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No Small Matter!

Nanotech Particles Penetrate Living Cells and Accumulate in Animal Organs

***Issue**:* At a mid-March fact-finding meeting at the US Environmental Protection Agency (EPA), researchers reported that nanoparticles are showing up in the livers of research animals, can seep into living cells, and perhaps piggyback on bacteria to enter the food chain. The commercial use of nanoscale carbon was likened to either "the next best thing to sliced bread or the next asbestos." Despite these revelations, there is no regulatory body (and no plans for one) dedicated to overseeing this potent and powerfully invasive new technology.

Context: Touted as the greenest and greatest techno-fix ever, proponents claim that these atomic-scale manipulations will solve our environmental woes and guarantee – not only *sustainable,* but *perpetual* – development. *Nanotechnology* is the manipulation of matter, working with elements in the Periodic Table (atoms and atom clusters [molecules] in the range of a nanometer [nm], one billionth of a meter). At the nanoscale, atoms function in the fabled realm of quantum physics, where ordinary elements can exhibit extraordinary strength, temperature tolerance, colors, chemical reactivity, and electrical conductivity – characteristics inconceivable at micro or macro scales. Companies are already cranking out tons of commercial nanomaterials for use as catalysts, in cosmetics, paints, coatings, fabrics, and to provide added strength. Some of the materials are familiar compounds that have never before been marketed on the nanoscale; other materials are atomically-modified elements that do not exist in nature. Some new forms of carbon (a component of all living things) – called nanotubes and fullerenes – are being manufactured for the first time and their impact on the environment is unknown.

***Implications**:* Nanotechnology – including nanobiotechnology – has been pegged by industry and governments to become the world's largest and fastest industrial revolution – dwarfing history's past technological upheavals. More than 450 dedicated nanotech enterprises are already in the marketplace manufacturing a host of "old-nano" products (e.g., particles used in cosmetics and sprays) and "new-nano" products (e.g., chips, sensors and new forms of carbon). Global R & D spending is at US$4 billion. The US National Science Foundation predicts that within ten years the entire semiconductor industry and half of the pharmaceutical industry will rely on nanotechnology and that, by 2015, the global market will be US$1 trillion.[1] Industry will fight hard to make sure that health and environmental concerns do not derail the progress of nanotech, as has happened with biotech.

***Policy**:* Because nanotech generally works with the elemental building blocks of life – rather than with life directly – it has largely evaded social, political and regulatory scrutiny. The US Food and Drug Administration (FDA) has thus far established no policies or protocols for considering the safety of nano-particles in products already on the market. Given the concerns raised over nanoparticle contamination in living organisms, Heads of State attending the World Summit on Sustainable Development in Johannesburg (Aug. 26-Sept. 4, 2002) should declare an immediate moratorium on commercial production of new nanomaterials and launch a transparent global process for evaluating the socio-economic, health and environmental implications of the technology.

"One thing we've concluded is whatever these things [nanomaterials] are going to do, they're not inert. What will they do when they get in the environment, and what will they do when they get into people?"[2]—Dr. Vicki Colvin, professor and co-director of the Center for Biological and Environmental Nanotechnology, Rice University, Texas

Small Matters: Nanotechnology operates in a realm not merely invisible to the naked eye but to all but the most sensitive instruments. At this scale, nanotech's "raw materials" are the diverse atomic elements of the Periodic Table. Industry predicts that nanotechnology will become the Great Enabler: allowing computers to get smaller and smarter; making more flexible drugs that work better and faster; creating catalysts (used to speed chemical reactions in the process of refining oil, for example) that are more reactive; building biosensors that can monitor crops, crooks, and biowarfare agents. A little further down the road, nanotech is predicted by many to have the potential to grow the crops, become the cops, and be the frontline military defense.

Today's applied nanotechnology is less conspicuous, focusing on sub-microscopic materials with useful properties. Researchers have found that nanoscale particles behave in ways that macroscale 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 heat-resistant or better conductors of electricity. It's like magic – pulling something out of a hat. But what comes out of the hat is essentially what went in – just vastly smaller and stronger – a ratty Clark Kent turned Mighty Mouse!

