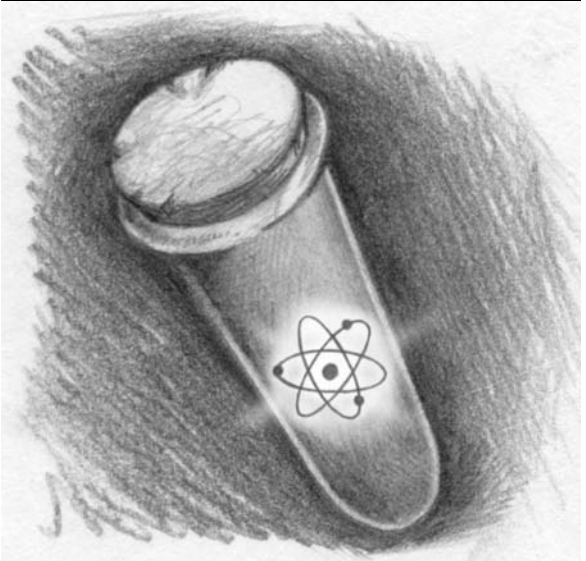


**A TINY PRIMER  
ON  
NANO-SCALE TECHNOLOGIES  
AND “THE LITTLE BANG THEORY”**



**June 2005**

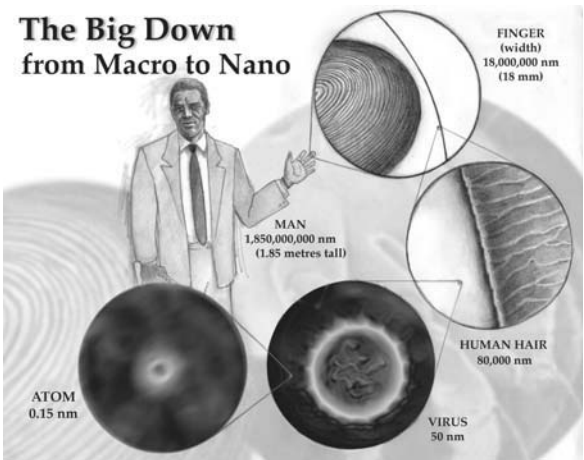
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Reymond Pagé. Nanotube on p. 12 from [http://  
www.ncnr.nist.gov/staff/taner/nanotube/types.html](http://www.ncnr.nist.gov/staff/taner/nanotube/types.html)  
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# A TINY PRIMER ON NANO-SCALE TECHNOLOGIES ... AND “THE LITTLE BANG THEORY”

## WHAT IS NANOTECHNOLOGY?

Nano-scale technology is a suite of techniques used to manipulate matter at the scale of atoms and molecules. “Nano” is a measurement – not an object. Unlike “biotechnology,” where you know that *bios* (life) is being manipulated, “nanotechnology” speaks solely to scale. A “nanometre” (nm) equals one billionth of a metre. One human hair is about 80,000 nanometres thick. It takes ten atoms of hydrogen side-by-side to equal one nanometre. A DNA molecule is about 2.5 nm wide. A red blood cell is vast in comparison: about 5,000 nm in diameter. Everything on the nano-scale is invisible to the unaided eye and even to all but the most powerful microscopes.

Key to understanding the unique power and potential of nanotech is that, at the nano-scale (below about 100 nanometres), a material’s properties can change dramatically – these unexpected changes are called “quantum effects.” With only a reduction in size and no change in substance, materials can exhibit new properties such as electrical conductivity, elasticity, greater strength, different colour and greater reactivity –



characteristics that the very same substances do not exhibit at the micro or macro scales. For example:

- Carbon in the form of graphite (like pencil lead) is soft and malleable; at the nano-scale carbon can be stronger than steel and is six times lighter.
- Zinc oxide is usually white and opaque; at the nano-scale it becomes transparent.
- Aluminum – the material of soft drink cans – can spontaneously combust at the nano-scale and could be used in rocket fuel.<sup>1</sup>

Scientists are exploiting property changes at the nano-scale to create new materials and modify existing ones. Companies are now manufacturing nanoparticles (i.e., chemical elements or compounds less than 100 nm in size) that are used in hundreds of commercial products.

