

# Nano Exposed: A Citizen's Guide to Nanotechnology

December 2010



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# Nano Exposed: A Citizen's Guide to Nanotechnology

## Section I: It's a Nano World After All

### ■ NANO 101

**Nanotechnology** is a powerful new set of technologies for observing, taking apart and reconstructing nature at the atomic and molecular level.

- *Nanotechnologies*: utilize nanomaterials to create novel structures, devices and systems for a variety of industries. Because the range of applications is diverse, think of *nanotechnologies* in the plural.
- *Nanoparticle* or *nanomaterial*: a particle or manufactured substance that has at least one component at the nanoscale.
- *Nanoscale*: based on the “nanometer” (nm), which equals one billionth of a meter.

For reference:

- A molecule of sugar measures 1 nm, about as big in relation to an apple as the apple is in relation to the earth.
- One molecule of DNA is about 2.5 nm wide.
- A human hair is huge by comparison, about 50,000 nm wide.
- The head of a pin is about 1 million nm wide.



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The first nanoparticles were discovered in 1985, when researchers using a scanning tunneling microscope discovered carbon fullerenes – hollow, spherical carbon molecules – often referred to as “buckyballs” after the architect Buckminster Fuller.

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### Commonly used nanoparticles:

- *Carbon nanotubes*: thin, hollow cylinders made of carbon atoms. At least 100 times stronger than steel, but only one-sixth as heavy, used in products like tennis rackets and bike frames.
- *Nano-silver*: an antimicrobial, used as a germ-killer in products ranging from toothbrushes to clothing to baby bottles.
- *Nanometal oxides*: often zinc or titanium compounds, used in sunscreens and cosmetics. Allow products to have transparent or “cosmetically clear” applications.
- *Carbon fullerenes*: the first class of nanoparticles to be discovered (*See Sidebar*). Used in face creams and moisturizers as well as found as an unintentional byproduct of fossil fuel combustion in air pollution.

## Making Nano

There are two ways to create nanoscale materials:

- *Top-down* approach: scientists take a large object and make it smaller and smaller until they get it to the size they want at the nanoscale.
- *Bottom-up* approach: scientists manipulating atoms or molecules at the nanoscale to assemble materials and compounds.

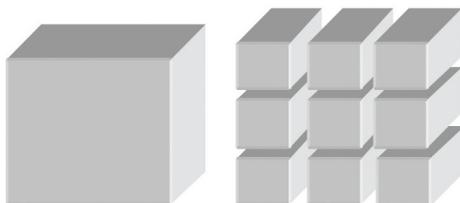
## What's the big deal with nano?

Nano means more than merely tiny; the radical reduction in size means that seemingly ordinary materials may behave completely differently than in their larger bulk or macro form.

- Many definitions of nano consider the nanoscale to start around 100nm. However, novel properties of some nanomaterials begin to occur around 300nm and the U.S. Food and Drug Administration uses a 1,000nm definition for nano-drugs.

*Novel properties include:* increased conductivity and elasticity; greater strength, mobility, and color; and increased reactivity and toxicity.

- Fundamentally different properties occur in nanomaterials because:
  - A different realm of physics, called quantum physics, comes into play at the nanoscale.
  - The reduction in size to the nanoscale results in an enormous increase of surface-to-volume ratio, giving nanoparticles more surface area compared to larger particles.



*(For example: the figure on the right has a surface area three times greater than the figure on the left, due to increased surface-to-volume ratio. This leads nanoparticles to have many of their novel properties.)*

These novel properties excite industries and governments, which are spending billions of dollars researching new nanomaterials in devices and systems.

## Scientific Unknowns

- **Unique risks:** The same features that industries find so useful create unpredictable risks to human health and the environment.
- **Novel size-related properties:** Experts agree that health and environmental effects cannot be predicted from the behavior of the same material in bulk form.
- **Research gaps:** Scientists are just beginning to understand the potential toxicity of nanomaterials but tools to measure most nanomaterials and nanoparticles are inadequate.

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Swiss Insurance giant Swiss Re noted that *“Never before have the risks and opportunities of a new technology been as closely linked as they are in nanotechnology. It is precisely those characteristics which make nanoparticles so valuable that give rise to concern regarding hazards to human beings and the environment alike.”*

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### Are Nanomaterials Natural?

The very reason that nanotechnology is hyped so heavily is because it allows materials to be incorporated into products that can do things that natural unrefined substances cannot. However, some naturally-occurring nanomaterials do exist, like nano-sized salt crystals found in ocean air or carbon nanoparticles emitted from fire. In addition, there are some nanoparticles that have been around for many years, although they are not naturally-occurring. For example, when cars combust fossil fuels they generate particulate matter, such as carbon fullerenes, that cause air pollution. This form of nanoparticle is neither naturally-occurring nor intentionally engineered. Engineered nanomaterials now in development and manufacturing are both different from anything that exists in nature and also modify “natural” nanomaterials.

## Section II: Nano Today

### ■ NANO COMMERCIALIZATION: THE FUTURE IS NOW

#### Colossal Investments

Over the last decade, governments worldwide have invested *\$40 billion* in nanotechnology.

- Globally, nanotech R&D spending reached \$13.5 billion in 2007, an increase of 14% from 2006.
- Corporate R&D spending reached \$6.6 billion in 2007, surpassing government spending for the first time.
- The U.S. alone has invested a total of around \$12 billion of public funds and the E.U. has invested €5.1 billion.
- However, government risk research is woefully underfunded, on average receiving less than 4% of total National Nanotechnology Initiative (NNI) funding in the U.S. [see *EHS Funding as percentage of NNI Funding between 2005-2010*] and a meager 4% (€28 million) of the annual EU budget.

