through the manipulation of Bits) and with Cognitive Neuroscience (enabling the control of the mind through the manipulation of Neurons). Controlling **B**its, **A**toms, **N**eurons and **G**enes adds up to a little **BANG** theory enabling a godlike mastery over all knowledge, matter, mind and life.

According to the little BANG theory, neurons could be re-engineered so that our minds "talk" directly to computers or to artificial limbs; viruses can be engineered to act as machines or, potentially, as weapons; computer networks can be merged with biological networks to develop artificial intelligence or surveillance systems. According to the US government, technological convergence will "improve human performance" in the workplace, on the playing field, in the classroom and on the battlefield.[7]

"Nanotechnology is a 'force multiplier.' It will make us faster and stronger on the battlefield." **Clifford Lau**, senior science adviser in the Pentagon's office of basic research, April 19, 2004[8]

While the nano-wave demands attention, we can't take our eyes off the BANG-tsunami not far behind. What is most chilling about the possibility of a converged future and what society must debate is the result of an ever-widening gulf between those who will be "improved" through technological convergence and those who will remain "unimproved," either by choice or lack of choice. As BANG (and the marketing of BANG) helps shift our concept of what is "normal," we'll all be playing catch-up or we'll be left behind. Whatever benefits BANG could bring, they will be neither cheap nor equitably distributed. What will happen to the unimproved? Will physical enhancement become a social imperative as well as an enforceable, legal one? A recent US court decision allowing prison officials to forcibly medicate a death row inmate to make him sane enough to execute suggests the complex issues involved in the notion of "improvement."[9] Other decisions (by the US Supreme Court) ruling that the Americans with Disabilities Act does not apply to persons with correctable impairments suggest that the rights of the disabled will be further eroded and disability will be seen more and more as a technological challenge instead of a social concern.[10] How long will it be before democratic dissent is viewed as a correctable "impairment" as well?



Big Problem Number 3: Nanobiotechnology and "Green Goo." Nanobiotechnology – a subset of convergence, which melds engineering, biotechnology, biology and chemistry – is the current darling of nanotech investment. Since 1999, 52% of the $900 million in venture capital funding for nanotech has gone to nanobiotechnology startups.[11]

The goals of nanobiotechnology are varied:

1) Some researchers are working on incorporating non-living, nano-scale materials in living organisms (such as drug delivery systems or sensors to monitor blood chemistry)
2) Other researchers are creating new synthetic materials that have biological components (such as proteins incorporated into plastics)
3) Other researchers are creating new living material that is capable, theoretically, of performing industrial functions (such as microorganisms that feed on industrial chemical spills or on greenhouse gases). In some cases, these new organisms incorporate synthetic, nano-structured materials. In other cases, they do not.

Incorporating non-living matter into living organisms is familiar to us (e.g., pacemakers, artificial joints), but presents particular challenges and opportunities at the nano-scale. Working at the nano-scale can facilitate biocompatibility because, at that scale, there are no clear distinctions between biological (living) and non-biological (synthetic) material. But the down side of "biocompatibility" is that nanomaterials – foreign to the human body, which is not designed to accommodate them – can slip past the guardians of our immune system and even cross the blood-brain barrier. The consequences for human health are unclear, but recent scientific studies investigating the effects of some nanomaterials on the health of mice and fish indicate that there are serious concerns.[12]

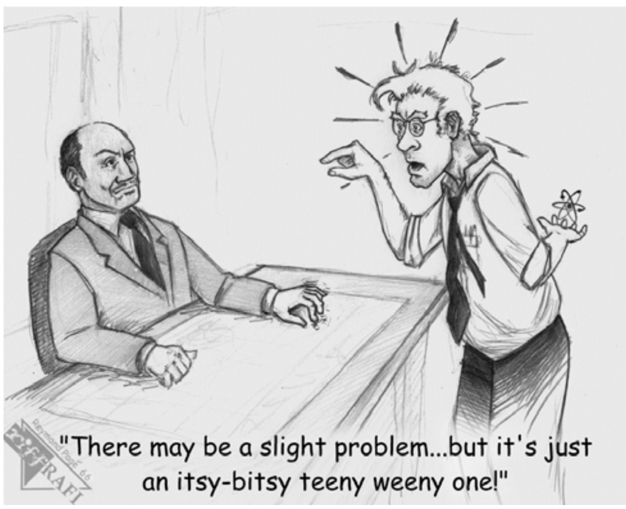
The unique feature of living organisms – whether you're talking about microbes, maize or mammals – is the ability to take nano-scale bits and pieces of chemical elements in the form of DNA molecules – and reproduce them with remarkable speed. This self-replicating "manufacturing platform" is so sophisticated and works so well that scientists are trying to harness it, not re-invent it. Reconfiguring life to serve the needs of industry makes economic and technological sense. It was done before in the Green Revolution and then again during the Gene Revolution. "Life," after all, "is cheap."