## **TINY TECH'S POTENTIAL IMPACTS ON THE WORLD ECONOMY ARE TITANIC**

**1. *Quantum changes:*** At the nano-scale, where the laws of quantum physics reign, ordinary substances can exhibit new properties, like extraordinary strength, colour changes, increased chemical reactivity or electrical conductivity – characteristics that the very same substances do not exhibit at larger scales. New designer materials mean multiple raw material options for industrial manufacturers and the potential to turn traditional commodity markets upside-down.

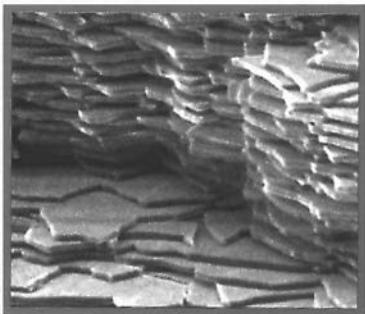
**2. *Quantity changes:*** Nanotech makes possible “bottom-up” manufacturing. Atoms and molecules are the building blocks of everything, from corn to cars to condos. By employing nanotech to build from the bottom up rather than processing down, the *quantity* of raw materials required could be sharply reduced.

**3. *Quality changes:*** The merging of living and non-living matter at the nano-scale, together with bottom-up assembly means new platforms for industrial manufacturing that could make geography, raw materials, and even labour, irrelevant.

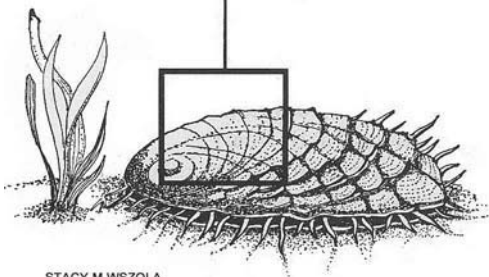
*Our thirty-year goal is to have such exquisite control over the genetics of living systems that instead of growing a tree, cutting it down, and building a table out of it, we will ultimately be able to grow the table.*

– Rodney Brooks, director of Artificial Intelligence Laboratory, MIT

Nanotech’s “raw materials” are the chemical elements of the Periodic Table – the building blocks of *everything* – both living and non-living. Nanotech tools and processes can be applied to virtually any manufactured good across all industry sectors, and that’s why the US National Science Foundation (NSF) predicts that nanotech will capture a \$1 trillion market by 2011 or 2012.<sup>2</sup> Researchers are employing nanotech to make faster computers; cell-specific drugs; powerful new chemical catalysts (used in the processing of petroleum); sensors monitoring everything from crops to crooks to customers; stronger, lighter, smarter, more durable materials, etc. Nano-scale technologies are poised to become the strategic platform for global control of manufacturing, food, agriculture and health in the immediate years ahead.



*The layers of an abalone shell, as seen through a scanning tunneling microscope. The nanostructured calcium carbonate — the same chemical compound as chalk — is nearly impenetrable.*



## WHAT DOES THE NANO-WAVE MEAN FOR THE SOUTH?

**Making waves:** “Nano” looms as the highest, widest technology wave ever encountered. Its accompanying turbulence has breathtaking societal implications, especially in the South. Nanotech’s new designer materials have the potential to topple commodity markets, disrupt trade and the livelihoods of the poorest and most vulnerable workers who do not have the economic flexibility to respond to sudden demands for new skills or different raw materials.

A 2004 report by industry analysts, Lux Research, Inc., highlights the potential of nanotech to “ultimately displace market shares, supply chains, and jobs in nearly every industry.” If a new nanoengineered material outperforms a conventional material and can be produced at low cost, we can expect the nanomaterial to replace the conventional commodity. For example, the US National Aeronautics and Space Administration (NASA) is investing \$11 million dollars to develop “quantum wires” made from carbon nanotubes as a replacement for traditional copper wires.<sup>3</sup> Though it’s too early to map with confidence which commodities or workers will be affected and how quickly, nations that are most dependent on agricultural and natural resource exports will face the greatest disruptions.