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#### *The U.S. National Nanotechnology Initiative (NNI)*

Founded in 2001, the NNI coordinates Federal nanotechnology research and development by providing a framework of shared goals, priorities, and strategies for the 25 participating government agencies. The NNI is the primary spokesperson and chief fundraising arm for collaborative and individual agency action on nanotechnology.

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### Commercialization: Moving at Lightning Speed

Nanoproduct inventories show over 1,000 nano-enabled products currently available globally. In 2008, \$166.6 billion in nano-enabled products were produced; by 2012 that figure is expected to grow to \$263 billion worldwide.



One inventory developed by the Wilson Center in March 2006 averages at least three to four new consumer products per week. Another inventory released collaboratively by the European consumer groups BEUC and ANEC contains a list of over one hundred nano-products available in EU markets. Both of these inventories are available online – see the Resource Guide at the end of the booklet for more details.

### A Wide Range of 1<sup>st</sup> Generation Nano-Products

Currently, the largest nano sectors are personal care products and antimicrobial products. Nano-products currently available include: paints, coatings, sunscreens, medical devices, sporting goods, cosmetics, clothing, dietary supplements, vitamins, food and food packaging, kitchenware, computer hardware, cell phones, digital cameras, film, automotive electronics and batteries, automotive exteriors, fuel additives, tires, children's toys and pacifiers, laundry detergent, fabric softeners, personal hygiene products, cleaning agents, air conditioning units, pet products, jewelry, bedding and furniture, lubricants and foams, waxes, self cleaning windows, antimicrobials, pesticides, MP3 players, and other electronics. However, because there are no labeling requirements, the known nano-products likely represent *only a small fraction* of the actual commercialized applications.

### Product Spotlight: Nano-silver

Nano-silver is an antimicrobial, and it is incorporated into hundreds of consumer products, including toothbrushes, toothpaste, clothing, cutting boards, food containers, food packaging, computer parts, curling irons, hair brushes, baby bottles and children's pacifiers.



However, products like this raise numerous public health and environment risks:

- Nano-silver has been found to bind with DNA, damaging the ability of DNA to replicate.
- Sock fabrics engineered with nano-silver leached nano-silver into water during washing tests, demonstrating the ease with which nano-silver can enter the environment.
- Nano-silver is toxic to certain aquatic organisms, beneficial bacteria and ecosystems. Once the product enters the natural environment, it has the potential to bioaccumulate, or buildup, in the tissue of living organisms.
- The unregulated release of nano-silver into the environment could compromise the effectiveness of nano-silver as an antimicrobial as harmful pathogens develop resistance to nano-silver germ-killing properties.



## ■ NANO AND PUBLIC HEALTH

*Unique Properties Present Unique Health Risks:* the novel properties and features of nanomaterials that appeal to manufacturing sectors are the same properties that cause public health risks.

- Exposure: from manufacturing or consumer products, nanoparticles can enter the human body via inhalation, ingestion or in some cases through the skin.
- Tiny size: nanomaterials can enter the body and pass through biological membranes – like cell walls, cell tissue, and organs – more easily than larger particles.
- Mobility: nanomaterials can move around the body in the blood stream and accumulate in organs and tissues including the brain, heart, liver, kidneys, spleen, bone marrow, and nervous system.
- Increased surface area: leads to increased reactivity and potential for toxicity, resulting in DNA mutation, structural damage within the cell, and cell death.



### Occupational Exposure: Carbon Nanotubes – the new asbestos?

Carbon nanotubes (CNTs) are thin, hollow cylinders made of carbon atoms designed and utilized for their lightweight strength. Discovered in 1991, these nanomaterials have many fascinating electronic, magnetic and mechanical properties.

- CNTs are used in tennis rackets and golf clubs, electronic goods, plastics, car parts, sporting equipment, fuel filters, the “smoke” the US military employs in Iraq and Afghanistan and other products; workers in many industries and positions may face occupational exposure.
- Preliminary studies demonstrate that some forms of CNTs can cause the development of asbestos-like responses including mesothelioma (tumors in the lining of the body cavity, lungs, heart or abdomen) and scarring of the lungs.
- Although workers in many industries may face occupational exposures to CNTs, currently there is no way to monitor the number of workers exposed to engineered nanoparticles or the level of exposure workers experience.
- While there are engineering measures that could potentially protect against occupational exposures to engineered nanoparticles, we don't know if or what extent work place facilities are using the appropriate or recommended exposure control techniques.

### Unlabeled, Untested, and On Your Shelf

Despite already being commercially available, nanoparticles in sunscreens and face creams are unlabeled and largely untested for their human health effects. However, much of the research raises red flags on nanomaterials' ability to enter the body through contact with the skin. Nanoparticles can penetrate skin, especially if the skin is flexed, such as during physical activity. Damaged skin can absorb particles 70 times larger than a nanoparticle, meaning that absorption of nanoparticles through the skin is more likely in people with eczema, acne or sunburned skin.

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Both Friends of the Earth and the Environmental Working Group have detailed lists of consumer products that contain nanoparticles. See the Resource Guide at the end of the booklet for more information.

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**Consumer Exposure: Sunscreens and face creams** – Metal oxides and carbon fullerenes are two common nanomaterials which pose significant potential human health risks.