"Much of what we manufacture now will be grown in the future, through the use of genetically engineered organisms that carry out molecular manipulation under our digital control. Our bodies and the material in our factories will be the same...we will begin to see ourselves as simply a part of the infrastructure of industry." **Rodney Brooks**, director of Artificial Intelligence Laboratory, Massachusetts Institute of Technology (MIT)[13]

Products of nanobiotechnology that are living organisms may continue to do what nature intended – procreate – but they may be more powerful by their boost from human technology: the emboldened *E. coli* bacteria will now take on oil spills; the nanobio polymer car door can use embedded proteins to repair itself after a collision. Plants too tough for bugs to bite? Fire-retardant fur? The possibilities are endless.

While "Gray Goo" has grabbed the headlines in the nano-media (where self-replicating nano-scale mechanical robots escape control until they wreak havoc on the global ecosystem), the more likely future scenario is that the merger of living and non-living matter will result in hybrid organisms and products that are not easy to control and behave in unpredictable ways. In a “Green Goo” scenario, a designer microbe has designs of its own. Industry hasn’t been able to control and contain genetically modified organisms. What will happen when a newly-made organism – the product of nanobio – becomes “adventitiously present?”[14]

Since 2002, Craig Venter (of genome-mapping fame) and his Institute for Biological Energy Alternatives has been awarded $12 million from the US government’s Department of Energy to create new life forms in the laboratory, which could be engineered to produce energy or clean up greenhouse gases. While Venter and other biotechnologists are building new life from stripped-down microbes, nanotechnologists are busy building biological machines – or hybrid machines employing both biological and nonbiological matter – from the bottom-up. The implications are breathtaking: not just new species and new biodiversity – but life forms that are human-directed and self-replicating.



Big Problem Number 4: The scientific uncertainty surrounding nanoparticle toxicity and the regulatory vacuum. The current market for nanoparticles is small, but analysts predict it will approach $1 billion next year (2005).[15] Some of the world’s largest companies (DuPont, BASF, L’Oréal, Hewlett-Packard, Mitsubishi, Toyota, Unilever, Kraft and IBM) as well as some of the world’s smallest (NanoProducts, Nanophase, Altair) are ratcheting up nanomaterial research and production.

Nano-scale particles behave in ways that macro-scale particles of the same material don’t. With only a reduction of size and no change in substance, materials may be stronger or lighter or more water-soluble or more heat-resistant or better conductors of electricity. A substance that is red when it is a meter wide may be green when its width is only a few nanometers; something that is soft and malleable on the macro-scale may be stronger than steel at the nano-scale. A single gram of a catalyst material that is made of particles 10 nanometers in diameter is about 100 times more reactive than the same amount of the same material made of particles one micrometer in diameter (1000 times bigger than a nanometer).[16] Industry is exploiting property changes at the nano-scale to create new products and new markets.

The potential impact of nanoparticles on the environment and on human health is enormous. Toxicological data on manufactured nanoparticles are scarce, even though commercial products are already on the market (including food, cosmetics and sunscreens). And nanoparticles are not regulated by any government in the world! Results from a March 2004 study revealed that nano-scale molecules of carbon (called buckyballs) can cause brain damage in fish.[17] Researchers studying the effects of carbon nanotubes (another form of nano-scale carbon) on the lungs of rats reported in 2003 that nanotubes are more toxic than quartz dust.[18] Other scientists have presented varying but still worrying findings on nanotube toxicity.

In May 2004, the European Commission's Health and Consumer Protection Directorate-General released a report warning that "some engineered nanoparticles produced via nanotechnology may have the potential to pose serious concerns" and that "adverse effects of nanoparticles cannot be predicted (or derived) from the known toxicity of bulk material."[19] In other words, just because we know how a micron-sized particle will behave in the environment doesn't mean we have a clue how a nano-sized particle of the same substance will behave. Accordingly, the report recommended "striving for the elimination whenever possible and otherwise the minimization of the production and unintentional release of nanosized particles."[20]

Let's assume scientists figure out how to solve the teeny-weeny problems they've created. Couldn't the nano-wave bring benefits, especially to the poor? It's possible, but the track record is not promising. Like earlier promises made by proponents of nuclear, chemical and biotechnologies, nanotech enthusiasts claim it will solve problems of hunger and poverty, cure cancer and clean up the environment. The simple truth is that new technologies cannot solve old injustices. Technology is not an alternative to sound social policies. As some scientists have pointed out, nanotech could possibly bring better, cheaper disease diagnostics for people and crops and improve water purification and the performance of solar cells. Further, nanotech could reduce raw material demands, increase recycling and slash transport and energy costs. But even if we can diagnose diseases better, will the diseases of poor people be the focus of corporate research, and will the patented drugs be affordable? Globalization – in the form of today's trade, finance and patent systems – ensures that the control of new technologies will remain with the rich. Intellectual property regimes and marketplace oligopolies along with government collusion have usually managed to dictate which technologies come forward and whose interests they serve.