*“Just as the British Industrial Revolution knocked handspinners and handweavers out of business, nanotechnology will disrupt a slew of multi-billion dollar companies and industries.”*

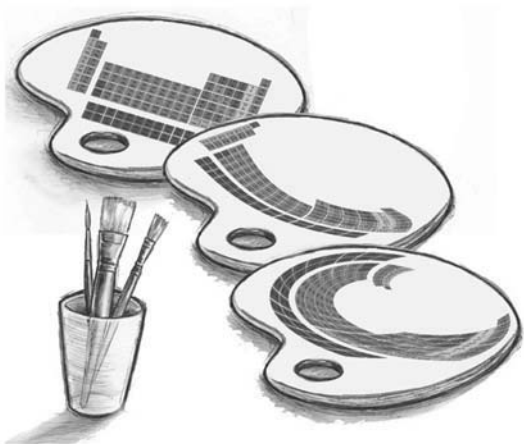
– Lux Research, Inc. *The Nanotech Report 2004*

Some predict that nanotech will trigger an economic and cultural utopia combining material abundance, sustainable development and profit. The history of technology waves suggests otherwise: major new technologies, at least initially, destabilize marginalized peoples while the wealthy anticipate, manipulate and ride the wave’s crest. They have the economic flexibility to remain buoyant while those who are already floundering get washed away along with the obsolete economy.

**Take Rubber:** Industry is designing nanoparticles to strengthen and extend the life of automobile tires and creating new nanomaterials that could substitute for natural rubber. Demand for natural rubber could plummet with devastating consequences for millions of small rubber tappers and the national economies of Thailand, India, Malaysia and Indonesia. The point is not that the *status quo* should be preserved – but that society is ill-prepared.

**Consider Cotton:** Natural fibres like cotton, and the farmers who grow them, are also vulnerable. One product in the pipeline is a synthetic fibre manipulated at the nano-scale that has the same texture as cotton – but is much stronger. What will nanotech's fibres mean for the 100 million families engaged in cotton production worldwide? The value of world cotton production was US\$24 billion in 2003; 35 of the 54 African countries produce cotton – 22 are exporters.

**Wrong Wavelength?** In a just and judicious context, nanotech could bring useful benefits to the poor. There could also be environmental gains from replacing some conventional materials with new nanomaterials. But in a world where privatization of science and unprecedented corporate concentration prevail, democracy and human rights are being eroded and national sovereignty is undermined. The grab for patents on nano-scale



*Researchers seek to exploit the Periodic Table of Elements in the way that a painter uses a palette of pigments. The goal is to create new materials and modify existing ones.*

*“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.”*

– Carlota Perez, Visiting Senior Research fellow, Cambridge University, writing on technology revolutions

products and processes could mean mega-monopolies on the basic elements that are the building blocks of the entire natural world. If current trends continue, nano-scale technologies will further concentrate economic power in the hands of multinational corporations. How likely is it that the poor will benefit from a technology that is outside their control?

**Who's involved?** Investment in nanotechnology around the world – by both the private and public sectors – was an estimated \$8.6 billion (US) dollars in 2004. 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 approaching one billion dollars per year, making it the biggest publicly-funded science endeavour since the Apollo moon shot.<sup>4</sup> (In 2004, the Department of Defense received the bulk of the US government's money earmarked for nanotech.) At least 35 countries have some kind of national nanotech research programme. According to one industry observer, there are more scientists working on nanotech in the Beijing area than in all of Western Europe – at one-twentieth the cost.

