

NGLS DEVELOPMENT DOSSIER

Downsizing Development

An Introduction to
Nano-scale Technologies
and the Implications
for the Global South

by ETC Group

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Downsizing Development:

An Introduction to Nano-scale Technologies and the Implications for the Global South



UN Non-Governmental Liaison Service (NGLS)



action group on erosion, technology and concentration



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Table of Contents

Preface	7
Introduction	9
What is Nanotechnology?	11
Nanotech’s “miracle molecules”: Carbon nanotubes, buckyballs and quantum dots	15
No Small Matter – Potential Risks of Nanoparticles	16
Nanotech’s Implications for the Global South	20
What Role do Developing Countries Currently Play in Nanotech R&D?	22
The Potential Impacts of Nano-Scale Technologies on Trade and Commodities	24
A First Look to the Potential Impacts of Nano-scale Technologies	24
The Potential Impacts of Nano-scale Technologies on the Market for Rubber	28
The Use of Nano-scale Technologies to Replace Platinum as a Catalyst in Catalytic Converters, Batteries, Fuel Cells and in Electrode Components	30
The Potential Impacts of Replacing or Reducing Markets for Platinum-based Catalysts for Developing Countries	33
Power Cable Made of Carbon Nanotubes Aims to Replace Copper Wiring	35
Potential Impacts of Nanotechnology-Induced Copper Replacement on Developing Countries	37
What Role will Nano-enabled Medicine Play in Addressing Sickness and Poverty in the Global South?	40
Nano-scale Engineering to Produce Anti-malarial Drug	41
VivaGel – Downsizing Microbicides	45

Table of Contents

Nanomonopoly	46
Diamond vs. Chakrabarty Remembered	49
The Chakrabarty “Life Patenting” Timeline	51
Lessons learned from Chakrabarty	53
From Dust to Dust: A concise history of patent monopoly	54
Technologies Converging at the Nano-Scale	55
Synthetic Biology and Nanobiotechnology	56
Conclusion and Policy Recommendations	59
Appendixes	63
Appendix A: ICENT	64
Appendix B: Glossary of Terms	69
Appendix C: A Case Study of Patents on Carbon Nanotubes	75
Appendix D: Resources for learning more about nano-scale technologies	81
Acronyms	83
Endnotes	85
Charts and Tables	
Table 1: Government funding for nanotechnology, 1997-2006 (US\$ billions)	10
Table 2: Global distribution of nanotechnology activity by country and classification	23
Chart 1: Global natural rubber production, 2004	29
Chart 2: Platinum demand by application, 2006	33
Table 3: Employment: Chilean mining/production, 2000-2004	38
Table 4: Zambia's copper production, 2002-2004	39
Table 5: International patents on nanotechnology, 1997-2006	47

Preface

The fifteenth in the NGLS series of *Development Dossiers*, *Downsizing Development: An Introduction to Nano-scale Technologies and the Implications for the Global South*, authored by ETC Group, looks at the many aspects of nanotechnology and related scientific, social, environmental and ethical issues.

Although the nanotech market is estimated to surpass US\$1 trillion by the year 2015 and hundreds of products containing unregulated and unlabeled nano-scale particles are commercially available, no government has developed a regulatory regime that addresses the nano-scale. Intellectual property issues, “patent thickets” and the risk of “nanomonopoly” will also play a major role in deciding who will capture nanotech’s trillion dollar market.

While nanotechnology offers the potential to develop low-cost solar cells, filters for cleaning contaminated water, cancer-killing molecules and more, ETC Group warns that small wonders could also mean colossal woes as the effects of nano-scale particles on human health and the environment are unknown. Further, nanotech’s new designer materials could topple commodity markets, disrupt trade and eliminate jobs for the poorest and most vulnerable workers.

Downsizing Development outlines the wide spectrum of nanotechnology science—including nanobiotechnology where the distinction between living and non-living blurs—and the growing nanotechnology industry and some of its uses. It looks at the role that nano-enabled medicine could play in addressing sickness and poverty and provides case studies on engineered microbes for an anti-malarial drug and microbicides to reduce or prevent the transmission of HIV. It also provides case studies on rubber, platinum and copper to offer a glimpse of the potential impacts of nano-scale materials and processes on commodity dependent and other developing countries, while noting that the potential impacts cannot be hailed as “good” or dismissed as “bad.”

The publication poses a number of questions: Who will control nanotech? Who will benefit from it? Who will lose? Will it introduce new risks for human health, safety and the environment?

Preface

Downsizing Development warns that the immediate and most pressing issue is that nanotechnologies are likely to bring huge socio-economic disruptions for which society is not prepared. Governments must gain the capacity to understand and address the potential impacts of nano-scale technologies, to participate in assessing them and determine research priorities based on human needs and development.

The Dossier ends by calling for a coherent UN approach to nanotechnology and advocates an International Convention on Evaluation of New Technologies (ICENT), put forward by civil society, to monitor and assess the introduction of new technologies in a participatory and transparent process that supports societal understanding, encourages scientific discovery, and facilitates equitable benefit-sharing.

Elisa Peter
Officer-in-Charge
UN Non-Governmental Liaison Service (NGLS)
March 2008

Introduction

Every decade or so we're bombarded by a new industrial technology that promises the next cure for society's ills: Better living through chemistry. Energy too cheap to meter. Genetically engineered crops to feed the hunger. Nanotechnology – the manipulation of matter on the scale of atoms and molecules – is the newest technofix, and its proponents promise the greatest and greenest industrial revolution ever.

The impacts of nanotech, we're told, will rival those brought about by the steam engine, electricity, the transistor and the Internet.¹ Big names in development – such as Mohamed Hassan, Executive Director of the Third World Academy of Sciences, as well as Gordon Conway, former president of the Rockefeller Foundation and now the UK's chief scientific advisor on international development – see enormous potential for nanotechnology to improve the conditions of poor people in the developing world.²

In 2003, then US Undersecretary of Commerce for Technology, Phillip Bond, described tiny tech's potential as “truly miraculous: enabling the blind to see, the lame to walk, and the deaf to hear; curing AIDS, cancer, diabetes and other afflictions; ending hunger; and even supplementing the power of our minds... nanotechnology will deliver higher standards of living and allow us to live longer, healthier, more productive lives. Nano also holds extraordinary potential for the global environment through waste-free, energy-efficient production processes that cause no harm to the environment or human health.”³

Though nanotechnology has been hyped to the hilt, it's no joke – and its societal impacts will be titanic. Worldwide, industry and governments invested almost US\$12 billion in nanotech research and development (R&D) in 2006, and for the first time, industry investment exceeded the investment by national governments.⁴ The European Union, Asia and USA are the leading nano-backers, but at least 30 countries have established national nanotech research programmes.⁵ The US government's National Nanotechnology Initiative (NNI) has spent over US\$5 billion on nanotech R&D since 2001, making it the biggest publicly funded science endeavour since the Apollo moon shot.⁶ The NNI distributes nanotech R&D funds to 13 federal agencies – US government funding has tripled, from US\$465 million in 2001 to almost US\$1.4 billion in 2006.⁷ The US Department of Defense has received a greater share of nanotech R&D funds than any other federal agency.

Table 1: Government funding for nanotechnology

US\$ millions	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
North America	\$ 116	\$ 191	\$ 256	\$ 339	\$ 512	\$ 753	\$ 1,044	\$ 1,579	\$ 1,750	\$ 1,836
Europe	\$ 128	\$ 128	\$ 152	\$ 203	\$ 532	\$ 657	\$ 766	\$ 925	\$ 1,897	\$ 2,073
Asia	\$ 133	\$ 162	\$ 204	\$ 359	\$ 656	\$ 1,028	\$ 1,265	\$ 1,551	\$ 1,510	\$ 1,671
Rest of world	-	-	-	\$ 30	\$ 61	\$ 68	\$ 77	\$ 101	\$ 170	\$ 204
TOTAL	\$ 377	\$ 482	\$ 613	\$ 932	\$ 1,761	\$ 2,507	\$ 3,152	\$ 4,156	\$ 5,327	\$ 5,785

Source: Lux Research, *The Nanotech Report, 5th edition*⁸

There are an estimated 1,200-nanotech start-up companies, half of which are US-based.⁹ In 2000, IBM was the only major corporation funding a nanotechnology initiative.¹⁰ Today, virtually all Fortune 500 companies invest in nanotech R&D. The US National Science Foundation estimates that the nanotech market will surpass US\$1 trillion by 2015. Industry sources predict the value of commercial products incorporating nanotechnology will reach US\$2.6 trillion (15% of global manufacturing output) by 2014 – 10 times biotech and equaling the combined informatics and telecom industries.¹¹ More than US\$50 billion in nanotechnology-enabled products were sold worldwide in 2006, according to nanotechnology consulting firm, Lux Research.

Nanotechnology offers potential to develop low-cost solar cells, filters for cleaning contaminated water, cancer-killing molecules, and more. But small wonders could also mean colossal woes. Nanotech's new designer materials could suddenly topple commodity markets, disrupt trade and eliminate jobs for the poorest and most vulnerable workers – especially those in the developing world who don't have the economic flexibility to respond to sudden demands for new skills or different raw materials. Nanotech is considered a "platform technology" – meaning that it will be applied across several sectors of the economy all at once. The impacts of the nanotech revolution won't compare to training typists to use word processors. What's more, nanotechnology brings with it novel toxicological risks – for example, the effects of nano-scale particles on human health and the environment are unknown and unpredictable.

Society is not prepared for the technological tsunami approaching. Learning from the experiences of past technology waves (chemical, nuclear, biotech), now is the time to determine: Who will control nanotech? Who will benefit from it? Who will lose? Will it introduce new risks for human health, safety and the environment? If current trends continue, nanotech threatens to widen the gap between rich and poor and further consolidate economic power in the hands of multinational corporations.

What is Nanotechnology?

Nanotechnology isn't a discreet industry sector – but a range of techniques used to manipulate matter at the nano-scale – where size is measured in billionths of meters. A nanometer (nm) equals one billionth of a meter. It takes ten atoms of hydrogen side-by-side to equal one nanometer. One human hair is about 80,000 nanometers thick. 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 except with the aid of powerful “atomic force” microscopes.

The real power of nano-scale science is the potential to converge disparate technologies that operate at the nano-scale – including biotechnology, cognitive sciences, informatics, and robotics (see section on converging technologies, page 55). With applications spanning all industry sectors, technological convergence at the nano-scale is poised to become the strategic platform for global control of manufacturing, food, agriculture and health in the immediate years ahead.

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. At the nano-scale, where quantum physics rule, a material's properties can change dramatically. With

only a reduction in size (below about 100 nanometers, roughly), and no change in substance, materials can exhibit new properties related to electrical conductivity, elasticity, strength, color and chemical reactivity – characteristics that the very same substances do not exhibit at the micro or macro scales. What's more, a material's quantum properties can change within the nano-scale. Some nanoparticles of gold are inert, for example, while other gold nanoparticles of a different size are reactive. Shape contributes to quantum effects, too. There are no current models that can predict a material's quantum properties. 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.¹²
- Nano-scale copper becomes a highly elastic metal at room temperature – stretching to 50 times its original length without breaking.¹³

Exploiting quantum property changes at the nano-scale is the key to nanotech's novelty, power and potential. Through nano-scale manipulations, scientists are dramatically transforming existing materials and designing new ones.

Companies are now manufacturing nanoparticles (chemical elements or compounds less than 100 nanometers) for use in hundreds of commercial products – from crack-resistant paints and stain-resistant clothing, to odor-eating socks, self-cleaning windows and anti-graffiti coatings for walls. For example:

- Exploiting the anti-bacterial properties of nano-scale silver, Smith & Nephew developed wound dressings (bandages) coated with silver nano-crystals designed to prevent infection. Hundreds of products incorporating nano-silver are now on the market, including sheets, towels, appliances, socks, toothbrushes, toothpastes and children's toys.
- Nanoparticles of titanium dioxide (TiO₂) are transparent and block ultraviolet (UV) light. Nano-scale TiO₂ is now being used in sunscreens and in clear plastic food wraps for UV protection.