Facts of the Matters: Using the strictest definition of nanotechnology, an estimated 470 nanotech companies are evenly distributed across North America, Asia and Europe.[3] Right now, more than a third of those companies are working with nanoparticles and scaling up for mass manufacture of "bulk nano" particles or specialty ("designer") nanomaterials that will find their way into every industry from tyres to tacos. The big push is on new forms of nanoscale carbon. Fifty-five companies are making carbon nanotubes and at least twenty companies are gearing up for mass production (hundreds of tons annually) of fullerenes (also known as buckeyballs). And the industry is ready to make use of nanoscale compounds such as gallium arsenide. Made from gallium and arsenic, it is a semiconductor like silicon but faster, and unlike silicon, it can transmit light. It already has widespread use in microelectronics, but could be dangerous on the nanoscale where it may find its way into living cells and organs.[4] Dr. Jennifer West, studying the environmental implications of nanomaterials at Rice University's Center for Biological and Environmental Nanotechnology (CBEN), warns that even minute traces of gallium arsenide in the body could prove toxic. She reserves particular concern, however, for carbon nanotubes that, because carbon is such a fundamental element in the body, will set off no alarm bells but could wreak havoc because of their unique structure (see below). Dr. Mark Wiesner, professor of Civil and Environmental Engineering at Rice's CBEN, is also worried about the commercial use of carbon nanotubes. He asks, "Where does this stuff go? What will be its interaction with the environment? Is it the next best thing to sliced bread or the next asbestos?"[5] For example, both Wiesner and West have expressed concerns that companies are now looking into using carbon nanotubes in radial tyres. Old used tyres are ubiquitous from backyards to landfills to lake bottoms and groundwater.

These concerns were first made public when the on-line journal, *Small Times*, reported on a March meeting called "Nanotechnology: Environmental Friend or Foe?" that was held at EPA headquarters in Washington, DC.[6] Dr. Barbara Karn, who is in charge of directing nanotechnology research at EPA, wondered about the potential for harm to the environment or to health if nanoparticles proved difficult to control; so she invited scientists from Rice's CBEN to come to Washington and offer their advice and expertise.[7]

Nano Forever? According to Dr. Wiesner, tests that measure the accumulations of materials in the livers of laboratory animals have demonstrated that nanoparticles accumulate within organisms and that nanomaterials, even inorganic ones, have been absorbed by living cells.[8] At their mid-March fact-finding meeting, Wiesner informed EPA officials, "We know nanomaterials have been taken up by cells. That sets off alarms…If bacteria can take them up, then we have an entry point for nanomaterials into the food chain."[9]

Dr. West explains that if nanoparticles are present in the bloodstream, proteins in the blood will attach to the surface of the nanoparticles in an attempt to "wrap them up," like beans in a tortilla. When the proteins envelop the nanoparticles, the proteins' shape as well as their function may change. Parcels of nanoparticles in the bloodstream may be useful for some medical applications, such as drug delivery, but the changes in the proteins could trigger other unintended and dangerous effects, such as blood clotting.[10] Equally alarming, West sees a need to examine whether nanoparticles absorbed into bacteria enhance the ability of other materials to piggyback their way in and cause damage.[11] The nanomaterial itself may be benign, but, in the same way that proteins will bind to nanomaterials in the bloodstream, toxins, such as pesticides, could bind with nanoparticles in water, facilitating their transport.[12]

> **"Where does this stuff go? What will be its interaction with the environment? Is it the next best thing to sliced bread, or the next asbestos?"—**Dr. Mark Wiesner, Rice University, on the release of carbon nanotubes in the environment

It may be that the quality that makes nanoparticles so attractive to researchers trying to develop better drug-delivery systems—namely, their ability to enter the bloodstream and to cross the blood-brain barrier, as well as their ability to be taken up by individual cells—will turn out to be the same quality that makes them dangerous. The potential downside to the mobility of nanoparticles, including the possibility of "bad" particles joining forces with "good" nanoparticles, should be investigated with the utmost urgency, as companies race to find ways to bring us into intimate contact with human-made nanoparticles:

- ***NanoGuard***: Researchers at Nanosphere (Alachua, FL) are working to incorporate nanoparticles into medications, which can be detected later through breath analysis in order to monitor patient compliance.