## **WHO'S IN CONTROL?**

Remember that almost as soon as scientists figured out how to *manipulate* life through genetic engineering, corporations figured out how to *monopolize* it. A dangerous precedent was set back in the 1960s when a Nobel Prize-winning physicist “invented” the chemical





element *Americium* (element no. 95 on the periodic table) and acquired US patent #3,156,523. In the US alone, patents awarded annually on nano-scale products and processes have tripled since 1996.<sup>5</sup> The current nanotech patent grab is reminiscent of the early days of biotech – “it’s like biotech on steroids” in the words of one patent attorney.<sup>6</sup> At stake is control over nano-scale building blocks and tools that span all industry sectors – from electronics, energy, mining and defense to new materials, pharmaceuticals and agriculture. As the *Wall St. Journal* put it, “companies that hold pioneering patents could potentially put up tolls on entire industries.”<sup>7</sup>

*“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<sup>8</sup>

*“What is claimed is Element 95.”*

– from Glenn Seaborg’s US patent 3,156,523, issued November 10, 1964 – the shortest patent claim on record

## WHAT ARE CONVERGING TECHNOLOGIES AND HOW DO THEY ADD UP TO BANG?

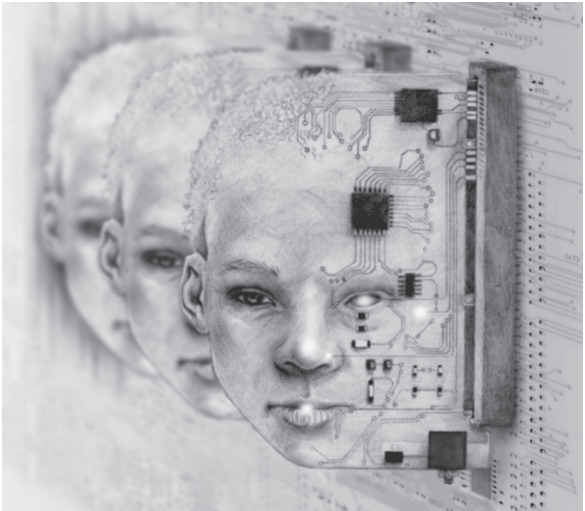
The real power of nano-scale science is the *convergence* of diverse technologies – including biotechnology, cognitive sciences, informatics, robotics, etc., with nanotechnology as the key enabler. The logic behind technological convergence lies in the fact that the building blocks of all matter, fundamental to all sciences, originate at the nano-scale.<sup>9</sup>

Scientists and governments in the US and Europe have a strategy to merge the sciences based on “material unity at the nano-scale.”<sup>10</sup> 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. According to this 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!** ETC Group uses the term “BANG” to describe convergence. **Bits**, **Atoms**, **Neurons** and **Genes** add up to a little **BANG** theory – the technological quest to control all matter, life and knowledge.

<b>Information technology</b>	controls	<b>Bits</b>
<b>Nanotechnology</b>	controls and manipulates	<b>Atoms</b>
<b>Cognitive Neurosciences</b>	enables control of the mind by manipulating	<b>Neurons</b>
<b>Biotechnology</b>	manipulates	<b>Genes</b>

According to the little BANG theory, neurons will 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.

If realized, the US government’s goal of enhancing human performance will exacerbate the 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 won’t be cheap or equitably distributed. What will happen to the unimproved? Will physical enhancement become a social imperative as well as an enforceable, legal one? In 2004, for example, a US court ruled that prison officials were allowed to forcibly medicate a death row inmate to make him sane enough to execute.<sup>11</sup> In a world where human “enhancement” becomes a technological imperative, the rights of the disabled will be further eroded and disability will be perceived as a technological challenge rather than an issue of social justice. How long before democratic dissent is viewed as a correctable “impairment” as well?

*“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)<sup>12</sup>

## **WHAT IS LIFE IN THE AGE OF NANOTECH?**

Synthetic biology refers to the construction of new living systems in the laboratory that can be programmed to perform specific tasks. The programming and functioning of “living machines” frequently involves the integration of living and non-living parts at the nano-scale – also known as *nanobiotechnology*.

**Get a Life:** Nanobiotechnologists aim to harness nature’s self-replicating “manufacturing platform” for industrial uses. Today, researchers are building biological machines – or hybrid machines employing both biological and non-biological 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.