- Nano-scale particles of hydroxyapatite have the same chemical structure as tooth enamel. Researchers at BASF are hoping to incorporate the nanoparticles in toothpaste to build enamel-like coating on teeth and to prevent bacteria from penetrating.¹⁴ Japan's Sangi Co. Ltd. says it has been selling a toothpaste containing nano-hydroxyapatite since 1980.
- Nano-Tex sells "Stain Defender" for khaki pants and other fabrics – a molecular coating that adheres to cotton fiber, forming an impenetrable barrier that causes liquids to bead and roll off.
- Pilkington sells a "self-cleaning" window glass covered with a surface layer of nano-scale titanium dioxide particles. When the particles interact with UV rays from sunlight, the dirt on the surface of the glass is loosened, washing off when it rains.
- BASF sells nano-scale synthetic carotenoids as a food additive in lemonade, fruit juices and margarine (carotenoids are antioxidants and can be converted to Vitamin A in the body). According to BASF, carotenoids formulated at the nano-scale are more easily absorbed by the body and also increase product shelf life.
- Syngenta, the world's largest agrochemical corporation, sells two pesticide products containing nano-scale active ingredients.¹⁵ The company claims that the extremely small particle size prevents spray tank filters from clogging and the chemical is readily absorbed into the plant's systems and cannot be washed off by rain or irrigation.
- Altair Nanotechnologies is developing a water-cleaning product for swimming pools and fishponds. It incorporates nano-scale particles of a lanthanum-based compound that absorbs phosphates from the water and prevents algae growth.¹⁶

Coatings, sprays and powders containing nano-scale particles are just the beginning. Nanotechnology also makes possible "bottom-up" manufacturing where self-assembling molecules become the Lego-like blocks for constructing nano-scale devices. Building devices from molecular scratch is still in the early stages. Nanofabricated products are being developed for use as electronic circuitry, for example. Chip makers envision the use of self-assembling molecular structures to store data or turn the flow of electrons on and off in a circuit. If molecular transistors work, carbon nanotubes could replace silicon, yielding ultra-fast computers that

perform “orders of magnitude” beyond silicon.¹⁷ Both Intel and Hewlett-Packard have announced strategies to replace silicon with nano-engineered materials to keep computer processing power growing at exponential rates.

Scientists are also developing nano-devices for molecular drug delivery. For example, biological engineers at the Massachusetts Institute of Technology (MIT) are testing a nano-structured drug delivery device in mice, which can chemically target and penetrate a tumor cell when injected in the bloodstream.¹⁸ Dubbed the anti-cancer “smart cell,” the nano-scale device delivers a one-two therapeutic punch: first, by releasing a chemical that cuts off the tumors’ blood supply. Second, after the outside shell of the nano-device dissolves, the inner core releases a chemotherapy drug to kill the cancer cells from the inside.

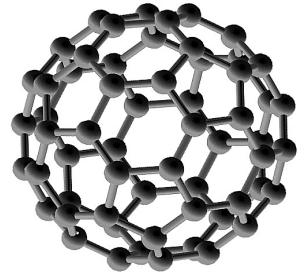
Invisible and highly-invasive nano-scale sensors are being developed for a wide range of applications. For example:

- MIT’s Institute for Soldier Nanotechnologies, created in 2002 with a US\$50 million grant from the US Department of Defense, aims to create a “21st century battlesuit” to enhance “soldier survivability.”¹⁹ One research team is using nanotech to develop a battlesuit that incorporates:
1) highly sensitive chemical and biological sensing technologies; 2) protective fiber and fabric coatings that will neutralize bacterial contaminants and/or chemical attack agents (i.e., nerve gas and toxins). The battlesuit’s fabric may feature nanopores that “close” upon detection of a biological agent. Researchers are also developing infrared monitoring based on nano-crystals (quantum dots) to detect the presence of chemical agents.
- Scientists at Hebrew University of Jerusalem and at the US Department of Energy’s Brookhaven National Laboratory have implanted a gold nanoparticle into the enzyme glucose oxidase – a step that researchers say will pave the way for a nano-scale device that can more accurately measure blood glucose in diabetic patients.²⁰
- Scientists at Kraft Foods, as well as researchers at Rutgers University and the University of Connecticut, are working on nano-particle films with embedded sensors to detect food pathogens. Dubbed “electronic tongue” technology, the sensors can detect harmful substances in parts per trillion and would trigger a color-change in food packaging to alert the consumer if a food is contaminated or has begun to spoil.

Nanotech's "miracle molecules": Carbon nanotubes, buckyballs and quantum dots

Carbon nanotubes and buckyballs are pure crystalline carbon molecules – as are diamond and graphite, the only other known forms. A buckyball is a hollow sphere made of 60 carbon atoms. A carbon nanotube is a variant of a buckyball, one that is elongated in the middle, like a buckyball seen in a fun-house mirror. Nanotubes can be hollow like straws (known as single-walled) or rolled up like posters in a mailing tube (multi-walled). Both buckyballs and nanotubes are self-assembled molecules, meaning that when conditions are just right (e.g., temperature, presence of a catalyst), they form their distinctive configurations all on their own.

Buckyballs and nanotubes are getting lots of attention because they are relatively recent discoveries (neither was known before 1985) and because they have extraordinary properties. Since buckyballs are hollow, they make ideal nano-vessels. Researchers envision them filled with medicines that could be delivered throughout the body or filled with fuel and used as rocket propellant. Their ability to withstand pressure is enormous: in one experiment, a researcher crashed buckyballs speeding at 15,000 miles/hour into a steel plate – the buckyballs bounced off and remained intact, no worse for wear.²¹



Nanotubes are 100 times stronger than steel and six times lighter; they can now be produced with 1 nm diameters and several millimeters long. Nanotubes can be either semi-conductors or insulators, depending on how their carbon sheets are rolled up. Dozens of products containing carbon nanotubes are commercially available (in order to increase strength without increasing weight) including tennis racquets, bicycle frames and auto body parts. Researchers are hoping that one day nanotubes will replace copper in wiring and silicon in computer chips.



Quantum dots are semiconductor nanoparticles whose unique properties promise a wide range of applications across several industrial sectors. Different-sized quantum dots emit distinctly different colors. A particular quantum dot or several dots of different sizes can be attached to or incorporated in materials, including biological materials, to act as a barcode or tracking device. One company, Evident Technologies, aims to incorporate quantum dots into products that are commonly counterfeited, including paper money, to act as “security inks.”²² Quantum dots are being used to label biological material *in vitro* and *in vivo* in animals (other than humans) for research purposes – they can be injected into cells or attached to proteins in order to track, label or identify specific biomolecules. In 2004, researchers announced that quantum dots injected in animals circulated in the blood for hours and continued emitting their distinctive colors for eight months!²³ (Once they stopped circulating, the dots collected in the liver, spleen, lymph nodes and bone marrow, suggesting they were scooped up by immune cells, whose job it is to clear circulating debris.) The hope is that one day quantum dots could be used in humans to treat and monitor diseases such as cancer. Researchers will have to proceed with caution, however, because the core material in most quantum dots is highly toxic cadmium and toxicological analysis has yet to be tackled.

No Small Matter – Potential Risks of Nanoparticles

In recent years, a growing number of scientific studies and government reports have warned that engineered nanoparticles could pose unique risks to human health and the environment. But nanotech products have come to market in the absence of public awareness and regulatory oversight. Hundreds of products containing unregulated and unlabeled nano-scale particles are commercially available – and thousands more are in the pipeline.²⁴ Engineered nanoparticles are already showing up in products applied to our skin (cosmetics and sunscreens), sprayed on our fields (pesticides), and in our refrigerators (nano-scale food additives) – but no national government has developed a regulatory regime that addresses the nano-scale or the societal impacts of the invisibly small.

It was neither government regulators nor industry that first blew the whistle on the potential health and environmental hazards of nanoparticles. In 2002, civil society organizations called for a moratorium on the release of manufactured nanoparticles until lab protocols are established to protect workers, and until regulations are in place to protect consumers and the environment.²⁵ A 2004 report

on the potential risks of manufactured nanoparticles published by Swiss Re, the world's largest re-insurance company, concluded that, "no reasonable expense should be spared in clarifying the current uncertainties associated with nanotechnological risks."²⁶

While nano-scale particles have existed in our environment for millennia (salt nanocrystals in ocean air or nanoparticles of carbon in soot), attention is now focused on new, intentionally-manufactured nanoparticles that result from miniaturizing chemical elements or compounds, such as gold, carbon or silicate. New, manufactured nanomaterials such as nanotubes, buckyballs and quantum dots are also being scrutinized for their potential hazards.

Very few toxicological studies exist on engineered nanoparticles, but it appears that nanoparticles as a class are more toxic due to their smaller size. When reduced to the nano-scale, particles have a larger surface area that can make them more chemically reactive. As particle size decreases and reactivity increases, a substance that may be inert at the micro- or macro-scale, can assume hazardous characteristics at the nano-scale. One concern is that the increased reactivity of nanoparticles could harm living tissue, perhaps by giving rise to "free radicals" that may cause inflammation, tissue damage or growth of tumors.

Nanoparticles can be inhaled, ingested or pass through the skin. Once in the bloodstream, nanoparticles can slip past traditional guardians of the body's immune system such as the blood-brain barrier. Ironically, the very same properties that make engineered nanoparticles so attractive for the development of targeted drug delivery systems – namely, their mobility in the bloodstream and ability to penetrate cell membranes – could also be qualities that make them dangerous.

Recent toxicological studies on the health and environmental impacts of manufactured nanoparticles indicate that there's reason for concern:

- 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.²⁷
- In 2005 researchers at the US National Aeronautic and Space Administration (NASA) reported that when commercially available carbon nanotubes were squirted into the lungs of rats it caused significant lung damage.²⁸ (The researchers indicated that the nanotube "dosage" 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 (NIOSH) reported in 2005 substantial DNA damage in the heart and aortic artery of mice that were exposed to carbon nanotubes.²⁹
- In 2005 University of Rochester (US) researchers found that rabbits inhaling buckyballs demonstrate an increased susceptibility to blood clotting.³⁰
- A 2005 study shows that buckyballs clump together in water to form soluble nanoparticles and that even in very low concentrations they can harm soil bacteria, raising concerns about how these carbon molecules will interact with natural ecosystems.³¹
- A 2006 study suggests that the increased reactivity of titanium dioxide nanoparticles, which are frequently used as an ingredient in sunscreens, can cause damage to brain microglia – cells that product/protect the central nervous system.³²
- A 2007 study suggests that iron oxide particles less than ten nanometers in diameter stunt the growth of nerve cells. (Nanoparticles of iron oxide are being considered for applications such as enhancing magnetic resonance images and killing cancer cells; they are already used in cosmetics, including lipstick and rouge.)³³

In response to heightened concerns about nanoparticles, some scientists suggest that it might be possible to mitigate potential toxic effects by controlling the surface chemistry of nanoscale materials, or by coating them in protective substances.³⁴ These efforts are complicated by the fact that there is currently no standard method for measuring or characterizing nanoparticles, no regulatory regime to ensure that particles have been made “safe,” nor is it possible to know how long protective coatings might last.

Given the knowledge gaps, expert reports are urging caution, and recommending that release of nanoparticles be restricted or prohibited:

“Release of nano-particles should be restricted due to the potential effects on environment and human health.” – 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 and reduce them in 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 (UK)**, July 2004.

Currently, nano-scale chemicals are escaping regulatory oversight if the same chemical compound has been approved at the micro- or macro-scale. Manufacturers of carbon nanotubes, for example, sometimes simply identify their product as “graphite” – another well-known type of pure carbon molecule – even though nano-scale carbon has vastly different properties and applications. Similarly, if a substance has already been approved as a food additive at a larger scale (such as titanium dioxide), nanoparticles of the same substance don’t automatically trigger new regulatory action – even though, by definition, nano-scale ingredients have new and different properties.³⁵ And although some companies claim that they have conducted their own toxicological studies on nanoparticles, those studies are rarely in the public domain.

The US government’s 2007 nanotech budget requested US\$45.8 million for environmental, health and safety research on nanomaterials – less than 4% of the National Nanotechnology Initiative’s (NNI) total budget.³⁶ Critics note that the amount allotted by the NNI for risk assessment is a fraction of what is needed, and it may include research on environmental applications of nanotech, as well as the implications of nanomaterials for safety and the environment.

While US and European governments are belatedly conceding that the products of nanotechnology are indeed different, no new, mandatory regulations are forthcoming. The US Environmental Protection Agency (EPA) is developing a voluntary “stewardship program” for nano-scale materials, and a Nanotechnology Task Force established by the US Food and Drug Administration (FDA) acknowledged that, while nano-scale materials present “regulatory challenges,” there was no need for products to be labeled.³⁷ In Europe, the Commission plans to adopt a voluntary “Code of Conduct for Responsible Nanosciences and Nanotechnologies Research,” which will “invite” Member States, industry and university researchers

to follow its principles. In response to the regulatory vacuum, 40 civil society organizations from around the world collaborated to produce a set of principles for adequate nanotechnology oversight, based on a precautionary approach.³⁸

Principles for Adequate Nanotechnology Oversight

(endorsed by more than 40 organizations from around the world, July 2007)

- I. A Precautionary Foundation:** Product manufacturers and distributors must bear the burden of proof to demonstrate the safety of their products: if no independent health and safety data review, then 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. (Available on the Internet: http://www.icta.org/doc/Principles%20for%20the%20Oversight%20of%20Nanotechnologies%20and%20Nanomaterials_final.pdf)

Nanotech's Implications for the Global South

"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.

Nanotech enthusiasts insist that nanotech will address the South's most pressing needs,³⁹ and European governments have identified nanotechnology as an important tool for achieving the United Nations Millennium Development Goals.⁴⁰ Current research on energy and water are two oft-cited examples of nanotech's potential contributions to environmental sustainability and human development.