**Nano-sized metal oxides:**

*What is it:* titanium dioxide (TiO<sub>2</sub>) and zinc oxide (ZnO)

*Use:* in sunscreens, nano-size allows for transparent or “cosmetically clear” application. Nano-TiO<sub>2</sub> is also used in food additives, water treatment and in drugs. Zinc oxide, in nano *and* conventional/bulk form, is unapproved in cosmetics in the EU due to inherent toxicity.

*Toxicity Concerns:*

- Toxic to human skin cells and cause DNA damage when exposed to UV light.
- Nano-TiO<sub>2</sub> can pass from pregnant mice to their offspring, causing functional and pathological disorders due to nerve system and genital damage.
- Nanoparticles do not even have to enter a cell to be toxic – simple contact between nano-TiO<sub>2</sub> and the cell membrane is enough to damage cell membranes in bacteria and crustaceans.
- Nano-TiO<sub>2</sub> has caused cancer in mice. The UCLA researchers that conducted the study suggest that the cancer was caused by genetic damage from the ingestion of the nano particles and warn against occupational exposure, ingesting food colors, vitamins, and drug additives and spraying sunscreens containing titanium dioxide nanoparticles.

**Carbon fullerenes or “Buckyballs”:**

*What is it:* hollow, spherical carbon molecules, essentially a spherical version of a carbon nanotube

*Use:* in face creams and moisturizers

*Toxicity Concerns:* toxic to cultured human liver cells, even at low levels of exposure, and to human lens cells, which could induce early-age cataracts.

**■ NANO AND THE ENVIRONMENT:  
A NEW FORM OF POLLUTION**

As little as we know about the health impacts of these materials, we know even less about their impacts on the environment, particularly over their lifetime. Yet, nanomaterials are already entering the environment through manufacturing, transport, use and disposal.



### Potential Impacts of Nanomaterials:

- Mobility – can reach places larger particles cannot, move with great speed through aquifers and soils, and settle slower than larger particles
- Transport – harmful chemicals could absorb or bond to active nano surfaces and be carried long distances
- Reactivity – can interact with substances in the soil and develop new and possibly toxic compounds
- Fate and persistence – once in the environment, it is unknown how long they will take to break down or change form
- Bioaccumulation – once in the body of living organisms, nanoparticles can aggregate and move up the food chain with unknown ecotoxicity

### Nanotoxicology

Toxicology assesses health risks related to exposure to a hazardous substance. However, the biological activity of nanoparticles is likely to depend on unique characteristics that are not routinely considered in toxicity screening studies.

- There are many more factors affecting the toxicological potential of nanoscale materials than the two or three factors normally analyzed, including: size, surface area, surface charge, solubility, shape or physical dimensions, surface coatings, chemical composition, and aggregation potential.
- Unfortunately, U.S. agencies are still relying on outdated testing methods instead of implementing nano-specific testing; while experts disagree about the need for this testing (in comparison to employing existing protocols), in many cases nanomaterials appear to present unique risks.

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“Fixed” or “Free”? Many nanomaterial products (such as cosmetics and sunscreens) consist of “free” or unfixed nanoparticles. Unfixed nanomaterials are loose and can easily separate from their product, speeding up their interaction in the environment.

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Despite rapid nano-commercialization, many potential risks remain untested and we lack adequate field measuring, monitoring, and control technologies.

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U.K.'s Royal Society on the release of nanomaterials into the environment: *“Until more is known about their environmental impact, we are keen that the release of nanoparticles and nanotubes in the environment be avoided as far as possible. Specifically we recommend as a precautionary measure that factories and research laboratories treat manufactured nanoparticles and nanotubes as hazardous, and seek to reduce or remove them from waste streams.”*

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## ■ NANO REGULATION: BIG HYPE, LITTLE OVERSIGHT

*With the governmental policy of “all talk, no action,” oversight has languished far behind the commercialization curve.*

*There are no nano-specific laws*

Even though they are marketed and patented for their new properties, nanomaterials are not yet considered new substances for purposes of regulation, nor is labeling required. Experts disagree as to whether it is better to work within existing regulatory frameworks, or create new, nano-specific, regulations.



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As early as 2004, the preeminent U.K.'s Royal Society and Royal Academy of Engineers concluded that nanomaterials need to be differentiated from other materials and treated as new substances “to take account of the enhanced or different properties that some nanoparticles (and nanotubes) may have compared with larger particles of the same chemical species.”

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### Voluntary programs have failed

- In January 2008, the Environmental Protection Agency (EPA) started its voluntary risk data program; after a year, only 29 companies had signed up, representing less than 10% of the unique nanomaterials EPA estimates are already commercially available. Of the 29 companies, only four agreed to do any additional nano-specific testing and those that did participate submitted very little actual data.
- The United Kingdom ran its own Voluntary Reporting Scheme (VRS) from September 2006–September 2008 and had a grand total of eleven submissions, nine from private companies and two from academia.

### Existing Regulatory Systems: Square peg, meet nano hole

- Although many U.S. laws and federal agencies deal with nanomaterials in varied ways, there is no consistent set of regulations governing nanomaterials.
  - Oversight is problematic due to outdated laws, the dearth of data, and lack of funding and focus.
- Existing regulatory norms need significant adjusting
  - Many ways we currently assess the risks and toxicity of nanoparticles are based on the properties of bulk, conventional materials that do not necessarily correspond to nanomaterials.
  - Existing metrics, assessments, and implementation mechanisms must be adjusted to address the new challenges of nanomaterials.