- Researchers are using proteins from spinach chloroplasts to create electronic circuits – resulting in the world’s first solid-state photosynthetic solar cell.<sup>13</sup>
- Engineer Carlo Montemagno has created a device, less than a millimetre long, made from rat heart cells combined with silicon.<sup>14</sup> Muscle tissue growing on the device’s “robotic skeleton” allows it to move, and researchers believe it could someday power computer chips. Montemagno describes his creations as “absolutely alive...the cells actually grow, multiply and assemble – they form the structure themselves.”<sup>15</sup>
- Material scientists have genetically engineered the DNA of viruses and induced them to grow tiny

inorganic wires that may someday provide circuitry in high-speed electronic components.<sup>16</sup>

- With funding from the US Department of Energy, Craig Venter's Institute for Biological Energy Alternatives is building a new type of bacterium using DNA manufactured in the laboratory. His goal is to build synthetic organisms that can be programmed to produce hydrogen or be used in the environment to sequester carbon dioxide.<sup>17</sup>

In the wake of startling advances in the field of synthetic biology, the potential "for abuse or inadvertent disaster" is enormous.<sup>18</sup> In January 2005 scientists unveiled a new, automated technique that makes it faster and easier to synthesise long molecules of DNA.<sup>19</sup> But researchers warn that this revolutionary advance for synthesising DNA will also permit the rapid synthesis of any small genome, including the smallpox virus or other dangerous pathogens that could be used for bioterrorism.

*"If biologists are indeed on the threshold of synthesizing new life forms, the scope for abuse or inadvertent disaster could be huge."*

– Philip Ball, *Nature*, October 7, 2004.

**Green Goo:** Human intervention aims to create new living systems that are more powerful: the emboldened



*Governments have failed to adopt regulations that address the unique properties of nano-scale materials.*

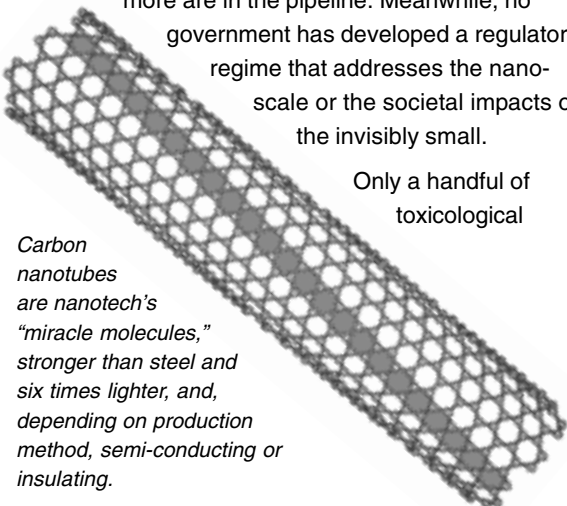
*E. coli* bacteria will now take on oil spills; the nanobio polymer car door can use embedded proteins to repair itself after a collision. Plants too tough for bugs to bite? Fire-retardant fur? The possibilities are endless. The plan, of course, is that these new creations would be strictly controlled by their creators. But what if nanobio's new life forms, especially those that are designed to function autonomously in the environment, prove difficult to control or contain? While "Grey Goo" has grabbed the headlines in the media (where self-replicating nano-scale mechanical robots escape control until they wreak havoc on the global ecosystem), the more likely future threat 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. That's the spectre of Green Goo.

## **WHAT DOES NANOTECH MEAN FOR HUMAN HEALTH, SAFETY AND THE ENVIRONMENT?**

**Unknown and Unpredictable:** Governments, industry and scientific institutions have allowed nanotech products to come to market in the absence of public debate and regulatory oversight. An estimated 475 products containing invisible, unregulated and unlabeled nano-scale particles are already commercially available<sup>20</sup> (including food products, pesticides, cosmetics, sunscreens and more) – and thousands more are in the pipeline. Meanwhile, no

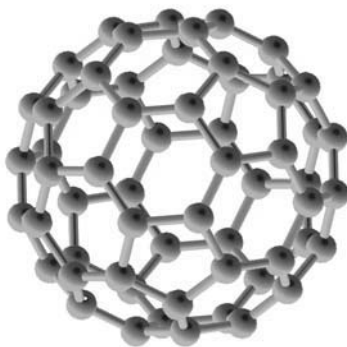
government has developed a regulatory regime that addresses the nano-scale or the societal impacts of the invisibly small.