Today, more than a billion people lack access to safe drinking water. Polluted water contributes every year to the death of an estimated 15 million children under age five.⁴¹ Researchers are developing both nanofilters and engineered nanoparticles to clean contaminated water, for example:

- Nanotechnologists at Rensselaer Polytechnic Institute (Troy, New York) and the Banaras Hindu University (Varanasi, India) are teaming up to develop carbon nanotube filters to remove contaminants from water. The filters allow water molecules to pass through a cluster of carbon nanotubes while trapping harmful bacteria like *E. coli* and poliovirus as tiny as 25-nanometers wide.⁴² Their goal is to develop a low-cost water filter that can be cleaned and re-used.
- With funding from the US Air Force, Vermont-based Seldon Technologies has developed a portable, hand-held filter that can quickly purify water from any source – a mud puddle, river or ground water – and render it clean enough to use on the battlefield for emergency medical treatment.⁴³ The company claims that its patented, prototype filter, also based on carbon nanotube technology, is now ready for large-scale production and provides “an absolute barrier against passage of microbial contaminants.”⁴⁴
- In countries like Bangladesh, naturally occurring arsenic in wells is a major threat to public health, afflicting an estimated 10-20% of the Bangladeshi population. Researchers at Rice University's Center for Biological and Environmental Nanotechnology are developing magnetite (iron oxide) nanocrystals to capture and remove arsenic from contaminated water.⁴⁵ At Oklahoma State University, chemists have used zinc oxide nanoparticles to clean up arsenic in water.⁴⁶ Although research is ongoing, the UK's Royal Society and Royal Academy of Engineering recommends that the use of engineered nanoparticles in groundwater remediation be prohibited until more is known about their health and environmental impacts.⁴⁷

Access to inexpensive, safe and renewable energy is key to sustainable development worldwide. In the developing world, an estimated 2 billion people lack access to modern energy sources. Nanotech enthusiasts point to cheap, flexible and efficient solar cells as one of the most promising areas of “green nanotechnology.”⁴⁸

In 2004, the US Department of Defense granted over US\$18 million to three nanotech start-up companies to develop military applications of solar energy. With additional backing from corporate partners and venture capitalists, Nanosys (Palo Alto, CA), NanoSolar (Palo Alto, CA) and Konarka (Lowell, MA), a new generation of light-weight, flexible solar cells are being developed that are based on semi-conducting nanoparticles.⁴⁹ Inorganic nanomaterials such as “quantum dots” that absorb a wide spectrum of light are printed on large sheets of metal foil that can be rolled out like plastic onto rooftops – allowing homes or office buildings to generate their own power. Nanosolar is also developing a semiconductor paint that could allow nano-powered solar cells to be applied to any surface.

In addition to current research related to water and energy, nanotech proponents point to the future environmental benefits of revolutionary manufacturing processes associated with bottom-up construction “that leaves no wasted material behind.”⁵⁰ Beyond minimizing waste, however, nano-scale manufacturing platforms could also make geography, raw materials, as well as labor, irrelevant. By employing nanotech to build from the bottom-up rather than processing down, the quantity of raw materials required could be sharply reduced.

What Role do Developing Countries Currently Play in Nanotech R&D?

A number of developing countries are already active in nanotech R&D and support national nanotechnology initiatives. According to a 2005 survey conducted by Donald Maclurcan, 62 countries, 18 of them categorized as “transitional” and 19 “developing,” are currently engaged with nanotechnology on a national level. A further 16 countries demonstrate either individual or group research in nanotechnology, three of which are categorized as transitional and 12 developing (including one categorized as “Least Developed Country” [LDC]). An additional 14 countries have expressed interest in engaging in nanotechnology research. Of these countries, one is categorized as transitional and 13 developing, including three LDCs. Maclurcan’s findings are presented in the table opposite.

Table 2: Global distribution of nanotechnology activity by country and classification

Least Developed	Developing	Transitional	Developed
National Activity or Funding			
	Argentina; Armenia; Brazil; Chile; China; Cost Rica; Egypt; Georgia; India; Iran; Mexico; Malaysia; Philippines; Serbia & Montenegro; South Africa, Thailand, Turkey; Uruguay; Vietnam	Belarus; Bulgaria; Cyprus; Czech Republic; Estonia; Hong Kong; Hungary; Israel; Latvia; Lithuania; Poland, Romania; Russian Federation; Singapore; Slovak Republic; Slovenia; South Korea; Ukraine	Australia; Austria; Belgium; Canada; Denmark; Finland; France; Germany; Greece; Iceland; Ireland; Italy; Japan; Luxembourg; Netherlands; New Zealand; Norway; Portugal; Puerto Rico; Spain; Sweden; Switzerland; Taiwan; United Kingdom; United States of America
Individual or Group Research			
Bangladesh	Botswana; Colombia; Croatia; Cuba; Indonesia; Jordan; Kazakhstan; Moldova; Pakistan; Uzbekistan; Venezuela	Macau, (China); Malta; United Arab Emirates	Liechtenstein
Country Interest			
Afghanistan; Senegal; Tanzania	Albania; Bosnia and Herzegovina; Ecuador; Ghana; Kenya; Lebanon; Macedonia; Sri Lanka; Swaziland; Zimbabwe	Brunei Darussalam	

Source: Donald C. MacLurcan, "Nanotechnology and Developing Countries: What Realities?" *Online Journal of Nanotechnology*, October 19, 2005. On the Internet: www.azonano.com/Details.asp?ArticleID=1429.

The Potential Impacts of Nano-Scale Technologies on Trade and Commodities⁵¹

“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.

Governments, industry and scientists in Organisation for Economic Co-operation and Development (OECD) countries are quick to point out the potential contributions of nano-scale technology to development in the South. To date, however, the potential disruptive impacts of nanotech on developing economies and human development have received far less attention. At the first North-South dialogue on nanotechnology sponsored by the United Nations Industrial Development Organization (UNIDO) in February 2005, scientists from developing countries pondered the opportunities and challenges posed by nano-scale science and technology.⁵² While most of the discussion focused on promoting nanotech R&D and avoiding a “nano-divide” between South and North, representatives from India and South Africa warned that raw materials and labor in developing economies risk becoming “redundant in the nano-age.”⁵³ According to South Africa’s Minister of Science and Technology, Mosibudi Mangena: “With the increased investment in nanotechnology research and innovation, most traditional materials ... will... be replaced by cheaper, functionally rich and stronger [materials]. It is important to ensure that our natural resources do not become redundant, especially because our economy is still very much dependent on them.”⁵⁴ To counter the potential loss of markets, the South African government has initiated Project Autek to develop new, industrial uses for gold – South Africa’s largest export earner.⁵⁵

A First Look to the Potential Impacts of Nano-scale Technologies

Nanotech R&D on beverages and emerging nanotech products in the textile sector offer a first glimpse of how commodity developing countries could be affected by nano-scale technologies in the future.

Tropical Beverages: Current R&D at one of the world's largest food and beverage corporations offers a glimpse of the potential impact of nanotech on tropical commodities (especially beverages). In 2000, Kraft Foods, the US\$34 billion Altria (formerly known as Phillip-Morris) subsidiary, launched the NanoteK consortium to develop nanotechnology to be used in foods.⁵⁶ The consortium involved fifteen universities and public research labs. None of the scientists involved in the consortium were food scientists by training; rather, they were a diverse group of molecular chemists, material scientists, engineers and physicists. Perhaps in response to concerns about the safety of nanoparticles, Kraft re-focused the research consortium in 2004 and renamed the project. It is now known as the Interdisciplinary Network of Emerging Science and Technologies.⁵⁷ The researchers are reportedly continuing to develop nanocapsules for beverages: every colourless beverage would contain a dozen or more encapsulated flavours, with the capsules designed to burst at different microwave frequencies. The idea is that the consumer will be able to choose – based on individual aesthetics, nutritional needs or flavour preferences of the moment – which components will be activated and then delivered and which will remain dormant. Countless nanocapsules would remain intact (and un-tasted) and only the desired flavours (and colours) would be activated. While this project may ultimately result in little more than niche, novelty products, it could also introduce a new beverage flavouring technology that could transform the entire beverage industry. With nano-scale flavour technology Kraft hopes to achieve greater bioavailability (more easily absorbed by the body), fresher tastes and stronger aromas.⁵⁸ Increasing the shelf-life of food and beverages is another goal of formulating ingredients at the nano-scale.⁵⁹ However, the health effects of dormant ingredients or un-opened nanocapsules would also need to be evaluated. Food corporations hope to avoid potential controversy over nanotechnology, and are increasingly reluctant to discuss research in this area.

It is too soon to predict the long-term impacts. If it happens that only nano-scale amounts of tea, coffee, cacao or tropical fruit juices are needed to flavour beverages in the future, commodity markets could be severely affected. Although it is too soon to predict the long-term impacts, the project highlights the potential shifts in demand for conventional commodities due to advances in nano-scale technologies. In the case of tropical beverage commodities, a sudden drop in demand could have serious consequences for developing countries. Consider, for example, that coffee represents 75% of Burundi's total exports, 62% of Ethiopia's, 54% of Uganda's and 24% of Guatemala's; cocoa represents 36% of Côte d'Ivoire's total exports, 24% of Ghana's.

Textiles: If there is one image that symbolizes nanotechnology's commercial potential, it is nano-engineered fabrics – invisibly transformed to exhibit entirely new and improved qualities, leaving desirable properties unchanged, and introduced seamlessly into the global market. Nano-enabled fabrics are already commercially available and are bought by some of the world's largest clothing manufacturers.⁶⁰ When US President George W. Bush visited China in 2002, his hosts presented him with a “self-cleaning” necktie that is stain-repellant due to a nano-scale coating.⁶¹ The gift demonstrated China's prowess in cutting-edge technologies; as the world's largest producer of both cotton and silk, however, China must closely follow developments in nano-scale technologies that could dramatically affect the demand for natural fibres.⁶²

Nano-Tex, a California-based company, has licensed its nanotech “fabric enhancements” to more than 80 textile mills worldwide – including India's two largest mills.⁶³ The treatments, incorporated in clothing and furniture sold by more than 100 companies, reportedly make the fabrics stain- and spill-resistant, without changing texture. The Nano-Tex enhancement is permanently attached to the fibre at the nano-scale level so it is undetectable to the human eye, and is designed to last the life of the fabric. One treatment called “Coolest Comfort” wicks moisture away and dries quickly, features that are designed to make synthetic fabrics mimic the qualities of cotton. Other treatments include a permanent anti-static treatment for synthetic fabrics and one that releases stains.⁶⁴

In China, researchers have developed a nano-enabled fabric enhancement that is applicable to silk, wool and cotton. Song Yanlin, from the Chinese Academy of Sciences (CAS), explains that the technique produces a “fuzz-like framework on the surface of the cloth, just like that on lotus leaves... [that] absorbs air molecules and forms a thin covering that protects the cloth from oil and water.”⁶⁵ CAS scientists have developed other nano-treatments that improve the ability of synthetic fabrics to absorb water, that prevent wool from shrinking and silk from becoming discolored.⁶⁶ Song envisions future nano-scale manipulations of fabric that will allow clothing to be sensitive to changes in light, temperature, humidity, radiation and changes in the body temperature of the wearer.⁶⁷

Nanotech-fabrics are already influencing the textile sector, a topic that has been the focus of international conferences for the past several years, in Europe and in Asia.⁶⁸ The Third International Conference on Nanotechnology and Smart Textiles for Industry and Fashion was held in London in March 2008.⁶⁹

Although the full implications are not clear, it is critical for developing economies to anticipate the possible impacts of developments in nano-scale technologies on markets for natural fibres: Will nanotech be used to mimic the texture and properties of natural fibres like cotton and silk? If so, will some natural fibres become obsolete with the development of new nano-inspired fibres? Will stain-resistant enhancements intended for niche fabrics like silk result in increased demand? How will longer-lasting, stain-resistant fabrics affect levels of consumption?

To suggest the dramatic nature of the market disruption in the event of commodity obsolescence, it is useful to consider cotton. Cotton represents 38% of the global fibre market. Though China, India, and Pakistan, together with the US, account for approximately two-thirds of world output, cotton is grown in over 100 countries.⁷⁰

Cotton is grown in 35 countries in Africa and is a critical export earner. Cotton is the main cash crop for small-scale farmers in Zambia, with cotton production estimated to have reached a 10-year high in 2003/04.⁷¹ Cotton is the main cash crop in the Central African Republic as well, where cash crop production accounts for only 3% of GDP but is the principal source of income for most of the rural population.⁷² Cotton accounts for 39% of Burkina Faso's exports, 37% of Chad's and 33% of Benin's.⁷³ With a global market value of US\$24,000 million (in 2003) and over 1,000 million people engaged in cotton production worldwide, nanotech's potential impact on the textile sector is an area that requires close monitoring and additional research.⁷⁴

The following case studies on rubber, platinum and copper illustrate the potential impacts of nano-scale technologies on traditional commodity markets in developing countries.

“The implications of reverse-engineering Mother Nature’s designs for our own technological devices will be most profound on the economies of manufacturing. When companies can cheaply and chemically assemble materials and devices in the same manner that beer, cheese, and wine are manufactured today, it spells disruption and dramatic shifts in supply and value chains.” – Lux Research, Inc. The Nanotech Report 2004, p. 16.