### Workers beware

Although Congress is *considering* the inclusion of nanomaterials in the law governing toxic and hazardous chemicals *there are currently no occupational exposure limits specifically for engineered nanomaterials*. Current standards for worker safety do not address the unique risks and behaviors of engineered nanomaterials.

### Precaution abroad, Recklessness at home

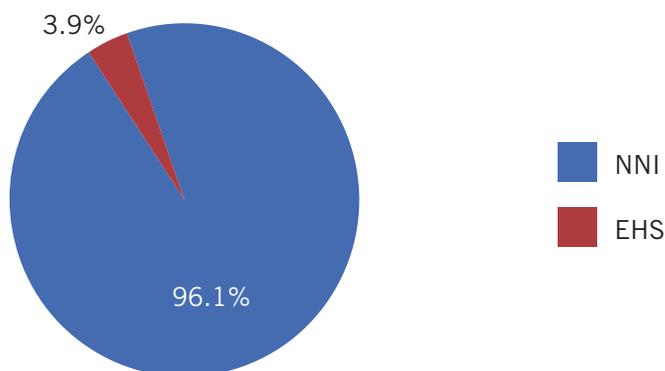
- In the EU, nano use in cosmetics and in food is receiving government attention
- In the U.S., these products reach market shelves with little testing and no labeling
- Unlike current U.S. chemical law, the EU's general chemical law (known as REACH) contains nano-specific requirements
- REACH is based on the precautionary principle and has a “no data, no market” requirement.

### Environmental, Health, and Safety (EHS) Research Funding

Despite research findings and risks, government funding for health and risk assessment remains regrettably low.

In 2005, the National Nanotechnology Initiative (NNI) first began tracking U.S. government funding for environmental, health, and safety (EHS) research. Since that time, *less than 4%* of all nanotechnology funding has been devoted to EHS research.

Environmental, Health, and Safety Funding as  
Percentage of Total NNI Funding between 2005-2010



## Section Three: Issues and Concerns

### ■ THE TINY ARMS RACE: NANO IN THE MILITARY

The U.S. government, industry, and foreign governments have invested heavily in the military applications of nanotechnology.



The U.S. Department of Defense (DoD) is interested in nanomaterials and nanotechnologies in order to create:

- Smaller, more lightweight devices
- More efficient and faster electronics and energy systems
- Stronger, more resilient materials and weapons

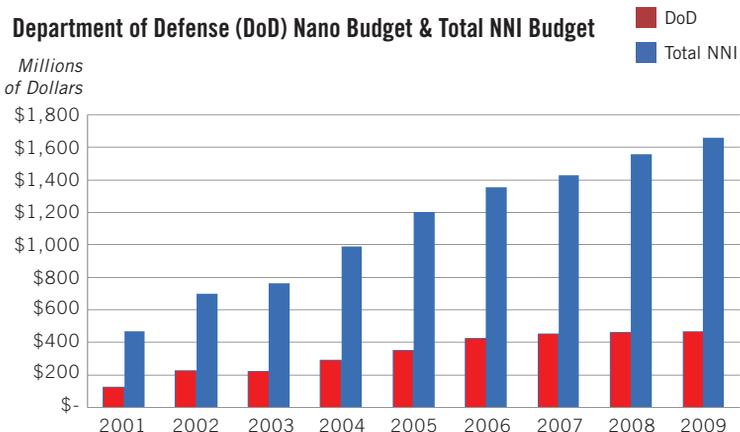
#### Program area funding

The DoD is the largest recipient of Federal funding for nano R&D. DoD funding for nanotechnology covers all major DoD departments and agencies, with an estimated 2009 “nano budget” of over \$464 million. DoD-funded R&D follows the framework of the National Nanotechnology Initiative (NNI), of which DoD is a participant.

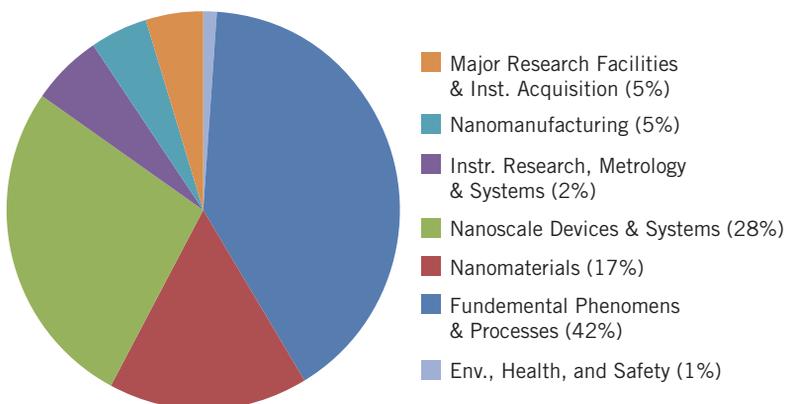
More than half of the DoD’s nanobudget is allocated to the Defense Advanced Research Projects Agency (DARPA), one of the many defense agencies that are actively developing advanced nano military technologies.

- EHS studies remain at the bottom of the funding priorities.
  - In 2009, the DoD devoted less than 1% of its total budget of \$464 million to EHS research. Furthermore, many research areas are classified, so toxicity and EHS impact data may not always be available to the public or other agencies. [See *DoD 2009 Est. Budget* below]
  - The lack of proper funding of EHS research is especially disconcerting given that many potential uses for nanomaterials involve explosives used in ballistics and weapons or remote sensors that will potentially degrade over time and release nanoparticles into the environment.
  - Therefore, it is extremely important that the U.S. military adequately fund research that examines the toxicity of nanoparticles as well as their impact on human health and the environment *before* deploying nano-enabled products.