- ***NanoBite*** Scientists working for Kraft Foods are adding nanoparticles to fluids hoping to create "interactive beverages" that will change color or flavor at the whim of the consumer.[13]

- The food science department at Rutgers University (NJ, USA) has recently hired what it believes is the first "professor of food nanotechnology."[14] At Rutgers, Professor Qingrong Huang will focus on developing two applications of nanotechnology in the food industry: "nutraceutical" foods that will use proteins to deliver drugs to targeted areas of the body and food packaging that responds to chemical changes in its contents (such as when what's inside starts to spoil).

- ***NanoDoc*** Advectus Life Sciences (Vancouver, Canada), focusing on the treatment of brain cancer, is one of many pharmaceutical companies experimenting with improved drug delivery by means of nanotechnology. Advectus scientists have been able to send nanoparticles of a potent anti-tumor drug across the blood-brain barrier, a notoriously fastidious doorman: the nanoparticles are injected into the bloodstream where they attract lipoproteins (cholesterol) that adhere to the surface of the drug-particles and mask them by wrapping them up; from there it's smooth sailing all the way to the brain where lipoprotein receptors unknowingly absorb both the cholesterol and the anti-tumor drug hidden beneath. Advectus sees their "Nanocure" technology as a likely candidate for fast track designation by the US FDA.[15]

What's the big deal? So what if nanoparticles, even inorganic ones, enter cells or accumulate in the liver? So what if they bring some unsavory partners with them? How much harm can a nano-sized speck of anything do? Even a whole bunch of nano-sized specks? The big deal may lie in the unique nature of the technology's scale. The impetus behind nanotechnology as a field of research—the reason it has attracted four billion research dollars worldwide—derives from the fact that materials act in different, sometimes useful, often unpredictable ways at the nano-scale. 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]

The changes in color, strength and reactivity that are observable at the nanoscale are attributed solely to the reduction in the size of the particles. The point is we don't know what accumulated amounts of any human-made nanomaterial will do in our lungs or our livers or in our groundwater, even if we do know how bigger particles of the same material behave in our lungs and livers and groundwater. And so far no one has bothered to find out.

"We know nanomaterials have been taken up by cells. That sets off alarms…If bacteria can take them up, then we have an entry point for nanomaterials into the food chain."—Dr. Mark Wiesner, Rice University

The Future is Now: At the same time that properties of nano-sized elements and compounds are being intensively researched in hopes of near-future applications in the electronics and biomedical and food industries, the materials science industry is already producing nanomaterials in bulk quantities. For example, Nanophase, Inc., based outside Chicago (IL, USA), sells nine different nanoparticle compounds available in formats tailored to different applications: from zinc oxide and titanium dioxide nanoparticles bought by sunscreen manufacturers for their ability to block UV light to nanoscale antimony tin oxide (used in coatings and paints) to iron oxide and cerium oxide (used as catalysts). Nanophase shipped out over 250 tons of zinc oxide nanoparticles last year.

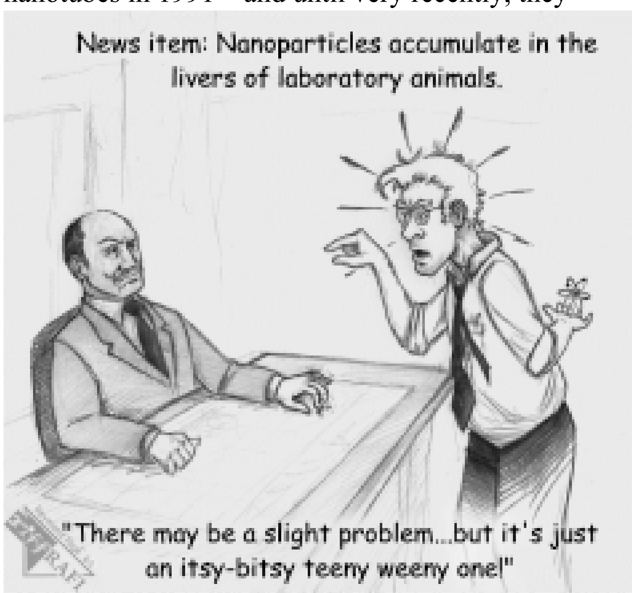
A Rose is a Rose, but not by every measure With some important exceptions (see below for a discussion of carbon nanoparticles), most nanoparticles that are produced today are mini-versions of particles that have been produced for a long time. While the larger versions have undergone testing and regulation, their tiny siblings haven't. But it is crucially important to ask whether or not a nanoparticle of a compound or an element or an approved drug is the same as a macroparticle of the same substance. The nanoparticle and the macroparticle may be called by the same name and they may be composed of the same stuff but they won't look or act the same. If nanotech companies are forced to defend their products, will they borrow familiar arguments from their biotech colleagues to try to lessen regulatory burden? On the one hand, we're told that the products are so wonderfully novel, they deserve monopoly patent protection; on the other hand, they're not so very different and they do not require special regulatory oversight.