The Potential Impacts of Nano-scale Technologies on the Market for Rubber

Rubber occurs naturally as a milky emulsion, known as latex, in the sap of a number of plants. The major source of latex used for commercial rubber is the Para rubber tree, *Hevea brasiliensis*. Rubber is an elastomer, meaning that it is an amorphous polymer (long chain of molecules) that is relatively soft and malleable at ambient temperatures.⁷⁵ Rubber can also be produced synthetically. 8.6 million tonnes of natural rubber were produced in 2004, reflecting a market value of US\$11.6 thousand million. Seventy-nine percent of all natural rubber was produced in Southeast Asia in 2004.⁷⁶

At this point, it is difficult to evaluate how the market for natural rubber will be affected by future developments in nano-scale technologies. It is possible, for instance, that some nanotech techniques could increase the demand for rubber by enhancing its properties and even creating whole new uses for it. For example, researchers are experimenting with adding nano-fillers to rubber that will increase strength, durability and/or elasticity. (If durability is increased, however, it is logical that demand for rubber would decrease, as many products containing rubber would last longer.) Researchers in Japan are adding carbon nanotubes to rubber in order to strengthen the rubber and to make it more thermally stable with reduced permeability.⁷⁷ Researchers in the US, using a method called “supercritical carbon dioxide processing,” are creating nanocomposites out of rubber and a variety of nano-scale filler materials, with results similar to those in Japan.⁷⁸

The rubber market is heavily dependent on the tyre industry. Tyre production is the largest consumer of rubber – two-thirds of the world’s rubber goes into tyres. As Bob Nelson, sales manager at Goodyear Chemical Corporation, puts it: “The rubber industry goes as the tyre industry goes.”⁷⁹ Currently, around 40% of a car tyre is made from rubber, some synthetic and some natural. Researchers are designing nanoparticles to strengthen and extend the life of rubber tyres and are designing new nanomaterials that could entirely replace rubber.

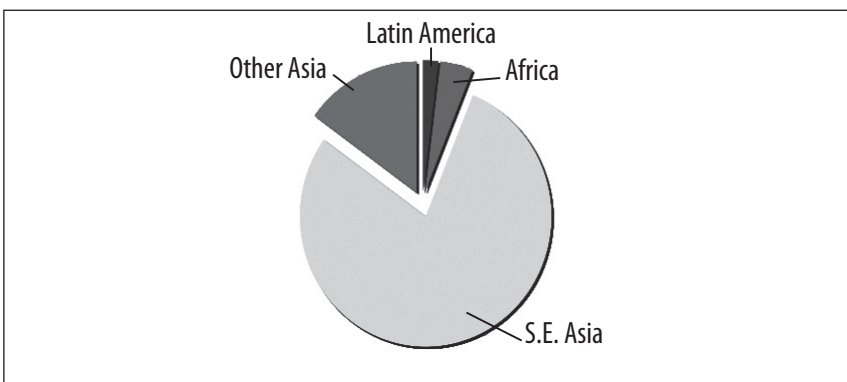
Nanoparticles of silicon carbide have been incorporated into tyres, so that the enhanced elastomer shows improved skid resistance as well as a nearly 50% reduction in abrasion, promising a tyre with significantly improved durability.⁸⁰ Inmat LLC is producing nanoparticles of clay that can be mixed with plastic and

synthetic rubber to seal the inside of tyres, creating an air-tight surface – potentially decreasing the amount of natural rubber required and making tyres lighter, cheaper and cooler running. The technology has already been incorporated in tennis balls, commercially available since late 2001. The technology was originally developed in the late 1990s in a joint R&D project of Michelin and Hoechst Celanese.⁸¹

An extremely lightweight and strong material known as an aerogel – billions of air bubbles trapped in a matrix of nano-sized particles of silica (glass) and plastic – is heat-resistant and an excellent insulator. Aerogels were originally developed in the 1930s but their usefulness was limited because they were brittle and absorbed moisture. Aerogel technology is currently being revisited, and one researcher describes the new generation of aerogels as the “strongest, lightest material known to man.” Aerogels are already being incorporated in building materials, and researchers also envision their use to create lighter, longer-lasting tyres.⁸²

There could be significant environmental gains from replacing natural rubber with nanomaterials, though the new materials could also introduce new disposal problems and new contaminants in the environment. Nonetheless, if demand for natural rubber plummets with the introduction of new, nano-engineered materials or because tyres are lasting twice as long, the world’s top producers of natural rubber – workers in Thailand, Indonesia and Malaysia – will be severely affected.

Chart 1: Global Natural Rubber Production, 2004



Source: International Rubber Study Group; S. E. Asia = Cambodia, Indonesia, Malaysia, Myanmar, Philippines, Thailand and Vietnam

In an effort to lift world rubber prices past the US\$1/kg mark, the top three rubber-producing countries, in mid-2002, entered an agreement to cut output by 10% and exports by 4% over the next three years.⁸³

- Natural rubber is cultivated in the south of Thailand, a country where 13.6 million people – 40% of the workforce – are employed in the agriculture sector.⁸⁴ Thailand surpassed Malaysia in 1991 to become the world’s largest producer of natural rubber – almost 3 million tonnes in 2004, accounting for more than 34% of total global production.⁸⁵ There appears to be some awareness in Thailand that developments in nano-scale technologies will affect the rubber market, with current research focused on using nano-scale technologies to enhance the properties of natural rubber. At the end of August 2005, Chulalongkorn University in Bangkok hosted a conference on the “Future of Natural Rubber for Industrial Applications.” Researchers presented papers on rubber and nanoparticle composites as well as using atomic force microscopy to better understand the behaviour and properties of natural rubber.
- Indonesia is the world’s second largest producer of natural rubber, producing over 2 million tonnes in 2004, accounting for almost one-quarter of global production.⁸⁶ According to the *Economist Intelligence Unit* (EIU), over 1.3 million tonnes were produced by Indonesia’s smallholders.
- Malaysia produced almost 1.2 million tonnes of natural rubber in 2004, representing almost 14% of global production. In September 2005, the Malaysian Rubber Board organised a 10-day trade mission to China – thought to be the first official visit by Malaysian rubber industry executives in 10 years. China is seen as an ideal trading partner because of its robust demand for rubber products, a result of its sharply increased auto sales.⁸⁷

The Use of Nano-scale Technologies to Replace Platinum as a Catalyst in Catalytic Converters, Batteries, Fuel Cells and in Electrode Components

Platinum is a chemical element in the periodic table that has the symbol Pt and atomic number 78.⁸⁸ Platinum is known for its outstanding catalytic properties. (A catalyst is a substance that speeds up a chemical reaction.) The automotive industry is the largest consumer of platinum-group metals, chiefly for their use

as catalysts in catalytic converters, which are used to treat automobile exhaust emissions. According to market research firm Johnson-Matthey, the use of platinum as an autocatalyst accounted for 54% of the total demand for platinum worldwide in 2006.⁸⁹ Platinum is also the primary catalytic material in batteries and fuel cells, and in electrode components. The use of platinum as a catalyst in fuel cells and batteries accounts for an estimated 40% of the products' total cost.⁹⁰ In 2006, the demand for platinum for use in autocatalysts was 4.995 million ounces (reflecting a market value of almost US\$5 billion).⁹¹

The development of hydrogen fuel cells could be the best route for replacing fossil fuels with cleaner and more abundant energy sources. But one obstacle is the high cost of platinum – the catalyst that is used in fuel cells to strip electrons from hydrogen atoms to generate electricity. Platinum is expensive (average price: US\$942.00 per ounce in 2006), and supplies are limited.⁹² To make today's fuel cell designs economically viable, researchers must find a substitute for the platinum catalyst – or reduce the amount of platinum used by 90%.⁹³

Both academic and private-sector researchers, including two California-based nanotech start-up companies, QuantumSphere, Inc.⁹⁴ and Nanostellar, Inc.,⁹⁵ are dedicated to developing nano-scale materials that will partially or fully replace platinum catalysts with cheaper, better-performing substitutes.

QuantumSphere, Inc. aims to lower the cost of hydrogen fuel cells by replacing platinum catalysts with the company's proprietary metallic nanomaterials, nano-nickel/cobalt alloy. Kevin Maloney, the CEO of QuantumSphere, Inc., claims that his company's proprietary metallic nanopowders “will liberate companies from their dependence on platinum, lower the cost of production and increase profit margins, enabling firms to offer new products at a price point that will be accepted in the market.”⁹⁶

QuantumSphere has applied for three broad patents for nano-scale nickel that the company claims will provide a cheaper, more effective catalyst than platinum.

A team of computational physicists from the Massachusetts Institute of Technology (MIT) and Stanford University are using computer models of atomic-scale structures to determine what makes platinum a superior catalyst. (Computational physics is the study and implementation of numerical algorithms in order to solve problems in physics for which a quantitative theory

already exists.) In essence, the researchers are modeling materials one atom at a time.⁹⁷ At the nano-scale, a material's properties are determined by the arrangement of its atoms. For instance, graphite and diamonds are composed of the same chemical element – carbon. When carbon atoms assemble so that each one bonds to four others in a pyramid-like pattern, the substance is diamond. When the atoms are arranged in a flat-plane structure with three atoms bonding to each carbon atom, it becomes graphite. Using computer simulations of nano-scale platinum, Stanford researchers have discovered that a configuration of 611 atoms of platinum provides the most stable and efficient fuel cell catalyst.⁹⁸ After determining the optimum atomic configuration, the researchers searched databases to find non-platinum materials with similar quantum properties. In theory, the use of computer models to simulate atomic structures gives researchers the ability to fashion new materials and devices – and “to predict behaviour before making them.”⁹⁹

In 2003, Stanford University professor Kyeongjae Cho co-founded privately held, nanotech start-up company, Nanostellar, Inc., to commercialize nano-structured catalysts.¹⁰⁰ A May 2005 progress report on the US government's National Nanotechnology Initiative acknowledges Nanostellar, Inc. for its work to develop nanomaterials for clean energy:

“Nanostellar has dramatically reduced the amount of platinum required for automotive emission control by designing and producing nanoparticles that combine the precious metal with other less costly metals.”¹⁰¹ Nanostellar launched its first-generation emission-control product – a platinum and palladium alloy with 25-30% better performance than pure platinum catalysts – in mid-2006.¹⁰²

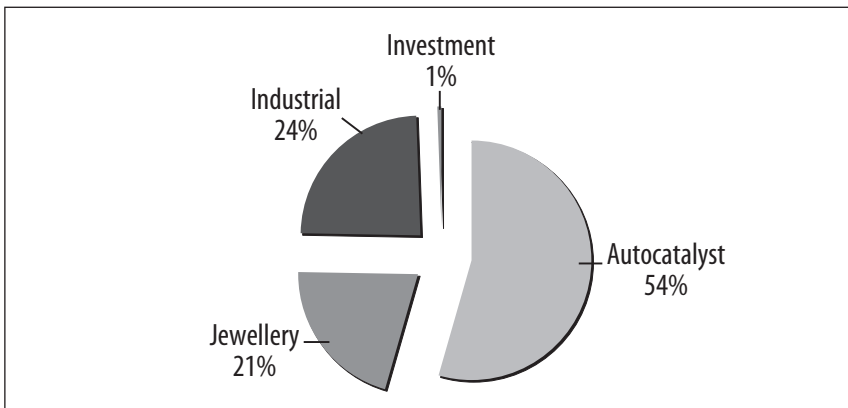
In separate research, scientists at the US Department of Energy's Brookhaven National Laboratory (Long Island, New York) and the University of Wisconsin-Madison are “atomically engineering” the surfaces of metals to boost their catalytic properties – with the goal of reducing the amount of platinum required.¹⁰³ The research team reported in 2005 that a single atomic layer of platinum applied to palladium (another chemical element) is more than 20 times more active on a per atom basis than commercial catalysts.¹⁰⁴ If the amount of platinum catalyst could be reduced to a layer of platinum one atom thick, it would sharply reduce the quantity of platinum used and make commercial fuel cells economically viable. The findings demonstrate the potential of nanostructured surfaces to improve the efficiency and lower the cost of catalysts, and drastically alter the requirements for raw materials.

How real and how immediate is the possibility that new, nano-scale materials will replace or reduce demand for platinum metal? Tom Kendall of Johnson-Matthey, the UK-based platinum research firm, does not dismiss the potential for new nanotechnology-based developments in the future, but “we don’t see anything on the horizon immediately that threatens platinum.”¹⁰⁵ Kendall notes that platinum has excellent durability in its favour, and that it would take the auto industry years – not months – to begin using a new auto catalyst system. He also points out that good results in the laboratory are one thing, but scaling up to industrial production is a very different matter.

The Potential Impacts of Replacing or Reducing Markets for Platinum-based Catalysts for Developing Countries

The global market value of platinum is over US\$6,000 million worldwide (for newly mined, not recycled metal).¹⁰⁶ In 2006, worldwide demand for platinum was 6.78 million ounces and the average price of platinum was US\$942.00 per ounce. Production of autocatalysts was the largest single use of platinum – accounting for 54% of the total demand. The largest producers of platinum are South Africa, North America, Russia and Zimbabwe. Europe, North America and Japan account for two-thirds of the platinum demand worldwide.¹⁰⁷

Chart 2: Platinum Demand by Application, 2006



South Africa is the world's largest producer of platinum by far (in addition to being the world's leading producer of gold, chrome, ferro-chromium, manganese, vanadium and vermiculite). The industry is centred in the north of the country.