**Department of Defense (DoD) Nano Budget & Total NNI Budget**



U.S. Department of Defense 2009 Estimated Nano Budget



## ■ NANO APPLICATIONS AT THE DOD

### Current Uses:

- Artificial smoke made with carbon nanotubes (currently being tested for combat use)
- Sensors with nanopores designed to detect water-borne toxins
- Self-decontaminating surfaces for use in military hospitals, facilities, and in the field
- Quantum dots being tested as radar deflectors

### Future Uses:

- High-strength nano-carbon fibers for use in rocket motors and airplane wings
- Liquid nano-iron solutions that become rigid using magnetic fields, creating “instant armor”
- Nano-sensory surveillance devices to track the movement of people and vehicles
- Other potential future applications include: self-replicating nano-machinery, fabrics that can react to the environment and sensors that can detect pollutants and airborne toxins

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### *Institute for Soldier Nanotechnology*

In 2002, the U.S. Army awarded the Massachusetts Institute of Technology \$50 million to establish an Institute for Soldier Nanotechnology (ISN) with the goal of increasing the protection and survivability of the U.S. soldier through the aid of nanoscience.

Staff at the ISN work in collaboration with the Army as well as industry partners like defense contractor Raytheon Co. and chemical company DuPont.

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### Weapons of Mysterious Destruction

Despite the numerous promises made by government officials and industry, the many uncertainties surrounding the use of nanotechnology in the military are rarely mentioned but could vastly outweigh the potential benefits.

**Lack of Adequate Public Transparency** – At present, many of the nanotechnologies already being used by the military have been documented to potentially cause harm to human health or the environment. Despite outcries from civil society organizations, increases in funding of military development of nano applications have continued unconstrained by increases in EHS funding. Additionally, there is little discussion on the ethical and social concerns of furthering novel military technology – for example, replacing human soldiers with an autonomous nano-robotic army – without adequate input from the public.

**From the front lines to our phone lines** – Military nanodevices may forever transform how the U.S. military conducts domestic and foreign surveillance. However, there is little being done to assure the public that surveillance devices in development will not further intensify concerns about personal privacy and freedoms, similar to the ongoing controversy over warrantless wiretapping .

**Escalating Tiny Arms Race** – The surge in nano R&D over the past decade and the current plans for nanotechnology have a prophetic similarity to the development of chemical weapons, atomic weapons, and biological agents. The development of advanced nano-weapons in the U.S. will in due course lead to nano proliferation abroad and cause an escalating “tiny arms” race between global military powers.

### ■ NANO AND CLIMATE CHANGE

Global climate change is the greatest threat facing our planet and may be the greatest challenge facing both current and future generations. The difficulty in addressing the moral implications of the environmental, human health and economic consequences of climate change is exemplified by the use of nanomaterials.



Nanotechnology has been hyped as panacea to “solve” climate change by aiding in the engineering our world in an attempt to adjust to the unsuitable environment we have created rather than making meaningful reductions in greenhouse gas emissions and curbing the consumptive behavior of society as a whole.

### Nanotechnology's role in the climate change discussion is two-fold.

1. Mitigation: nanotechnology as tool in geo-engineering schemes to reduce climate change by sequestering or capturing greenhouse gas emissions through biological, chemical, or physical processes.
2. Adaptation: “green” technologies implementing nanotechnology in their search toward methods for producing “clean” energy.

### What is Geo-engineering?

The intentional large-scale manipulation of the environment, geo-engineering uses novel technologies to mitigate climate change impacts. These schemes are considered to be quick-fix climate change solutions, yet most have the potential to cause significant – and perhaps devastating – environmental damage, including the

release of additional greenhouse gases into the atmosphere. While some forms of geo-engineering may prove useful, they should not be allowed to undermine attempts to address the *real* problem – and they could have adverse environmental effects of their own.

### Geo-engineering Case Study: Ocean Fertilization with Nanoscale Iron

*What it is:* Depositing massive quantities of nano-iron into the ocean

*Why:* Iron stimulates growth of phytoplankton, like algae, to encourage carbon sequestration and deep-sea carbon storage.

*Potential environmental impacts:* Increased greenhouse gases, like methane and nitrous oxide (around 20 and 300 times more potent than carbon dioxide, respectively); toxic plankton blooms; and other unforeseen impacts on ocean ecosystems.

*Feasibility:* Largely discredited by the scientific community as a meaningful climate solution.

*Current situation:* In May 2008, at the UN Convention on Biodiversity, 191 countries agreed to a moratorium on commercial ocean CO<sub>2</sub> sequestration, the first-ever global decision on a geo-engineering technology. Unfortunately, experiments continue to be attempted in violation of the agreement.

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The Inter-Governmental Panel on Climate Change has stated that geo-engineering projects like ocean fertilization “are likely to be ineffective, expensive to sustain and/or to have serious environmental and other effects that are in many cases poorly understood.”

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### “Clean” Energy Technology

Nanotechnology is a component in many “clean” energy technologies such as carbon capture and sequestration, advanced automotive batteries and fuel cells, wind power and solar energy. Proponents suggest that nanotechnology may have the ability to improve the efficiency and availability of “clean” energy technologies. However, many of these technologies are still years away from affordable and widespread commercialization and a growing body of research suggests that environmental costs of production may outweigh environmental gains from certain nanomaterials. Before commercialization occurs, the energy costs must be determined and the environmental and health risks assessed across the entire life cycle of the product.