Same Old Stuff?
Will government regulatory agencies like the FDA develop guidelines to regulate a new nanoscale industry? The following example suggests that the fragmented and case-by-case method of overseeing the biotech industry is likely to prevail in the age of nanotech as well:
While an FDA panel was working to establish regulations for ingredients in over-the-counter sunscreen products, there was some discussion about whether nanoscale titanium dioxide was a new ingredient or whether it was the same ingredient as the larger scale titanium dioxide particles that had already been approved for use. For starters, the nanoscale titanium dioxide no longer met the definition of a "sunscreen opaque sunblock" because, at the nanoscale, titanium dioxide particles are transparent rather than opaque. Also, nanoscale titanium dioxide is not included in the *US Pharmacopeia* (USP), a collection of over 3,800 monographs establishing standards for pharmaceuticals; and, it was noted, there is a potential for nanoparticles to accumulate under the skin. In the end, the FDA panel did not consider nanoscale titanium dioxide to be a new ingredient, but rather a specific grade of the already approved titanium dioxide. The panel omitted opacity as a criterion for OTC sunscreens and stated, "the agency is not aware of any evidence at this time that demonstrates a safety concern from the use of [nanoscale] titanium dioxide in sunscreen products."[17]

Cutting Edge Carbon? Nanotubes and Fullerenes
In addition to the bulk-production of conventional compounds that exhibit different properties due to the nano-size of their particles, new nanomaterials are now being produced that have not existed in our environment before. Two forms of pure carbon that appear to be the *wunderkinder* of the nanoworld are being manufactured in bulk—one form is soccer-ball shaped and called a fullerene and the other, called a nanotube, is long and cylindrical. Nanotubes in particular promise new and useful applications across every major industrial sector, including the life sciences, materials science and electronics. Nanotubes are 100 times stronger than steel and about one-fifth lighter. The French tennis-racquet manufacturer Babolat already incorporates

nanotubes into its "Nanotube VS" racquets, but they could also be used to strengthen and lighten all kinds of materials, including synthetic bone implants and artificial joints. Because nanotubes are good conductors of electricity, they are raising hopes for faster, more accurate diagnostics in the biomedical field and more efficient drug delivery methods.[18] A Stanford University chemist, for example, is working to develop a glucose sensor using a single carbon nanotube, which could be implanted into patients with diabetes.[19] Due to their semi- conducting properties, nanotubes may be the building blocks for smaller, faster computers and nanotube transistors have been shown to outperform silicon transistors.[20]

These forms of pure carbon were discovered rather than invented —fullerenes were discovered in 1985; nanotubes in 1991—and until very recently, they



could not be manufactured at will. Neither form exists in our environment naturally.[21] It would be difficult to estimate the quantity of nanotubes and fullerenes that has been produced in laboratories so far. They are now being manufactured all over the world and scientists are continually tweaking production methods (which they patent) in order to make them in greater quantities, faster and more cheaply. Several companies in the U.S. and Europe produce nanotubes and two companies in Japan have just been created to make them in bulk quantities: Frontier Carbon Corporation (a joint venture of Mitsubishi Corp. and Mitsubishi Chemical Corp.) plans to produce 40 tons of nanotubes next year and Carbon Nanotech Research Institute aims for an annual production of 120 tons.[22] That's a lot of nanotubes when you consider that a single nanotube is so small it's invisible and that companies in the U.S. (e.g., Carbolex, Carbon Nanotechnologies, Inc.) now take orders in quantities weighing less than a hundred grams—at the rate of 100 grams per order, it would take 9,070 customers to equal 1 ton of nanotubes (with revenues amounting to around US$72,574,800 at Carbolex's price of US$80 per gram).