- South Africa produced 76% of the total global production of platinum from 2002-2006 and holds an estimated 87.5% of the world's reserves.
- South Africa's entire mining and quarrying sector directly employs over 416,920 workers, equivalent to 2.6% of the economically-active population. If one includes family dependants and those employed in trades ancillary to mining, the number of people dependent on mining as a source of income is close to 4 million.
- In 2002, the mining sector accounted for 33% of the overall value of South Africa's exported goods. (EIU)

Zimbabwe has seen a steady decrease in gold mining since the late 1990s, but the platinum sector is growing. In 2006, production increased 6% from the previous year.

- Zimbabwe is the world's fourth-largest exporter of platinum.
- South African mining companies (particularly Zimplats of Australia/South Africa) are investing in Zimbabwe's platinum mines. Anglo American invested US\$90 million in a new platinum mine, which is at the developmental phase with some trial mining underway.
- In February 2005 the government of Zimbabwe enacted legislation that will encourage platinum mining: platinum has been accorded "strategic metal status" alongside gold, which requires producers to sell their platinum to the Minerals Marketing Corporation of Zimbabwe (set up by the government). The government is setting up a platinum industry investment support programme that will encourage industry projects, particularly platinum refining. The new regime also calls for increased black Zimbabwean ownership within the mining sector. (EIU)

Power Cable Made of Carbon Nanotubes Aims to Replace Copper Wiring

In April 2005 the US government's National Aeronautics and Space Administration (NASA) awarded a four-year, US\$11 million contract to Rice University's Carbon Nanotechnology Laboratory in Houston, Texas.¹⁰⁸ The project aims to produce a prototype wire made entirely of carbon nanotubes, which could conduct electricity up to ten times more efficiently than copper. Under the terms of the contract, Rice University researchers are expected to provide a one-metre long wire spun from fibres of carbon nanotubes by 2010. Rice University researchers believe that wiring made of carbon nanotubes will someday transform the electrical power grid.

Power cable spun from carbon nanotubes is often referred to as "quantum wire" because it is the nano-scale quantum effects that endow these molecular structures with enormous strength and extraordinary electrical conductivity.¹⁰⁹

Rice University researchers have already spun carbon nanotube fibres about 100 metres long, but the challenge is to mass-produce uniform, well-aligned nanotubes that offer

superior conductivity – without loss of energy. Howard Schmidt, the executive director of Rice's Carbon Nanotube Laboratory explains: "We need to find a way to make just the nanotubes we want, and we need them in large quantities."

Carbon nanotubes can be produced in many different shapes and configurations. The current challenge is to uniformly and cheaply produce a specific type of carbon nanotube that has superior electrical conductivity. These nanotubes are known as "armchair" nanotubes because the configuration of their carbon atoms resembles an armchair. The late Richard Smalley, 1996 Nobel Laureate and Director of Rice University's Carbon Nanotechnology Laboratory, described the promise and potential of quantum wires:

What are carbon nanotubes? Carbon nanotubes are large molecules of pure carbon that are long and thin and shaped like tubes, about 1-3 nanometers (1 nm = 1 billionth of a meter) in diameter, and up to several millimetres long. As individual molecules, nanotubes are 100 times stronger than steel and six times lighter.

“Individual armchair [nanotubes] can conduct as much as 20 microamps of current. This doesn’t sound like much until you realize that this little molecular wire is only 1 nanometer in diameter. A half inch thick cable made of these tubes aligned parallel to each other along the cable would have over 100 trillion conductors packed side-by-side like pipes in a hardware store. If each of these tubes carried only one microamp, only 2% of its capacity, the half inch thick cable would be carrying one hundred millions amps of current. Fabricating such a cable – we call it the ‘armchair quantum wire’ – is a prime objective of our work.”

Smalley also foresaw the use of quantum wires in fuel cells, batteries and the replacement of copper wire currently used to assemble cars, trucks, aerospace and other heavy equipment.

“If the arm-chair quantum wire turns out in practice to be as good a conductor as we imagine, it will be used to replace copper in the wiring harnesses of cars and airplanes.” – **Richard E. Smalley** Nobel Laureate and former Director of Rice University’s Carbon Nanotube Laboratory.¹¹⁰

According to Smalley, if carbon nanotube wires can be configured to function without dissipating electricity in the form of heat, they could perform as well as existing semi-conductors, without expensive cooling equipment.¹¹¹

In June 2005 scientists at the University of California-Irvine announced that carbon nanotubes are capable of routing electrical signals on a chip faster than traditional copper or aluminum wires, at speeds of up to ten gigahertz (10⁹ per second). The findings have many potential applications because electrical signals are routed at high speed through virtually all electronic systems, and also through the airwaves in the case of wireless systems.¹¹²

Peter Burke, professor of electrical engineering and computer science at the University of California-Irvine explains the significance of his team’s finding: “Our prior research showed that nanotube transistors can operate at extremely high frequencies, but the connections between the transistors were made out of somewhat slower copper, thus forming a bottleneck for the electrical signals.” Burke continues, “In this technology we show that nanotubes can also quickly route electronic signals from one transistor to another, thus removing the bottleneck.”¹¹³

In the late 1990s the semiconductor chip industry shifted from using aluminum to copper for its interconnect wiring (connections between the transistors) because copper carries electrical signals faster than aluminum. If nanotubes can be produced uniformly and cheaply, however, “it is now clear that changing the industry from copper to nanotubes would provide even larger performance advantage in terms of speed.”¹¹⁴

Potential Impacts of Nanotechnology-Induced Copper Replacement on Developing Countries

Copper is a chemical element in the periodic table that has the symbol “Cu” and atomic number 29. Copper is a reddish-colored metal that is valued for its high electrical and thermal conductivity (among pure metals at room temperature, only silver has a higher electrical conductivity).¹¹⁵

Copper: Chile, Indonesia, the US and Australia are the world’s top producers of copper. Zambia has large copper deposits and was a major producer in the 1970s, though production fell steadily until 2000.¹¹⁶ Copper mining worldwide increased sharply beginning in 1995, but production remained essentially unchanged in 2003 at 13.6 million metric tonnes (Mt). Producers, primarily in Chile and the US, cut back on production, despite an almost 800,000 Mt increase in global mine capacity during 2001-2003.¹¹⁷

Chile has an estimated one-third of the world’s copper reserves, and is by far the world’s largest producer.

- In 2004, mining accounted for a record 7.9% of Chile’s GDP and for US\$16,400 million, or 51%, of exports. Copper accounted for US\$14,300 million, or 45% of Chile’s exports in 2004; an estimated 74,000 workers were employed in Chilean mining and quarrying sector.
- In 2004, Chile produced 5.45 million tonnes of refined copper, representing 38% of total world output and more than three times the 1990 output level.
- The opening of La Escondida, a mine in the northern Atacama desert, in 1990 was the biggest single contributor to the rise in Chile’s copper production over the past decade. It is the largest copper mine in the world. A US\$1,100 million expansion programme was completed in 2002 that boosted capacity even further.

- A survey by the Comisión Chilena del Cobre reported in early 2005 that copper projects valued at US\$11,400 million were under construction or at various stages of evaluation and design.¹¹⁸

Table 3: Employment: Chilean mining/production

Year	2000	2001	2002	2003	2005
Total Chilean labour force	5,847,000	5,861,000	5,914,000	6,066,000	6,199,000
Mining & quarrying	73,000	72,000	72,000	68,000	74,000

Source: Banco Central de Chile, *Boletín Mensual*.

Indonesia has rich deposits of copper. Mining accounts for 12% of the country's GDP; in 2004, an estimated 500,000 Indonesian workers were employed in the mining and quarrying sector.¹¹⁹

- Indonesia produced 3.2 million tonnes of copper in 2003.
- The world's second-largest copper mine is at Grasberg in Papua and employs 18,000 people.
- A copper mine operated by Newmont Nusa Tenggara, a subsidiary of US firm Newmont Mining, on the island of Sumbawa in West Nusa Tenggara, opened in 1999. It processes 160,000 tonnes of ore a day.

From 1990-1999, **Zambia's** top three commodities accounted for an average 68% of its foreign exchange earnings and copper is Zambia's largest export earner. Zambia has some of the largest copper (and cobalt) deposits in the world and in the 1970s was among the top global copper producers. After the mines were nationalized in the early 1970s, annual production levels began to fall, while production levels of competitors, particularly Chile, rose. In 2000 Zambia's copper output fell to 256,900 tonnes (and cobalt production to 3,500 tonnes), the lowest level since the late 1950s. However, investment in the mining sector has increased with the privatization of Zambia Consolidated Copper Mines (ZCCM).

- Copper production in 2004 was 55% higher than in 2000.
- Proceeds from copper and cobalt mining dominate Zambia’s foreign-exchange earnings, typically contributing 55%-70% of the total.
- In 2005 Zambia enjoyed a small trade surplus as a whole, largely owing to copper exports, and its mining and quarrying accounted for about 8% of GDP.

Table 4: Zambia’s Copper Production

Year	2002	2003	2004
Copper output (000 tonnes)	337	350	398
Employment in the Mining Sector	39,914	53,868	NA

Source: Bank of Zambia, International Monetary Fund (IMF), *Zambia: Selected issues and Statistical Appendix*; EIU.

Congo (Democratic Republic): While the entire mining sector contributed just 9% to Congo’s GDP in 2004, copper mining was once a mainstay of Congo’s domestic economy until the 1970s, when international prices fell sharply and domestic production suffered. Recorded production at the State-owned company, Gécamines, fell from an average of 500,000 tonnes a year during 1980-87 to only 7,700 tonnes in 2004.¹²⁰ The *Economist Intelligence Unit* estimates total national production – including Gécamines and private-sector companies – at about 80,000 tonnes per year and reports that copper production is on the rise.¹²¹

Summary of Case Studies: The case studies presented above offer a glimpse of the potential impacts of nano-scale materials and processes on commodity dependent and other developing countries. In most cases it is too early to predict with certainty which commodities or workers will be affected and how quickly. It is important to note that nano-scale technologies also offer potential for developing countries to innovate and add value to current commodities. The potential impacts cannot be hailed as “good” or dismissed as “bad.” However, it is clear that

commodity dependent developing nations are the poorest, most vulnerable and will likely face the greatest disruptions.¹²² Currently, nanotech innovations and intellectual property are being driven from the North (especially the US, Japan and Europe). History shows that there will be a push to replace commodities such as rubber, cotton and strategic minerals with cheaper raw materials that can be sourced closer to home. Nanotech's new designer materials could topple commodity markets, disrupt trade and eliminate jobs. Worker-displacement brought on by commodity-obsolescence or a drop in prices will hurt the poorest and most vulnerable, particularly those workers in the developing world who don't have the economic flexibility to respond to sudden demands for new skills or different raw materials.

In the face of perennially low and volatile prices for primary export commodities, and the persistent poverty experienced by many workers who produce commodities in the South, few would argue in favor of preserving the *status quo*. Preservation of the *status quo* is not the issue. The immediate and most pressing issue is that nanotechnologies are likely to bring huge socio-economic disruptions for which society is not prepared. Governments must gain the capacity to understand and address the potential impacts of nano-scale technologies, to participate in assessing them and determine research priorities based on human needs and development.

What Role will Nano-enabled Medicine Play in Addressing Sickness and Poverty in the Global South?

“Some day soon, in a remote village in the developing world, a health worker will put a drop of a patient’s blood on a piece of plastic about the size of a coin. Within minutes, a full diagnostic examination will be complete including the usual battery of blood work tests, plus analysis for infectious diseases such as malaria and HIV/AIDS, hormonal imbalances, even cancer. That remarkable piece of plastic is called a lab-on-a-chip and it is one of the revolutionary products and processes currently emerging from nanotechnology research with the potential to transform the lives of billions of the world’s most vulnerable inhabitants.” – News Release, University of Toronto, **Joint Centre for Bioethics**, 31 March 2005. ¹²³

Medical applications of nano-scale technologies have the potential to revolutionize healthcare by delivering powerful tools for diagnosing and treating disease at the molecular level. As of mid-2006, 130 nanotech-based drugs and delivery systems and 125 devices or diagnostic tests are in preclinical, clinical or commercial development.¹²⁴ The combined market for nano-enabled medicine (drug delivery, therapeutics and diagnostics) will jump from just over US\$1 billion in 2005 to almost US\$10 billion in 2010,¹²⁵ and the US National Science Foundation predicts that nanotechnology will produce half of the pharmaceutical industry product pipeline by 2015.¹²⁶ What role will nano-enabled medicines play in addressing the health needs of marginalized communities in the global South?

Two products currently under development are frequently cited as examples of nanomedicine's potential to address major health problems in the developing world. The cases are highlighted below.