### Solar Energy

Nanotechnology could reduce production costs and increase manufacturing efficiency.

*Caveats:*

- *Ecotoxicity:* Studies show that nano-sized titanium dioxide, silver, cadmium, carbon nanotubes, and quantum dots (all used in solar energy development) are uniquely hazardous to human and environmental health.
- *Energy and water intensive processes:* There is no life cycle assessment of nanotechnology in solar energy products; therefore it is still unknown how energy and resource intensive the process is overall, especially in the nanomaterial manufacturing stage.

## ■ NANOTECHNOLOGY IN THE FUTURE: THE CASE FOR HEALTH, DEMOCRACY AND ENVIRONMENTAL JUSTICE

Nano advocates would have us believe that nanotechnology will solve all of the problems that have eluded human solutions for centuries. In the long term, some of the new nanotechnologies may prove themselves capable of making significant contributions to medicine, energy efficiency, or renewable energy. However, in the short term, current regulations are simply not up to the challenge posed by the possible EHS concerns that arise from nanomaterials.

A coalition of some 80 environmental, health, and science policy NGOs from six continents has developed eight fundamental principles for the oversight of nanotechnologies and nanomaterials.<sup>1</sup> These principles should be implemented BEFORE any new technology – including nanotechnology – is marketed.

- I. **A Precautionary Foundation:** Product manufacturers and distributors must bear the burden of proof to demonstrate the safety of their products: if there is no independent health and safety data review, then there should be no market approval.
- II. **Mandatory Nano-specific Regulations:** Nanomaterials should be classified as new substances and subject to nano-specific oversight. Voluntary initiatives are not sufficient.
- III **Health and Safety of the Public and Workers:** The prevention of exposure to nanomaterials that have not been proven safe must be undertaken to protect the public and workers.
- IV. **Environmental Protection:** A full lifecycle analysis of environmental impacts must be completed prior to commercialization.
- V. **Transparency:** All nano-products must be labeled and safety data made publicly available.
- VI. **Public Participation:** There must be open, meaningful, and full public participation at every level.
- VII. **Inclusion of Broader Impacts:** Nanotechnology's wide-ranging effects, including ethical and social impacts, must be considered.
- VIII. **Manufacturer Liability:** Nano-industries must be accountable for liabilities incurred from their products.

If nanotechnologies continue to be developed and allowed on the market without the kind of oversight envisioned by the Principles, then consumers, workers, and future generations will bear the health, environmental, and economic costs of nanotechnologies, but few of their benefits. We must be forward-thinking to ensure that short-term solutions do not carry with them long-term problems.

*NanoAction* is a project of the International Center for Technology Assessment, a non-profit, bi-partisan organization committed to providing the public with independent, timely, and comprehensive assessments and analyses of technological impacts on society and the environment.