Again, what's the big deal? The big deal is uncertainty, but scientists see two potential problems specific to these forms of carbon—one problem has to do with their shape and one, apparently, has to do with their size. It turns out that Dr. Wiesner's comparison of carbon nanotubes with asbestos is not merely rhetorical, highlighting the need to assess the dangers of a material before it becomes ubiquitous. Carbon nanotubes resemble asbestos fibers in shape: they are long and needle-like. According to Dr. Wiesner, carbon nanotubes cannot pose much of a threat at present because, in our environment, they tend to clump together rather than exist as single fibers (which have the potential to cause serious respiratory problems as asbestos fibers have). However, an intensive area of research is to figure out a way to solubilize nanotubes—in effect, to de-clump them—so that they can be more easily used as single, detached fibers.[23] Two patents on methods of solubilizing nanotubes in organic solutions have issued in the last year to the University of Kentucky (USA).[24] Very few studies have been done to learn what might happen if nanotube fibers were breathed in or if they were used in drug delivery or disease diagnoses or as biosensors.[25] Immunologist Silvana Fiorito has discovered in preliminary research that when a 1 micrometer-wide particle of pure carbon (in the form of graphite) is introduced into a cell, the cell responds by producing nitric oxide, which indicates that the immune system is working and the body is fighting back against an invading foreign substance.[26] When a *nano-sized* particle of the same substance – pure carbon – is added to cells (in the form of either nanotubes or fullerenes), the cells fail to produce an immune response—they welcome the alien carbon like a long lost relative. The ability to slip past the immune system may be desirable for drug delivery, but what happens when uninvited nanoparticles come calling? In other words, once nanotechnologists have figured out how to distract the bouncer guarding the door, how can you be sure you're still keeping out the riff-raff?

Nano-Advocates: The prospect of a new industrial revolution—on the order of a US$1 trillion market by 2015—has excited governments, scientists, industry, and venture capitalists. None of the scientists working with nanomaterials today, even those who have questioned their fate in the environment, could be accused of being technophobic or alarmist when it comes to the advancement of the technology. For example, the EPA supports nanotech research leading to environmentally-beneficial applications, as part of its "Science to Achieve Results (STAR)" program and no more than ten percent of its research funds will target the potentially detrimental impacts of nanomaterials. Rice University's CBEN aims "to shape nanoscience into a discipline with the relevance, triumphs, and vitality of a modern day polymer science" and is one of six major Nanoscale Science and Engineering Centers in the U.S. funded by a $10.5 million grant from the government-supported National Science Foundation.[27] Rice University is home to Richard Smalley, Nobel Prize winner in Chemistry for his discovery of fullerenes in 1985 and he is a member of the CBEN's research team. Silvana Fiorito, the immunologist who is investigating how cells respond to nanoscale carbon, works in the lab of Patrick Bernier, who co-founded Nanoledge, a nanotube producer in Montpellier, France. The fact that no scientists working in the field are able to insure a happy, certain fate of nanomaterials should focus our attention on the urgent need for regulatory oversight.

The vast majority of nanotech researchers is united in their stance that today's nanotechnology, applied to produce useful materials, is beneficial and benign. Claes-Göran Grandqvist, Professor of Solid State Physics, Uppsala University (Sweden) believes that nanomaterials should not be portrayed as anything radically new or foreign. He points out that nanomaterials can indeed clean up and destroy pollutants and he warns against drawing alarmist conclusions. "I do think that potential dangers of nanotechnologies should be studied, and that this should be done now," he adds.[28]

We have been told that if nanotechnology has a down-side, it won't manifest itself until some point in a distant future that may never even arrive. Some believe that self-replicating nanomachinery (nano-sized robots, or nanobots) may exist one day and with just a very small stretch of the imagination, it becomes easy to visualize a doomsday scenario: what if nano-bots started replicating—themselves or anything else—and couldn't be stopped? Though no self-replicating machines of any size exist today, their potential existence continues to be debated in the safe, theoretical realm.[29] (Micro-sized robots do exist, which are able to execute nano-sized commands controlled by a central computer [see ETC group's news release, "Nanotech Takes a Giant Step Down," March 6, 2002, www.etcgroup.org.). Ironically, while a few farsighted scientists are focusing on potential dangers of future nanotech applications, virtually no one has been tracking the potentially negative impacts of nanotechnology's present-day products.[30]

See no evil? Debates about nanotechnology's (and our) possibly apocalyptic future are redundant if we fail to ask and answer the most basic questions about the impact of nanomaterials on the environment today. As was the case with biotechnology, the products of a new technology have been rushed to market without proper foresight and assessment and with little public discussion. The provocative questions raised by a handful of researchers working in the field highlight the need for governments and civil society to come to grips with this powerful new technology. One thing is certain: size matters.