Only a handful of toxicological



*Carbon nanotubes are nanotech's "miracle molecules," stronger than steel and six times lighter, and, depending on production method, semi-conducting or insulating.*

*Buckyballs are hollow nano-spheres of pure carbon. The Washington Post dubbed them “unluckyballs” after new findings revealed they may be harmful to the environment.*

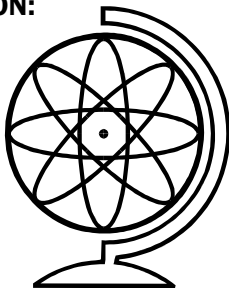


studies exist on engineered nanoparticles, but it appears that nanoparticles as a class are more toxic than larger versions of the same compound because of their mobility and increased reactivity.<sup>21</sup> This raises serious health concerns because nanoparticles can slip past guardians of the body’s immune system, across protective membranes such as skin, the blood brain barrier or perhaps the placenta. Recent toxicological studies on environmental and health impacts of nanoparticles raise red flags:

- A study published in July 2004 found that nano-scale molecules of carbon (a type known as buckyballs) can cause rapid onset of brain damage in fish.<sup>22</sup>
- In 2005 researchers at the US National Aeronautic and Space Administration (NASA) reported that when commercially available carbon nanotubes were injected into the lungs of rats it caused significant lung damage.<sup>23</sup> (The researchers indicated that the nanotube dosage applied to rats was roughly equivalent to worker exposure levels over a 17-day period.) In a separate study, researchers at the US National Institute of Occupational Safety and Health reported in 2005 substantial DNA damage in the heart and aortic artery of mice that were exposed to carbon nanotubes.<sup>24</sup>
- In 2005 University of Rochester (USA) researchers showed that rabbits inhaling buckyballs demonstrated an increased susceptibility to blood clotting.<sup>25</sup>

## **NANOTECH'S BIG LESSON: SIZE MATTERS!**

- Below 100 nanometres quantum physics transforms the properties of common elements and compounds. Properties such as strength, elasticity, conductivity, and colour can change – and keep changing – the smaller things get.



- Nanoparticles demonstrate different toxicity from larger versions of the same substance. That's a concern because nanoparticles can move easily into the body and slip past the body's immune system. At 70 nanometres, nanoparticles can burrow deep into lung tissue; a 50 nm particle can slip into cells. Particles as small as 30 nm can cross the blood-brain barrier.

- Other studies show that nanoparticles can move in unexpected ways through soil, and potentially carry other substances with them.

Some governments and scientists are belatedly conceding that nano-scale particles raise unique risks for health, safety and the environment. Given the knowledge gap, some experts recommend that release of engineered nanoparticles be minimized or prohibited in the environment:

*"Release of nano-particles should be restricted due to the potential effects on environment and human health."*

– Nanotechnology and Regulation within the framework of the Precautionary Principle. Final Report for ITRE Committee of the European Parliament, February 2004

*"Until more is known about their environmental impact we are keen that the release of nanoparticles and nanotubes in the environment is avoided as far as possible. Specifically we recommend as a precautionary measure that factories and research laboratories treat manufactured nanoparticles and nanotubes as if*



*they were hazardous waste streams and that the use of free nanoparticles in environmental applications such as remediation of groundwater be prohibited.” – Royal Society and Royal Academy of Engineering, “Nanoscience and Nanotechnologies: Opportunities and uncertainties,” July 2004*