## NANO EXPOSED: A CITIZEN'S GUIDE TO NANOTECHNOLOGY RESOURCE GUIDE

- **ETC Group**  
<http://www.etcgroup.org/en/issues/nanotechnology>  
Contains an assortment of publications and other materials on nanotechnology and its impacts on society.
- **Friends of the Earth**  
<http://www.foe.org/healthy-people/nanotechnology-campaign>  
*Reports:*  
Manufactured Nanomaterials and Sunscreens: Top Reasons for Precaution  
Nanomaterials, Sunscreens and Cosmetics: Small Ingredients, Big Risks  
A Consumer Guide for Avoiding Nano-Sunscreens
- **Friends of the Earth – Australia**  
<http://nano.foe.org.au/>
- **Campaign for Safe Cosmetics**  
<http://www.safecosmetics.org/>
- **Transatlantic Consumer Dialogue Conference on Nanotechnology**  
[http://tacd.org/index.php?option=com\\_content&task=view&id=47&Itemid=129](http://tacd.org/index.php?option=com_content&task=view&id=47&Itemid=129)  
This conference brought together consumer groups, government officials, environmental groups, and industry groups from both sides of the Atlantic to explore issues related to the regulation of nanomaterials.
- **The Woodrow Wilson International Center for Scholars Project on Emerging Nanotechnologies**  
Includes numerous reports and a searchable consumer product database.  
<http://www.nanotechproject.org/inventories/>
- **BEUC: The European Consumer's Organization** <http://www.beuc.org/Content/Default.asp>
- **ANEC: The European consumer voice in standardization** <http://www.anec.org/anec.asp>  
ANEC/BEUC Joint Nano-Product Inventory [www.anec.org/attachments/ANEC-PT-2009-Nano-015.xls](http://www.anec.org/attachments/ANEC-PT-2009-Nano-015.xls)
- **Hazards Magazine-Special Issue on Nanotechnology**  
This special issue of this UK publication contains an extensive review of safety and health issues related to nanotechnologies.
- **The Royal Society--Royal Academy of Engineering**  
Seminal 2004 report outlining the risks of nanotechnology.
- **Environmental Working Group**  
Information on consumer products containing nanomaterials  
<http://www.ewg.org/bodyburden/consumerproducts>  
<http://www.ewg.org/node/26564>
- **National Nanotechnology Initiative**  
The U.S. government's official nanotechnology coordinating office.
- **The U.S. Food and Drug Administration**  
The FDA's nanotechnology policy page.
- **The Center on Nanotechnology and Society**  
Interdisciplinary center on the societal implications of nanotechnology with a special emphasis on the human condition  
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- Anderson, A., Gajjar, P., Britt, D., Huang, W., Johnson, W. 2009. Metal-containing nanoparticles: Effects on beneficial soil pseudomonad. Abstract and results presented at the American Chemical Society National Meeting 24 March 2009.
- Benn, T and P. Westerhoff. 2008. Nanoparticle Silver Released into Water from Commercially Available Sock Fabrics. *Environmental Science and Technology* 42 (11), 4133-4139.
- Blain, S. et al. 2007. Effect of Natural Iron Fertilization on Carbon Sequestration in the Southern Ocean *Nature* 446, 1070-1074 (26 April 2007) doi:10.1038/nature05700.
- Dawson, K. et al. 2009. Nanoparticles reconstruct lipids. *Nature Nanotechnology* 4.
- Donaldson K, Beswick P, Gilmour P. 1996. Free radical activity associated with the surface of particles: a unifying factor in determining biological activity? *Toxicol Lett* 88:293-298.
- Dunford R, Salinaro A, Cai L, Serpone N, Horikoshi S, Hidaka H, Knowland J. 1997. Chemical oxidation and DNA damage catalysed by inorganic sunscreen ingredients. *FEBS Lett* 418:87-90
- Folkman, J. et al. 2009. Oxidatively damaged DNA in rats exposed by oral gavage to C60 fullerenes and single-walled carbon nanotubes. *Environmental Health Perspectives* 117 (5).
- Heinlaan, M., Ivask, A., Blinova, I., Dubourguier, H., Kahru, A. 2008. Toxicity of nanosized and bulk ZnO, CuO, and TiO<sub>2</sub> to bacteria *Vibrio fischeri* and crustaceans *Daphnia magna* and *Thamnocephalus platyurus*. *Chemosphere* 71, 1308-1316.
- Helmut Kaiser Consulting. Nanotechnology Food Conference. Available at: <http://www.hkc22.com/Nanofoodconference.html>
- Innovative Research and Products, Inc. Nano-Enabled Packaging for the Food and Beverage Industry—A Global Technology, Industry and Market Analysis July 2009, p 107 Summary available at: [http://www.innoresearch.net/report\\_summary.aspx?id=68&pg=107&rcd=FT-102&pd=71/2009](http://www.innoresearch.net/report_summary.aspx?id=68&pg=107&rcd=FT-102&pd=71/2009)
- Inter-Governmental Panel on Climate Change, Summary for Policy Makers: Scientific-Technical Analyses of Impacts, Adaptations, and Mitigation of Climate Change, available at <http://www.ipcc.ch/pub/sarsum2.htm>
- Institute of Food Technologists. "Nanotechnology" Information Statement, 2006. Available at: <http://www.ifst.org/uploadedfiles/cms/store/ATTACHMENTS/Nanotechnology.pdf>
- King-Heiden, T., Wicinski, P., Mangham, A., Metz, K., Nesbit, D., Pedersen, J., Hamers, R., Heideman, W., Peterson, R. 2008. Quantum Dot Nanotoxicity Assessment Using the Zebrafish Embryo. *Environmental Science and Technology* Article ASAP, accepted December 3, 2008, published January 14, 2009.
- Long T, Saleh N, Tilton R, Lowry G, Veronesi B. 2006. Titanium dioxide (P25) produces reactive oxygen species in immortalized brain microglia (BV2): Implications for nanoparticle neurotoxicity. *Environ Sci Technol* 40(14):4346-4352.
- Mahendra, S., Zhu, H., Colvin, V., Alvarez, P. 2008. Quantum Dot Weathering Results in Microbial Toxicity. *Environmental Science and Technology* 42 (24) 9424-9439.
- Monteiro-Riviere N. 2007. Effects of mechanical flexion on the penetration of fullerene amino acid derivatized peptide nanoparticles through skin. *Nano Lett* 7(1):155-160.