Pressure is building for Heads of State at the upcoming World Summit on Sustainable Development in Johannesburg (August 26-September 4, 2002) to embrace nanotech as the newest, greenest technological fix for a sustainable future. Given the concerns raised over nanoparticle contamination in living organisms and unanswered questions about potential dangers of new forms of carbon, the Johannesburg Summit should instead be calling for an immediate moratorium on commercial production of new nanomaterials. Equally important is the need to launch a global process for evaluating the socio-economic, health and environmental implications of new technologies – a legally binding International Convention for the Evaluation of New Technologies (ICENT).

A Sampling of Nano-Producers around the World

Company	What They Make Now	Location
Hyperion Catalysis	Carbon Nanotubes—used as an electrically conductive additive in plastics for incorporation in car body panels and disc drives	Cambridge, MA (USA)
NanoCarbLab	Carbon nanotubes	Moscow, Russia
Nanoledge SA	Carbon nanotubes—for use in composite materials	Clapiers, France
Altair Technologies	Nanoparticles— specializes in titanium dioxide, used in coatings, thermal sprays, as catalysts	Reno, NE (USA)
Nanophase, Inc.	Nanoparticles—zinc oxide and titanium dioxide (used in cosmetics, sunscreen), cerium oxide and iron oxide (used as catalysts), aluminum oxide (used in ceramics)	Romeoville, IL (USA)
Frontier Carbon Corporation	Fullerenes—large scale production	Tokyo, Japan
Molecular Nanosystems	Carbon nanotubes—also engage in research, development and production of nanotube-based products	Palo Alto, CA (USA)
Southern Clay Products	Nanocomposite plastic—a naturally-occurring clay nanoparticle is added to plastics to make them lighter, stronger, more heat-resistant; mainly used in packaging and automotive plastics	Gonzales, TX (USA)
Carbon Nanotechnologies	Carbon nanotubes—uses technology developed at Rice University by Nobel Prize winner Richard Smalley	Houston, TX (USA)
Yorkpoint New Energy Science and Technology Development Co.	Carbon nanotubes—used in fuel cells	Guangzhou, Guangdong Province (China)

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[1] M. Roco and W.S. Bainbridge, eds., "Societal Implications of Nanoscience and Nanotechnology," National Science Foundation, March 2001, pp. 3-4, 74-75; available on the internet: http://www.wtec.org/loyola/nano/societalimpact/ nanosi.pdf

[2] Vicki Colvin, quoted by Brown, D., "Nano Litterbugs? Experts See Potential Pollution Problem," *Small Times*, March 15, 2002, URL: Article URL: http://www.smalltimes.com/document_display.cfm?document_id=3266

[3] CMP Cientifica, "Nanotechnology Opportunity Report," March 2002. CMP Cientifica's report focuses only on new technology that involves material smaller than 100nm; it estimates annual sales derived from nanotechnology to be US$30 million. Due to the report's prohibitive cost (US$1995), ETC's references come from a summary of the report: Eric Pfeiffer, "Nanotech Reality Check: New Report Tries to Cut Hype, Keep Numbers Real," *Small Times*, March 11, 2002; URL: Article URL: http://www.smalltimes.com/document_display.cfm?document_id=323. The NanoBusiness Alliance, a newly-minted US trade group, estimates nanotechnology's annual global revenues to be US$45.5 billion. The enormous discrepancy is due to the Alliance's inclusion of some products that are not truly nanoscale – a strict but widely accepted definition of nanotechnology limits the size of what is being manipulated to less than 100 nanometers. The Alliance figure includes MEMS – microelectrical mechanical systems, which are on the scale of micrometers. CMP Cientifica's figure excludes some products that are truly nanoscale but not new technologies (e.g., carbon black, nanoscale carbon particles – chemically the same as soot – have been used in the manufacture of tires for almost a century).

[4] Personal communication with Dr. Jennifer West at Rice University via telephone, July 12, 2002.