Nano-scale Engineering to Produce Anti-malarial Drug

Engineering microbes to produce an inexpensive anti-malarial drug is the *cause célèbre* of **synthetic biology**, a convergence of biotechnology and engineering to build biological systems in the laboratory to perform specific tasks. Malaria afflicts 300-500 million people and kills more than one million people per annum (58% of malaria cases occur among the poorest 20% of the world's population – mostly young children living in Africa).¹²⁷ The World Health Organization (WHO) regards artemisinin-based drugs as the best hope for treating malaria. Artemisinin, a natural product extracted from the leaves of the sweet wormwood plant *Artemisia annua*, has successfully treated all known strains of malaria. The Chinese have used the wormwood shrub as a medicinal plant for over 2,000 years. However, a global shortfall in the supply of natural artemisinin has kept the price of this much-prised compound out of reach for poor people.

Jay Keasling, professor of chemical engineering at the University of California Berkeley and now CEO of the new Joint BioEnergy Institute involving five public institutions, believes that synthetic biology is the tool that will allow unlimited and cheap production of a previously scarce drug to treat malaria in the developing world. In 2004, Keasling's Berkeley lab and his start-up company Amyris Biotechnologies, together with the non-profit Institute for OneWorld Health, received a 5-year, US\$43 million grant from the Bill and Melinda Gates Foundation to develop a microbe-derived version of artemisinin.

In April 2006 Keasling and 14 collaborators announced in *Nature* they had succeeded in engineering a yeast strain to produce artemisinic acid, which is a necessary step in the production of artemisinin itself.¹²⁸ The team claims to have discovered the genes involved in *Artemisia annua*'s natural production of artemisinic acid, and managed to insert and express them in a modified yeast strain. The microbe thus behaves like a miniature factory to produce artemisinic acid. According to Keasling, what's left to do is to increase the yields of artemisinic acid, and then use "high-yielding chemistry" to convert artemisinic acid to artemisinin.

Though they've produced only tiny quantities of artemisinic acid so far, Keasling's bacterial factories are already churning out copious amounts of priceless PR for the fledgling synbio industry. Will the focus on synthetic biology to tackle malaria divert attention and resources from less glamorous approaches that are nonetheless sustainable and de-centralized? Will alternative options for addressing malaria be cast aside in single-minded pursuit of synbio's silver bullet?

The current situation: WHO requires that artemisinin be mixed with other malaria drugs (a drug combination known as Artemisinin Combination Therapies or ACTs) to prevent the malaria parasite from developing resistance. Novartis' proprietary ACT drug (known as Coartem) is the only one that has received pre-clearance from WHO (meaning that it is approved for procurement by UN agencies), giving Novartis a virtual monopoly on ACT drugs. According to a 2006 study on artemisia conducted by the Royal Tropical Institute of the Netherlands: "This monopoly-like situation has created an imperfect market defined by scarcity of raw materials, speculation and extremely high retail prices."¹²⁹

Under contract to WHO, Novartis provides Coartem at cost (US\$0.90 to treat infants; US\$2.40 to treat adults) to the public sector in malaria-endemic countries in the South. A two-tier pricing system allows Novartis to sell their ACT compound for ten times the cost to Northern markets and international travelers. Other drug companies are developing ACT drugs, with Sanofi-Aventis closest to having a marketable product.¹³⁰

Novartis currently buys almost all of the world's wormwood crop, sourcing from thousands of small farmers across China, Vietnam, Kenya, Tanzania, India, Uganda, Gambia, Ghana, Senegal and Brazil. In East Africa, an estimated 1,000 small-scale farmers (average 0.3 hectares) and 100 larger scale farmers (average 3 hectares) currently grow artemisia.¹³¹ In light of global demand and recent campaigns to reinvigorate the fight against malaria, that figure is expected to grow to approximately 5,000 smallholders and 500 larger-scale farmers.¹³²

The report by the Royal Tropical Institute of the Netherlands concludes that the current artemisia shortfall could be met solely by increasing cultivation of wormwood, especially in Africa. Increasing local production is attractive as a sustainable and decentralized approach. “From a technical point of view, it is possible to cultivate sufficient artemisia and to extract sufficient artemisinin from it to cure all the malaria patients in the world. An ACT could be made available at an affordable price within just 2-3 years.”¹³³ The report estimates that between 17,000-27,000 hectares of *Artemisia annua* would be required to satisfy global demand for ACT, which could be grown by farmers in suitable areas of the South.¹³⁴

The Institute’s report warns, however, that the prospect of synthetic artemisinin production could destabilize a very young market for natural artemisia, undermining the security of farmers just beginning to plant it for the first time: “Growing Artemisia plants is risky and will not be profitable for long because of the synthetic production that is expected to begin in the near future.”¹³⁵

Sold on synbio’s synthetic vision: Keasling’s team believes that using synthetic microbes to manufacture artemisinin could increase supplies more quickly and reliably than planting new crops. “You would need to plant the state of Rhode Island to meet demand,” quips Jack Newman, co-founder – along with Keasling – of Amyris Biotechnologies, the company that will bring synthetic artemisinin to market.¹³⁶ Amyris predicts that microbial production will lower the cost of artemisinin to 25 cents per dose.¹³⁷ The company’s non-profit partner, OneWorld Health, will steer the product through the regulatory process and conduct preclinical studies to determine the safest artemisinin derivatives.¹³⁸

However, large-scale production of synthetic artemisinin still faces significant technical difficulties. The company’s non-profit partner, OneWorld Health, explains that “the yield of artemisinic acid would need to be improved several hundred fold to be economically acceptable for large-scale manufacturing.”¹³⁹ Meanwhile, WHO notes that “clinical trials have not yet begun, and filing for regulatory approval will probably not occur before 2009 to 2010.”¹⁴⁰

If microbial production of synthetic artemisinin is commercially successful, pharma giants like Novartis would benefit because it will allow them to replace a diverse set of small suppliers with one or two conveniently located production factories. The Royal Tropical Institute notes that, “pharmaceutical companies will accumulate control and power over the production process; artemisia

producers will lose a source of income; and local production, extraction and (possibly) manufacturing of ACT in regions where malaria is prevalent will shift to the main production sites of Western pharmaceutical companies.”¹⁴¹

Could artemisia be a viable crop for small farmers in sub-Saharan Africa?

Are local production, extraction and even manufacturing of ACTs possible in regions where malaria is prevalent? The Dutch researchers who studied this possibility conclude that it won't be easy – requiring not only a hefty capital investment, but also “a total redesign of the supply and distribution chain.”¹⁴² They suggest a number of policies that could be implemented to promote cultivation of *Artemisia annua* while at the same time protecting farmers from un-due risk. For example, a procurement fund could be established in Africa to stabilize the market for artemisia; quality seed could be made available to African farmers; other medicinal crops could be promoted to reduce the economic risk to farmers; a task force could be established to enhance transparency, coherent policy making and knowledge sharing.¹⁴³

Where ACT drugs are not accessible or affordable, community-based efforts are focusing on local production of artemisia plants for use in herbal tea to treat malaria. Conventional health systems such as WHO do not sanction the use of artemisia tea because of the difficulty of establishing a standard dosage and quality control. However, Anamed (Action for Natural Medicine), a Christian-based group of scientists and health workers, believes that the tea is effective in treating upwards of 80% of malaria cases.¹⁴⁴ Anamed's “grow your own” approach to fighting malaria provides artemisia seeds, community workshops and agronomic support for small-scale plots based on mixed farming methods across Asia and Africa. Anamed promotes a method of combining the tea with other compounds (either cheap medicines or locally adapted herbs) to mimic the combination effect of pharmaceutical ACTs, but without using proprietary drugs. Anamed believes that compounds found in artemisia leaves, including 36 different flavonoids, enhance the anti-malarial properties of the tea (which they say are lost when the compound is purified for drug use).¹⁴⁵

While the use of artemisia tea may be controversial, the need to increase the world's supply of artemisia is not. Anamed has developed a variety of artemisia adapted to African conditions known as *Artemisia annua anamed* (A-3) and the group has introduced over 715 artemisia growing projects in 75 countries.¹⁴⁶ Their partners include the World Agroforestry Center (ICRAF) in Mozambique, which has taught thousands of southern African farmers in their network how to grow artemisia from stem cuttings.¹⁴⁷ Anamed's seeds are sold for US\$.01 per seed and each plant can treat up to eight malaria sufferers. Those plants can then be further propagated by taking stem cuttings.¹⁴⁸

No one knows if synthetic biology will ultimately deliver safe and sufficient quantities of low-cost artemisinin for controlling malaria in the developing world. Can OECD donors and philanthropists who have failed to deliver malaria nets to malaria-stricken countries claim that hefty investments in synthetic biology will pay off for poor people? Those who are pouring money into the use of microbial production of artemisinin should insure that a single-minded, high-tech approach does not foreclose options for community-based, farmer-led approaches.

VivaGel – Downsizing Microbicides

“Microbicides” refer to a range of compounds now under development that aim to reduce or prevent the transmission of HIV and other sexually transmitted diseases (STDs) when applied topically. Worldwide over 7,000 women become infected with HIV every day. Some women’s health advocates are promoting the development of microbicides because they could put safe, affordable and accessible protection into the hands of women.¹⁴⁹ Microbicides are not yet commercially available, but almost 20 are in clinical trials.

One of the vaginal microbicides in human trials, Starpharma’s “VivaGel,” is based on nano-scale molecules called **dendrimers** – synthetic, three-dimensional molecules with branching parts. The active ingredient in VivaGel works like molecular velcro – inactivating HIV and genital herpes viruses by binding with receptors on the virus’s surface and preventing it from attaching to the host cells it is trying to infect.¹⁵⁰

VivaGel is being developed as a topical microbicide that has the potential to prevent the transmission of HIV and other sexually transmitted diseases when applied to the vagina prior to sexual intercourse. In animal studies, the main ingredient in VivaGel has also acted as an effective contraceptive.¹⁵¹ If VivaGel can protect against STDs and pregnancy, market analysts see it competing with the condom market.¹⁵² VivaGel is the first dendrimer to go through the FDA process and is now being tested around the world in various populations.¹⁵³ In 2005 the US National Institutes of Health (NIH) awarded Starpharma (based in Melbourne, Australia) US\$20.3 million to support the development of VivaGel for the prevention of HIV. In April 2006 the US NIH announced it would fund a clinical trial to test the use of VivaGel in the prevention of genital herpes.

VivaGel is a proprietary technology, and Starpharma's self-described business strategy "is to create value from dendrimer nanotechnology by utilising its IP through product development, licensing and partnerships."¹⁵⁴ Starpharma holds rights to three broad-based US patents in the dendrimer pharmaceutical area. Dendritic NanoTechnologies, Inc. (DNT) is a wholly owned subsidiary of Starpharma and holds more patents on dendrimer technology than any other company.

Ultimately, will vaginal microbicides be safe, affordable and accessible to those who need them most? (Sex workers in Nigeria are now applying lime juice to their vaginas in an attempt to protect themselves from contracting HIV – will they have access to high tech protection in the near future?¹⁵⁵) Some women's health advocates point out that a simple, low-cost technology already exists (condoms) that is easier to distribute and store – but condoms remain in short supply. For example, in 2003, donor contributions paid for the equivalent of one condom a year for each man of reproductive age living in the developing world.¹⁵⁶

According to Eldis (Institute of Development Studies, Essex) the development of a microbicide, which is replicable, sustains a good shelf life and is attractive to users, will require an estimated US\$600 million over the next ten years.¹⁵⁷ In theory, microbicides could give women greater power to protect themselves against HIV without having to rely on partner cooperation. But gender inequality is the root problem, and unless that is addressed, a new technology cannot offer a simple solution. Some women's health advocates believe that money could be better spent on programmes to empower women, to increase their income and ability to control their own lives. There are also numerous health and safety issues surrounding the development of microbicides, especially in the global South where poor living conditions can complicate safe and effective use. Based on historical patterns, there is concern that political pressures to approve effective microbicides could compromise rigorous testing and that vulnerable populations of women will be used as guinea pigs (i.e., early clinical trials of one microbicide [not Starpharma's] tested on sex workers actually increased the incidence of HIV infection in women).¹⁵⁸

Nanomonopoly

Ultimately, intellectual property issues will play a major role in deciding who will capture nanotech's trillion dollar market, who will gain access to nano-scale technologies, and at what price. According to Stanford University Law professor, Mark Lemley, "...patents will cast a larger shadow over nanotech than they have over any other modern science at a comparable stage of development."¹⁵⁹

Table 5: International patents on nanotechnology

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
U.S.	114	163	194	307	412	589	935	1,029	1,370	1,734
Europe	45	70	96	110	151	214	250	356	407	638
Asia	15	15	27	34	47	95	144	226	244	349
Rest of world	8	16	19	27	48	50	60	82	86	140
TOTAL	182	264	336	478	658	948	1,389	1,693	2,107	2,861

Source: Lux Research, *The Nanotech Report*, 5th edition

The world’s largest transnational companies, leading academic labs and nanotech start-ups are all racing to win monopoly control of tiny tech’s colossal market. A study conducted by the University of Arizona and the US National Science Foundation found that 8,630 nanotech-related patents were issued by the US Patent and Trademark Office in 2003 alone, an increase of 50% between 2000 and 2003 (as compared to about 4% for patents in all technology fields).¹⁶⁰ The top five countries represented were: US (5,228 patents), Japan (926), Germany (684), Canada (244) and France (183). The top five entities winning nanotech-related patents included four multinational electronic firms and one university: IBM (198 patents), Micron Technologies (129), Advanced Micro Devices (128), Intel (90) and University of California (89).