- Monteiro-Riviere N. et al. 2006. Skin penetration of fullerene substituted amino acids and their interactions with human epidermal keratinocytes. *Toxicol* 168 (#827).
- Mortensen L, Oberdörster G, Pentland A, DeLouise L. 2008. In Vivo Skin Penetration of Quantum Dot Nanoparticles in the Murine Model: The Effect of UVR. *Nano Lett* 8(9):2779-2787
- Nanomaterials, sunscreens and cosmetics: Small ingredients, big risks. *Friends of the Earth - Australia and Friends of the Earth - US*. May 2006.
- Nel A, Xia T, Li N. 2006. Toxic potential of materials at the nanolevel. *Science* 311:622-627
- Nygaard, U., Hansen, J., Samuelsen, M., Alberg, T., Marioara, C., Lovik, M. 2009. Single-walled and Multi-walled Carbon Nanotubes Promote Allergic Immune Response in Mice. *Toxicological Science* Advanced Access Published March 17, 2009.
- Oberdörster G. et al 2005. Nanotoxicology: an emerging discipline from studies of ultrafine particles. *Environ Health Perspect* 113(7):823-839.
- Ocean Fertilization 'Fix' For Global Warming Discredited By New Research. *ScienceDaily*. Retrieved July 29, 2009, available: <http://www.sciencedaily.com/releases/2007/11/071129132753.htm>
- Pegg, JR. Experts Urge Major US Investments in Carbon Storage Technology. Environment News Service 8 November 2007. available: <http://www.ens-newswire.com/ens/nov2007/2007-11-08-10.asp>
- Poland, C., Duffin, R., Kinloch, I., Maynard, A., Wallace, W., Seaton, A., Stone, V., Brown, S., MacNee, W., Donaldson, K. 2008. Carbon nanotubes introduced into the abdominal cavity of mice show asbestos-like pathogenicity in a pilot study. *Nature Nanotechnology* 3, 423-428. see also: Preliminary results available at: CDC NIOSH Science Blog: [http://www.cdc.gov/niosh/blog/nsb031909\\_mwcnt.html](http://www.cdc.gov/niosh/blog/nsb031909_mwcnt.html)
- Roberts, J., Wielgos, A., Boyes, W., Andley, U., Chignell, C. 2008. Phototoxicity and cytotoxicity of fullerol in human lens epithelial cells. *Toxicology and Applied Pharmacology* 228: 49-58
- Robock, A. 2008. 20 Reasons Why Geoengineering may be a Bad Idea. *Bulletin of the Atomic Scientists* 64 (2): 14-18.
- Robock, A. et al 2009. Benefits, Risks, and Costs of Stratospheric Geoengineering. Submitted for publication in *Geophysical Research Letters* May 2009. available: <http://envsci.rutgers.edu/~benkravitz/research/papers/GRLreview3.pdf>
- Rouse J. et al. 2007. Effects of mechanical flexion on the penetration of fullerene amino acid derivatized peptide nanoparticles through skin. *Nano Lett* 7(1):155-160.
- Ryman-Rasmussen J. et al. 2006. Penetration of intact skin by quantum dots with diverse physicochemical properties. *Toxicol Sci* 91(1):159-165. Salmen R, DePree K, Adkins E. 2003. Skin as a route of exposure and sensitisation in chronic beryllium disease, *Environ Health Perspect* 111:1202-1208.
- Salonen, E., Lin, S., Reid, M.L., Allegood, M., Wang, X., Rao, A.M., Vattulainen, I., & Ke, P.C. 2008. **Real-Time Translocation of Fullerene Reveals Cell Contraction**, *Small* 4 (11) : 1986 – 1992
- Sayes, C., Gobin, A., Ausman, K., Mendez, J., West, J., Colivin, V. 2005. Nano-C60 cytotoxicity is due to lipid peroxidation. *Biomaterials* 26: 7587-7595.
- Sayes C, Wahi R, Kurian P, Liu Y, West J, Ausman K, Warheit D, Colvin V. 2006. Correlating nanoscale titania structure with toxicity: A cytotoxicity and inflammatory response study with human dermal fibroblasts and human lung epithelial cells. *Toxicol Sci* 92(1):174–185.
- Schiermeier, Q. 2009. Ocean Fertilization Experiment Draws Fire. *Nature News* 9 January 2009
- Schiermeier, Q. 2007. Only Mother Nature Knows How to Fertilize the Ocean, *Nature* 23 April 2007 doi:10.1038/news070423-8;
- Schiestl, R., et al. 2009. Titanium dioxide nanoparticles induce DNA damage and genetic instability in vivo in mice. *Cancer Research* 69 (22) 8784-9.
- Scott-Fordsmand, J., Krogh, P., Shaefer, M., Johansen, A. 2008. The toxicity testing of double-walled nanotubes-contaminated food to *Eisenia veneta* earthworms. *Ecotoxicology and Environmental Safety* 71, 616-619.
- Senjen, R. 2009. European Environmental Bureau. *Nanotechnologies in the 21st Century: Challenges and Opportunities to Green Nanotechnologies* Issue 1, April.
- Song, Y., Li, X., Du, X. 2009. Exposure to nanoparticles is related to pleural effusion, pulmonary fibrosis and granuloma. *European Respiratory Journal* 34: 559 – 567.
- Takagi, A. et al. 2008. Induction of mesothelioma in p53+/- mouse by intraperitoneal application of multi-wall carbon nanotube. *Journal of Toxicological Science* 33 (1): 105-116.
- Takeda, K., Suzuki, K., Ishihara, A., Kubo-Irie, M., Fujimoto, R., Tabata, M., Oshio, S., Nihei, Y., Ihara, T., Sugamata, M. 2009. Nanoparticles Transferred from Pregnant Mice to Their Offspring Can Damage the Genital and Cranial Nerve Systems. *Journal of Health Science*, 55(5) 95-102.
- Tinkle S, Antonini J, Roberts J, Brunner T, Piusmanser P, Spohn P, Grass R, Limbach L, Bruinink A, Stark W. 2006. In Vitro Cytotoxicity of Oxide Nanoparticles: Comparison to Asbestos, Silica, and the Effect of Particle Solubility. *Environ Sci Technol* 40:4374-4381.
- Tinkle S. et al 2003. Skin as a route of exposure and sensitisation in chronic beryllium disease, *Environ Health Perspect* 111:1202-1208.
- Warburton, N. 2005. Food in the 21st Century, *Environmental Health Practitioner* August : 8. Available at: [http://www.cieh.org/ehp/food\\_in\\_the\\_21st\\_century.html](http://www.cieh.org/ehp/food_in_the_21st_century.html)
- Tollefson, J. 2008. U.N. Decision Puts Brakes on Ocean Fertilization *Nature News* 453 (704).
- Yang, W., Shen, C., Ji, Q., An, H., Wang, J., Liu, Q., Zhang, Z. 2009. Food storage material silver nanoparticles interfere with DNA replication fidelity and bind with DNA. *Nanotechnology* 20.

## (ENDNOTES)

- 1 See Nanoaction.org for a complete discussion of the Principles.

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