Can we stop the swamping, even if we can't stop the waves? Governments are beginning to recognize that the products of nanotechnology require special regulatory attention. However, in their desire to accommodate industry, will they simply tweak existing regulations to create a semblance of (retrospective) responsibility and/or will they make the regulations voluntary? But regulations, even if they are eventually put in place, are not enough. Society must be fully engaged in a discussion of the socio-economic as well as health and environmental implications of nano-scale technologies. Ultimately, all these issues must be considered by civil society in open, informed debates at the local, national and international levels. The international community must create a new body with the mandate to track, evaluate and accept or reject new technologies and their products through an International Convention on the Evaluation of New Technologies (ICENT).

Our thirty-year goal is to have such exquisite control over the genetics of living systems that instead of growing a tree, cutting it down, and building a table out of it, we will ultimately be able to grow the table.[21] **Rodney Brooks**, director of Artificial Intelligence Laboratory, MIT

[1] Anon., *AIST Today*, No. 10, Autumn 2003. Available on the Internet: http://www.aist.go.jp/aist_e/aist_today/2003_10/nanotech1_02.html (available as of April 23, 2004).

[2] On the negative impacts of Britain's industrial revolution on the health of the average population, for example, see Anon., "Bigger is Better," *The Economist*, February 28, 1998. See also, Carlota Perez, *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages*, 2002.

[3] Carlota Perez, *Technological Revolutions and Financial Capital*, pp.4-5.

[4] Quoted in Marsha Walton, "Will nanotech save the world or is it mostly hype?" April 16, 2004. Available on the Internet: http://www.cnn.com/2004/TECH/science/04/15/nanotech.ideas/ (available as of May 19, 2004).

[5] From a speech by Lila Feisee, available on the Internet (as of June 2, 2004): http://www.bio.org/speeches/speeches/041101.asp

[6] Mihail Roco and William Sims Bainbridge, eds., *Converging Technologies for Improving Human Performance*, NSF/DOC Report, June 2002.

[7] The slogan for NBIC, improving "human performance," has recently been downgraded to "human potential" in the face of concerns from civil society and some scientists.

[8] Quoted in Ted Leventhal, "Pentagon official says nanotechnology a high priority," April 19, 2004. Available on the Internet: http://www.govexec.com/dailyfed/0404/041904td1.htm (available as of June 1, 2004).

[9] Kate Randall, "Mentally ill Inmate Put to Death after Medical 'Treatment' Prepares Execution," 8 January 2004. Available on the Internet: http://www.cognitiveliberty.org/dll/singleton_executed.html (available as of May 26, 2004).

[10] On the US Supreme Court's interpretations of the Americans with Disabilities Act, see http://www.ncd.gov/newsroom/publications/supremecourt_adachart.html (available as of May 26, 2004).

[11] Robert Paull *et al*., "Investing in Nanotechnology," *Nature Biotechnology*, October 2003, p. 1146.

[12] See, for example, Barnaby J. Feder, "Health Concerns in Nanotechnology," *The New York Times*, March 29, 2004.

[13] Rodney Brooks, "The Merger of Flesh and Machines," *The Next Fifty Years: Science in the First Half of the Twenty-First Century*, ed. by John Brockman, 2002, p. 191.

[14] "Adventitious presence" is a term used by the biotech industry to refer to the unintentional contamination of amounts of one type of seed, grain or food product by another. According to the Biotechnology Industry Organization, "there are a number of factors that contribute to commingling of approved biotech products in nonbiotech products: Pollen flow; volunteerism; mixing during harvesting, transport, storage and processing; human error; and accidents can all play a role in adventitious presence." See http://www.bio.org/foodag/background/adventitious.asp (available as of June 2, 2004).

[15] The estimate is based on research by Business Communications Co., Inc. See "Altair Nanotechnologies Awarded Patent for its Nano-sized Titanium Dioxide," September 4, 2002. Available on the Internet: http://www.businesstoinvestor.com (available as of June 1, 2004).

[16] Claudia Hume, "The Outer Limits of Miniaturization," *Chemical Specialties*, September 2000.

[17] Mark T. Sampson, "Type of buckyball shown to cause brain damage in fish," *Eurekalert*, March 28, 2004. Available on the Internet at www.eurekalert.org (available as of June 1, 2004).

[18] Jenny Hogan, "How safe is nanotech?" Special Report on Nano Pollution, *New Scientist*, Vol. 177, No. 2388, 29 March 2003, p. 14.

[19] European Commission, Community Health and Consumer Protection, *Nanotechnologies: A Preliminary Risk Analysis on the Basis of a Workshop Organized in Brussels on 1-2 March 2004 by the Health and Consumer Protection Directorate General of the European Commission*, pp. 11, 17.

[20] *Ibid*., p. 27.

[21] Rodney Brooks, "The Merger of Flesh and Machines," *The Next Fifty Years: Science in the First Half of the Twenty-First Century*, ed. by John Brockman, 2002, p. 187.

The Action Group on Erosion, Technology and Concentration, formerly RAFI, is an international civil society organization headquartered in Canada. The ETC Group is dedicated to the conservation and sustainable advancement of cultural and ecological diversity and human rights. To this end, ETC Group supports socially responsible developments of technologies useful to the poor and marginalized and it addresses international governance issues and corporate power.

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