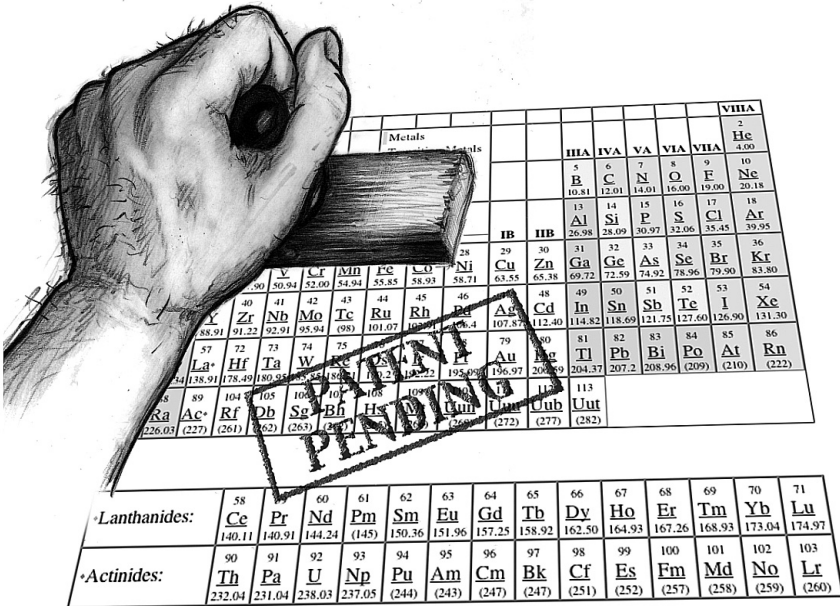
“It is true that one cannot patent an element found in its natural form; however, if you create a purified form of it that has industrial uses – say, neon – you can certainly secure a patent.” - Lila Feisee, Biotechnology Industry Organization’s Director for Government Relations and Intellectual Property¹⁶¹

“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.

Downsizing Development

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.¹⁶² Whereas biotechnology patents make claims on biological products and processes, nanotechnology patents may literally stake claims on chemical elements, as well as the compounds and the devices that incorporate them. In short, molecular-level manufacturing provides new opportunities for sweeping monopoly control over both animate and inanimate matter.

At stake is control over nano-scale materials, devices and processes that cut across multiple industry sectors because a single nano-scale innovation can be relevant for widely divergent applications. As the *Wall Street Journal* put it, “companies that hold pioneering patents could potentially put up tolls on entire industries.”¹⁶³



Today, broad patents are being granted that cut across multiple industry sectors and include sweeping claims on entire areas of the Periodic Table. Patents on individual chemical elements are not unprecedented. Glenn Seaborg, the 1951 Nobel Prize winning physicist won US patent #3,156,523 for the chemical element Americium (element no. 95 on the periodic table) on November 10, 1964. Seaborg's second patented element was Curium (#96) – US patent #3,161,462 granted on December 15, 1964. More recently, when Harvard University's Charles Lieber obtained a key patent (US patent 5,897,945) on nano-scale metal oxide nanorods, he didn't claim nanorods composed of a single type of metal – but instead claimed nano-structured compounds composed from any of 33 chemical elements. Patent lawyers have identified Harvard's patent (licensed exclusively to Nanosys, Inc.) as one of the top ten patents that could influence the development of nanotechnology.¹⁶⁴

Although industry analysts frequently assert that nanotech is in its infancy, “patent thickets” on fundamental nano-scale materials, tools and processes are already creating thorny barriers for would-be innovators. To the extent that these are “foundational” patents – that is, seminal breakthrough inventions upon which later innovations are built – researchers in the developing world could be shut out. Researchers in the global South are likely to find that participation in the “nanotech revolution” is highly restricted by patent tollbooths, obliging them to pay royalties and licensing fees to gain access.¹⁶⁵

Diamond vs. Chakrabarty Remembered

June 16, 2005 marked the 25th anniversary of *Diamond vs. Chakrabarty*, the landmark US Supreme Court decision that opened the floodgates to the patenting of all life forms. The anniversary offered a timely opportunity to examine current trends in intellectual property (IP) relating to nano-scale technologies – the world's newest technological wave. In 1971, Ananda Chakrabarty, an employee of General Electric, applied for a patent on a genetically modified, oil-eating microbe. His patent application was rejected by the US Patent & Trademark Office (US PTO) on the grounds that animate life forms were not patentable. When Chakrabarty won his case on appeal, the PTO Commissioner, Sidney Diamond, took the case to the US Supreme Court. On June 16, 1980 by a narrow 5-4 margin, the US Supreme Court ruled that Chakrabarty's oil-eating microbe was not a product of nature; living organisms could be seen as human made inventions and are therefore patentable subject matter. An ironic footnote to the saga is that the “invention” didn't work.

The monumental importance of the Chakrabarty decision did not register with the Court – or the public – at the time. (Some environmentalists were eager to embrace life patenting if it meant microbes could devour oil spills.) In 1980 the Supreme Court specifically noted that the Chakrabarty decision was a narrow case that would not affect the “future of scientific research.” The Court got it wrong. According to lawyer and activist Andrew Kimbrell, “The complete failure by the Court to correctly assess the impacts of the Chakrabarty decision may go down as among the biggest judicial miscalculations in the Court’s long history.”

As a result of Chakrabarty, the slippery slope of IP on living organisms became a patent landslide, and a bonanza for the biotech industry. Over the course of a single decade, the US government re-interpreted intellectual property laws to allow for exclusive monopoly control over all biological products and processes. After Chakrabarty, the once unthinkable patenting of genes, plants, animals, microorganisms and human genetic material would become common practice in the US – positioning industry and the US government to set the precedent for IP regimes worldwide via the World Trade Organization (WTO) and through bilateral and regional trade agreements.

The Chakrabarty “Life Patenting” Timeline

- 1980** – Diamond v. Chakrabarty – US Supreme Court case establishes precedent for the patenting of living organisms.
- 1980** – US Bayh-Dole Act allows businesses, universities and non-profit organizations to retain title to patents that result from federally-funded research, and to exclusively license them.
- 1984** – University of California wins US patent on a cell line developed from cancerous tissue of John Moore, a leukemia patient whose cancerous spleen cells were patented and commercialized without his knowledge.
- 1985** – US PTO rules that genetically engineered plants, seeds and plant tissue are patentable subject matter.
- 1986** – Uruguay Round of General Agreement on Tariffs and Trade (GATT) begins with Trade-Related Intellectual Property (TRIPs) on the table.
- 1987** – US PTO rules that genetically modified animals are patentable subject matter.
- 1988** – US PTO issues first patent on a living animal – a transgenic mouse. Harvard licenses the “OncoMouse” to Dupont.
- 1993** – Patent claim by the US Secretary of Commerce on the cell line of a 26-year old Guaymi indigenous woman from Panama. Following worldwide controversy, the US government abandoned its patent claim on the Guaymi cell line in November 1993.
- 1994** – European Patent Office (EPO) issues species-wide patent on all genetically modified soybeans to Agracetus (later acquired by Monsanto).
- 1995** – WTO comes into force at the conclusion of the Uruguay Round of GATT.

- 1995** – Civil society organizations and social movements in Europe defeat European Patent Directive that aims to harmonize patenting of genetic material within the EU. 1995 – US Supreme Court rules in *Asgrow vs. Winterboer* that farmers no longer have the right to harvest and re-sell proprietary seed for reproductive purposes (that is, proprietary seed protected by Breeders' Rights – plant variety protection – may be saved only for the purpose of re-planting the farmers' own acreage).
- 1995** – US PTO issues patent to US National Institutes of Health for an unmodified human cell line from an indigenous person from Papua New Guinea. Due to the international controversy, the US government is forced to disclaim the patent in December 1996.
- 1998** – European Parliament gives final approval to a controversial biotechnology “patent directive” that aims to harmonize national legislation on the patenting of genetic material within the EU. The Directive creates, for the first time in European history, an explicit legal right to patent higher organisms such as plants and animals.
- 2002** – Canadian Supreme Court rules against patenting of higher life forms – rejects patenting of genetically modified mouse.
- 2004** – Canadian Supreme Court (*Monsanto v. Schmeiser*) affirmed Monsanto's right to prosecute farmers who are found to have proprietary GM crops growing on their land – whether they wanted them or not.
- 2004** – US Patent & Trademark Office establishes nanotechnology patent class.
- 2006** – The European Patent Office begins to publicly classify nanotechnology patents.
- 2007** – The European Patent Office revokes Monsanto's species-wide patent on genetically modified soybeans, 13 years after it was first challenged.
- 2007** – The J. Craig Venter Institute applies for worldwide patents on the world's first-ever human-made species. The novel bacterium is made entirely with synthetic DNA in the laboratory.

Lessons learned from Chakrabarty

- Historic decisions allowing exclusive monopoly control of all biological products and processes involved no public input or wider societal debate; these decisions were made by a handful of individuals in the courts and patent offices – not by the US Congress. In essence, it was the courts and not citizens who gave biotech the green light in the US. Similarly, at the international level, intellectual property rules have been crafted by and for a narrow group of corporate interests.
- Following Chakrabarty, the US government’s aggressive life patenting policies set the bar for the rest of the world – especially at the World Trade Organization.
- The slope is slippery indeed. The history of patent monopoly (see box next page) demonstrates that patent holders typically seek wider patentability, more expansive scope of patent claims, longer patent terms and greater harmonization of patent rules worldwide.
- For many developing nations the rationale for accepting stronger IP regimes has been the argument that their economies would prosper from increased technology transfers and foreign direct investment. In the case of biotechnology, however, the vast majority of key enabling technologies are proprietary products and processes, tightly concentrated in the hands of multinational gene giants. Under these conditions, stronger levels of IP obligate developing countries to make a massive transfer of resources to the North, in order to acquire licenses for proprietary technologies.¹⁶⁶ A 2005 study by the World Bank concludes that the effects of stronger intellectual property regimes in creating greater trade flows to developing countries are “theoretically ambiguous.”¹⁶⁷ The authors conclude, however, that stronger levels of intellectual property in developing countries are not a factor in spurring high-technology trade flows.¹⁶⁸

From Dust to Dust: A concise history of patent monopoly

The rallying cry “no patents on life” has become a line in a technological and legal sandstorm. Although the notion of intellectual monopolies can be traced back to early Greece, patents did not come into their own until Britain’s Industrial Revolution when the inventors of textile machinery demanded “protection.” Recognizing that patents would make technology accessible only to well-heeled manufacturers, smaller enterprises protested. The response: “Don’t worry. We only seek to patent the machines we invented.”

In the 1920s and 30s, when rose and chrysanthemum breeders demanded intellectual property for their flowers, they argued that it was unfair to grant patents to machine inventors but to deny equal rights to ornamental inventors. Although some were repelled by the idea that living things could be patented, the flower companies replied, “Don’t worry. These patents protect only decorative plants – not food crops.”

In the 1960s, when plant breeders called upon governments to grant them intellectual property over food crops, they said it was unfair to recognize the minor contributions of ornamental breeders without recognizing the contributions of the breeders of crop varieties. The companies chided their critics by saying, “Don’t be alarmed. We just want breeders’ rights to protect plant varieties; we’re not patenting plants, animals or human genetic material, and we would never stop farmers from saving seed.”

In 1980, the Gene Giants won patents on genetically modified microbes. A few years later they applied for patents on plants and animals. When civil society protested, industry responded, “Why all the fuss? If you allow the patenting of micro-organisms, why not plants and lab rats?” In the 1990s, corporations and governments began to patent genes, snippets of DNA, and entire human cell lines.

When indigenous peoples protested, patent offices responded, “Don’t worry. Human cell lines are just microorganisms.” Meanwhile, patents made it illegal for farmers to save and re-use proprietary seed. The seed/biotech industry denounced the 12,000-year old right of farmers to save harvested seed as patent infringement. With the advent of nano-scale technologies, corporations are patenting essential building blocks of all living and non-living things. Industry is redefining life to create hybrid organisms that will take on machine functions. When we tell them they have gone too far, they will reply, “Don’t worry. We’re all just machines.”

Technologies Converging at the Nano-Scale

Nano-scale science offers the possibility of converging diverse technologies – including biotechnology, cognitive sciences, informatics, robotics, etc., with nanotechnology as the key enabler. That’s nano’s real power and its greatest attraction. The logic of technological convergence lies in an understanding that all matter, fundamental to all sciences, originates at the nano-scale where we find “material unity.”¹⁶⁹ In other words, macro-world distinctions – between materials and even between scientific disciplines – cease to exist at the level of atoms and molecules. At the nano-scale, there is no difference between living and non-living matter, for example: DNA becomes just one more molecule that can be combined or interchanged with other molecules.