## **WHAT DOES NANOTECH MEAN FOR HUMAN RIGHTS?**

Precise and sophisticated molecular-level manipulations will produce stronger, lighter materials, more precise and pervasive sensors and faster, smaller and more energy-efficient computers. These products are being developed simultaneously for civilian and military uses. Experts predict that nanotechnology will change the way wars are fought more than the invention of gunpowder.<sup>26</sup> BANG will produce soldiers with “enhanced” bodies and brains. It will also lead to the development of chemical and biological weapons that are more invasive, harder to detect and virtually impossible to combat. The invasive and invisible qualities of nano-scale sensors and devices could become extremely powerful tools for repression – posing a major threat to democracy and dissent and fundamental human rights.<sup>7</sup>

## **NEW TECHNOLOGIES ARE NO SUBSTITUTE FOR SOUND SOCIAL POLICIES**

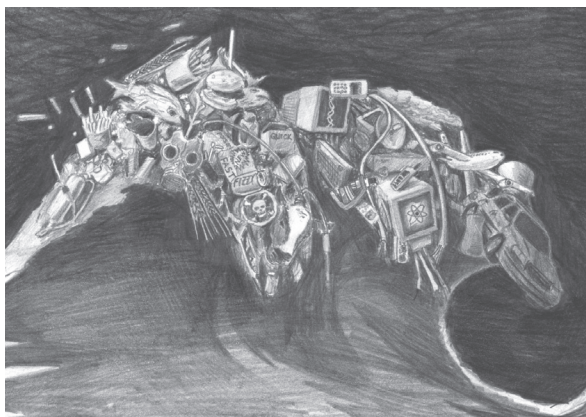
Like earlier promises made by proponents of nuclear, chemical and biotechnologies, nanotech enthusiasts make pie-in-the-sky claims: it will solve problems of hunger and poverty, cure cancer and clean up the environment. Other scientists point out that nanotech could bring better, cheaper disease diagnostics for people and crops and improve water purification and the efficiency of solar cells, reduce raw material demands, increase recycling and slash transport and energy costs. But even if we can diagnose diseases

*“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<sup>2</sup>

better, will corporate research focus on the problems of poor people, and will patented drugs be affordable?

The simple truth is that new technologies cannot solve old injustices. 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?**

ETC Group offers the following recommendations as a starting place for societal debate and action:

- First and foremost, society – including civil society organizations and social movements – must engage in a wide debate about nanotechnology and its multiple economic, health and environmental implications. Among others, the disability rights movement has a critical role to play and must be a key participant at all levels of debate.
- ETC Group has called for a moratorium on nanotech research and new commercial products until such time as laboratory protocols and regulatory regimes are in place to protect workers and consumers, and until these materials are shown to be safe. In the

meantime, all food, feed and beverage products, sunscreens and cosmetics that incorporate manufactured nanoparticles should be removed from shelves.

- Governments must also move immediately to establish a moratorium on lab experimentation with – and the release of – synthetic biology materials until society can engage in a thorough analysis of the health, environmental and socio-economic implications.
- Any efforts by governments or industry to confine discussions to meetings of experts or to focus debate solely on the health and safety aspects of nano-scale technologies will be a mistake. The broader social and ethical issues must also be addressed. Intellectual property issues must also be on the table. Who will control the technologies? Who will benefit from them? Who will play a role in deciding how nanotechnologies affect our future?
- The international community must create a new United Nations 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).

## **ADDITIONAL PUBLICATIONS FROM ETC GROUP ON NANO-SCALE TECHNOLOGIES**



*Down on the Farm: The Impact of Nano-Scale Technologies on Food and Agriculture*, November 2004, 68 pages.

*The Big Down: Technologies Converging at the Nano-scale*, January 2003, 80 pages.

*Size Matters! The Case for a Global Moratorium*, April 2003, 20 pages.

ETC Group publications are available in English and Spanish and can be downloaded free of charge from our website: [www.etcgroup.org](http://www.etcgroup.org)

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“But I am not afraid to consider the final question as to whether, ultimately — in the great future — we can arrange the atoms the way we want; the very atoms, all the way down!”

— Richard Feynman, *There's Plenty of Room at the Bottom*, 1959

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