[5] Dr. Mark Wiesner, quoted in Brown, D., "Nano Litterbugs? Experts See Potential Pollution Problem"

[6] Ibid. and "U.S. Regulators Want to Know whether Nanotech Can Pollute," *Small Times*, March 8, 2002 URL: Article URL: http://www.smalltimes.com/document_display.cfm?document_id=3231.
[7] The visitors from Rice had held their own conference a few months before: "Nanotechnology and the Environment: An Examination of the Potential Benefits and Perils of an Emerging Technology."
[8] Brown, D., "Nano Litterbugs? Experts See Potential Pollution Problem"
[9] Ibid.
[10] Personal communication with Dr. West via telephone, July 12, 2002; see also Gorman, J., "Taming High-Tech Particles: Cautious steps into the nanotech future," *Science News*, week of March 30, 2002; Vol. 161, No. 13; available on the internet: http://www.sciencenews.org/20020330/bob8ref.asp
[11] Gorman, J., "Taming High-Tech Particles: Cautious steps into the nanotech future"
[12] Personal communication with Dr. West via telephone, July 12, 2002.
[13] For info on Nanosphere, www.nanosphere.com; for Kraft's interactive beverage, see Charles Choi, "Liquid-coated fluids for smart drugs, food," UPI Science News, Feb. 28, 2002; available at www.upi.com.
[14] Elizabeth Gardner, "Brainy food: Academia, industry sink their teeth into edible nano," *Small Times*, June 21, 2002, URL: http://www.smalltimes.com/document_display.cfm?document_id=3989
[15] http://www.advectuslifesciences.com
[16] Claudia Hume, "The Outer Limits of Miniaturization," *Chemical Specialties*, September 2000.
[17] See "Sunscreen Drug Products For Over-The-Counter Human Use; Final Monograph." Available on the internet; URL: http://www.cfsan.fda.gov/~lrd/fr990521.html. The FDA documents refer to nanoscale titanium dioxide as "micronized titanium dioxide." According to Joseph Lipnicki, FDA, Center for Drug Evaluation and Research, there is no official definition of "micronized," but the particles are of a relatively homogenous size that is less than 250 nm. Personal communication via telephone with Mr. Lipnicki, July 16, 2002. The cosmetic-grade titaniumdioxide particles offered by Altair Nanomaterials, Inc. and Nanophase, Inc. have an average particle size that ranges from 25-51 nm.
[18] Alexandra Stikeman, "Nanobiotech Makes the Diagnosis," *Technology Review*, May 2002, pp. 60-66.
[19] Ibid., p. 63.
[20] D. Rotman, "the nanotube computer," *Technology Review*, March 2002, pp. 36-45.
[21] According to Dr. Richard Superfine, a physicist at the University of North Carolina at Chapel Hill (USA), fullerenes have been found on asteroids and are, in general, thought to be a result of a history of intense heat. He is not aware of carbon nanotubes being found naturally. Personal communication with Dr. Superfine, 2 July 2002.
[22] M. Waga, "Japanese Companies Getting Ready to Churn Out Nanotubes by the Ton," *Small Times*, March 13, 2002; URL: http://www.smalltimes.com/document_display.cfm?document_id=3258
[23] Personal communication with Dr. Mark Wiesner, June 18, 2002.
[24] US Patent 6,368, 569 issued 9 April 2002 and US Patent 6,331,262 issued 18 December 2001.
[25] Two researchers at the University of Poland, Warsaw, concluded that carbon nanotubes do not pose a significant asbestos-like health threat to humans after subjecting guinea pigs to carbon nanotubes and then examining their lungs four weeks later. Their research is published in *Fullerene Nanotubes and Carbon Nanostructures,* Volume 9 (2), p. 251-254.
[26] Gorman, J., "Taming High-Tech Particles: Cautious steps into the nanotech future"
[27] http://cnst.rice.edu/cben/CenterVision.shtml
[28] Personal communication with Professor Granqvist, 18 July 2002.
[29] See, for example, *Scientific American*, September 2001.
[30] See, for example, the Foresight Institute's web site, www.foresight.org.

The Action Group on Erosion, Technology and Concentration, ETC Group (pronounced Etcetera 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 in technologies useful to the poor and marginalized and it addresses governance issues affecting the international community. We also monitor the ownership and control of technologies, and the consolidation of corporate power. http://www.etcgroup.org