Scientists and governments in the US and Europe are advancing technological convergence through various strategies and many are convinced that it will trigger a huge industrial revolution and societal “renaissance” – a guarantee of unprecedented wealth, health and, in the case of the US, military hegemony. The US National Science Foundation refers to technological convergence as NBIC, an acronym derived from *nanotech*, *biotech*, *informatics* and *cognitive neuroscience*; European policy makers refer to CTEKS (**converging technologies for the European knowledge society**). Technological convergence also adds up to **BANG** – the quest to control all matter, life and knowledge through the manipulation of **Bits** (information technology), **Atoms** (nanotechnology), **Neurons** (cognitive neurosciences) and **Genes** (biotechnology).

According to this “little BANG theory,” nanotechnology will pave the way for re-engineering neurons so that our brains can “talk” directly to computers or to artificial limbs; viruses can be engineered to act as machines or even as weapons; computer networks can merge with biological networks to develop artificial intelligence or super 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. Some believe that BANG may even eliminate death, bringing about a fundamental change to the human condition – a dream-come-true according to some, a potential nightmare to others.¹⁷⁰

If realized, the goal of enhancing human performance will exacerbate an ever-widening gulf between those “improved” through technology and those who remain “unimproved,” either by choice or lack of choice. As technologies shift society’s concept of what is “normal,” we’ll all find ourselves 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 could forcibly medicate a death row inmate to make him sane enough to execute.¹⁷¹ In a world where "enhancement" becomes an imperative, the rights of the disabled will be further eroded if disability is perceived as one more technological challenge rather than an issue of social justice.¹⁷²

"This grand convergence of biotechnology and nanotechnology is going to blur the distinction between the animate and inanimate worlds, which could cause problems because the way we organize our society is based on a well-defined distinction between living and non-living. There could be ethical issues over the rights we assign to synthetic materials that are alive and at the same time not alive." – **Donald Fitzmaurice**, University College Dublin.

Synthetic Biology and Nano-biotechnology

At the nano-scale, the distinction between living and non-living blurs: DNA becomes just another molecule. "Nanobiotechnology" refers to the integration of biological materials with synthetic materials to build new molecular structures. Similarly, "synthetic biology" refers to the construction of new living systems in the laboratory that can be programmed to perform specific tasks. When synthetic biology involves the integration of living and non-living parts at the nano-scale, it's synonymous with nanobiotechnology.

With the rapid emergence of nanobiotechnology, genetic engineering is suddenly so last-century. The world's first synthetic biology conference convened in June 2004 at Cambridge (USA), followed by annual conferences at Berkeley (USA) in 2006 and Zürich in 2007. Also in 2004, the University of California at Berkeley established the first synthetic biology department in the United States. By July 2005 venture capitalists had raised US\$43 million to bankroll two start-up companies specializing in synthetic biology.¹⁷³

Synthetic biologists and nanobiotechnologists aim to harness nature's self-replicating "manufacturing platform" for industrial uses. Today, researchers are building biological machines – or hybrid organisms employing both biological and non-biological matter. The implications of human-directed, made-to-order life forms are breathtaking:

"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).¹⁷⁴

- Engineer Carlo Montemagno has created a device, less than a millimeter long, made from rat heart cells combined with silicon.¹⁷⁵ 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."¹⁷⁶
- Scientists at the University of California's new synthetic biology department are designing and constructing "biobots" – autonomous robots designed for a special purpose that are the size of a virus or cell, and composed of both biological and artificial parts.¹⁷⁷
- Chemists at New York University have created a two-legged, DNA robot capable of bi-pedal motion.¹⁷⁸ In the future, the researchers hope that they can coax cells to manufacture DNA-based robots. If nano-scale manufacturing is to become a reality, molecular-scale robots will need to assemble other nanomachines and be able to move molecules.

- Researchers are using proteins from spinach chloroplasts to create electronic circuits – resulting in the world’s first solid-state photosynthetic solar cell.¹⁷⁹
- Angela Belcher, material scientist at MIT, has genetically engineered the DNA of viruses, inducing them to grow tiny inorganic wires with magnetic and semiconducting properties that may someday provide circuitry in high-speed electronic components.¹⁸⁰
- With funding from the US Department of Energy, the J. Craig Venter Institute is building a new type of bacterium using DNA manufactured in the laboratory. The goal is to build synthetic organisms that can be programmed to produce hydrogen fuel or be used in the environment to sequester carbon dioxide.¹⁸¹ Venter launched Synthetic Genomics, Inc. in 2005 dedicated to creating designer organisms (see next page).
- Researchers at the Scripps Institute in La Jolla, California have created an artificial base that can be added to the four naturally-occurring bases of DNA (A, G, C and T). As the DNA strand replicates, the artificial base (known as 3FB) pairs up with another 3FB to form a completely new base pair. The goal is to incorporate the new and improved DNA into a microbe to learn how it evolves.¹⁸²

In the wake of startling advances in the field of synthetic biology, the potential “for abuse or inadvertent disaster” is enormous.¹⁸³ In January 2005 scientists unveiled a new, automated technique that makes it faster and easier to synthesize long molecules of DNA.¹⁸⁴ But researchers warn that this revolutionary advance for synthesizing 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.

The fields of synthetic biology and nanobiotechnology raise many concerns: Will new, self-replicating life forms, especially those that are designed to function autonomously in the environment, open a Pandora’s box of unforeseen and uncontrollable consequences? Some researchers in the field have begun to acknowledge potential risks and ethical implications of their work. In 2004 the editors of *Nature* called on scientists working in the field of synthetic biology “to consult and reflect carefully about risk – both perceived and genuine – and to moderate their actions accordingly.”¹⁸⁵

In June 2005 the J. Craig Venter Institute, the Center for Strategic & International Studies and MIT announced a joint project to examine the societal implications of synthetic biology and regulatory needs.¹⁸⁶ Unfortunately, those who are stepping up to assess the societal implications of synthetic biology are closely linked to those seeking to commercialize it. One of the project's directors, Drew Endy of MIT, is co-founder of Codon Devices, a company that synthesizes customized DNA segments.¹⁸⁷ Another project director, Robert Friedman, is employed by the Venter Institute, whose founder, Craig Venter, raised US\$30 million from private investors to establish Synthetic Genomics, Inc. in 2005, a company that aims to manufacture organisms for industrial purposes.

Propelled by venture capital and taxpayer dollars, the fields of synthetic biology and nanobiotechnology are advancing rapidly in the absence of public debate or regulatory oversight. For most governments, nanobiotechnology and synthetic biology aren't even on the radar. Efforts to address the far-reaching social, ethical and environmental implications of synthetic biology must not be confined to a group of self-appointed experts. Nor should oversight be postponed because the science is perceived (wrongly) to be in the distant future.

Conclusion and Policy Recommendations

In a just and judicious context, nanotech could bring useful benefits to the poor – cleaner water, cheaper energy and improved health. There could also be significant environmental gains from replacing some conventional materials with new nanomaterials. But in a world where privatization of science and unprecedented corporate concentration prevail, it is the technological imperative and pursuit of profits that are propelling the tiny tech revolution – not human development needs or social justice. Will poor communities gain access to nanotech's proprietary products? Will developing nations reap the benefits of new technologies that are being developed for military uses? Will today's nanotech patent grab establish barriers to entry and 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 and widen the gap between rich and poor. When the root problems are poverty and social injustice, new technology is never the silver bullet solution.

Haven't we been here before? Genetically modified crops came to market one decade ago with virtually no public discussion of their risks and benefits, and within regulatory frameworks that civil society organizations have described as inadequate, non-transparent or non-existent. As a result, questions and controversies surrounding socio-economic, health and environmental impacts of GM foods are unresolved, and millions of people have spurned GM products. The parallels between the introduction of biotech and nanotech are undeniable. Despite the nanotech community's persistent vows not to repeat the same clumsy mistakes, it has been following in the same footsteps.

In 2006, according to Lux Research estimates, the level of worldwide corporate and venture capital funding of nanotech R&D approached the level of government funding – with the private sector investing nearly US\$6 billion compared to governments' US\$6.4 billion investment.¹⁸⁸ The fate of converging technologies at the nano-scale will likely be sealed in the immediate years ahead. Unfortunately, governments are so far acting as cheerleaders – not regulators – in addressing the nanotech revolution. Convinced that technological convergence at the nano-scale is the “future,” leading nano backers – especially the US, Europe and Asia – are in an all-out race to secure economic advantage: health and environmental considerations are secondary; socioeconomic impacts will have to wait; regulations, if they can't be avoided, must be voluntary so as not to hinder commercial development of nanotech R&D.

With public confidence in both private and government science at an all-time low, full societal debate on nano-scale convergence is critical. It is not for scientists and governments to “educate” the public but for society to determine the goals and processes for the technologies they finance. How can society assert democratic control over new technologies, and participate in assessing research priorities? The following recommendations are offered as a starting place:

First and foremost, society must engage in a wide debate about nanotechnology and its multiple economic, health and environmental 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 – including intellectual property. Who will control the technologies? Who will benefit from them? Who will play a role in deciding how nanotechnologies affect our future?

The UN system has yet to wake up to the need to control and govern nanotechnology through their institutions. National delegates at the Convention on Biological Diversity (CBD) and at the Food and Agriculture Organization (FAO) have expressed concern outside the plenaries and suggestions have also been made that the United Nations Environment Programme's new Strategic Approach to International Chemicals Management (SAICM) should consider nanotoxicity in its scope. Unfortunately none of these bodies nor the United Nations Conference on Trade and Development (UNCTAD), the International Labour Organization (ILO), the World Health Organization (WHO) or the Human Rights Council have yet begun to consider nanotechnology risk issues or economic, societal, human rights and workforce implications. In February 2005, the United Nations Industrial Development Organization's research Center at Trieste did convene a small meeting of South and North scientists to discuss the potential application of nanotechnology to development issues. Unhappily, this was more a cheerleaders' and fund-seekers' gathering than a real discussion of the pros and cons – risks and opportunities of the new technology. The United Nations Educational, Scientific and Cultural Organization (UNESCO), too, has begun to address some ethical implications with the publication of a 2006 report, "The Ethics and Politics of Nanotechnology." Perhaps more significantly, the UN's own report warns that the accelerated introduction of new technologies outpaces governments' capacity to understand them – and could actually pose great risks for both society and the environment.¹⁸⁹ The South, especially, needs a coherent UN approach to nanotechnology.

Recent reports by governments and civil society have called for the restriction and/or prohibition of manufactured nanoparticles in the environment. Some civil society organizations have gone further, calling 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. Given the regulatory vacuum and inertia by leading nano nations to act, the call for a moratorium is justified and deserves public support.

Until society can engage in a thorough analysis of the health, environmental and socio-economic implications of synthetic biology, governments must move to establish a moratorium on lab experimentation with – and the release of – synthetic biology materials.

Society needs innovative approaches to monitor and assess the introduction of new technologies. The international community should create a new United Nations body with the mandate to track, evaluate and accept or reject new technologies and their products. Civil society organizations have put forward proposals for an International Convention on the Evaluation of New Technologies (ICENT) (See Appendix A).

Appendixes

Appendix A:

ICENT

A call for an early warning/early listening system

In June 2005 ETC Group began discussions with a number of governments, intergovernmental agencies, and civil society organizations in Geneva and elsewhere with the intent of developing a long-term strategy to address the introduction of significant new technologies. Although some parties would like to see a *sui generis* Nanotech Protocol similar to the Biosafety Protocol, there is growing sympathy for ending the “crisis cycle” that has dogged new technologies in recent years by establishing an intergovernmental framework that would allow for the monitoring and evaluation of new technologies as they evolve from initial scientific discovery through to possible commercialization. A generic, transparent, facility could earn the confidence of governments and society as well as of the scientific community and could reduce unproductive posturing and polemic debate.

For the purpose of discussion, ETC group has called this new facility ICENT. A description of this facility is summarized below.

ICENT: International Convention for the Evaluation of New Technologies

What is ICENT? A legally-binding United Nations Treaty either negotiated through a Specialized Agency such as UNCTAD or the ILO, or through ECOSOC’s Commission on Sustainable Development (CSD), ICENT is designed to provide an early warning/early listening system capable of monitoring any significant new technology.

Why ICENT? Southern governments will welcome the early warning, open assessment, and facilitated access elements of the initiative. Some risk assessment and regulatory expenses would be secured at the international level. The North – including scientific organizations, industry, and governments will welcome an end to unpredictability and societal distrust and the establishment of a generalized, non-crisis approach to technology diffusion. Civil society will welcome a transparent and participatory process with both early listening and technology conservation/diversification potential.

Objective: To create a socio-political and scientific environment for the sound and timely evaluation of new technologies in a participatory and transparent process that supports societal understanding, encourages scientific discovery, and facilitates equitable benefit-sharing. Further, to ensure the conservation of useful, conventional or culturally-distinct technologies and, in particular, to promote technological diversification and decentralization. Additionally, the process objective is to clarify the need for such a convention; to stimulate high-level and societal discussion, and, to encourage national and regional legislative and institutional initiatives that would compliment an international agreement.

Timeline: ETC Group estimates that governments will take 8-10 years to conclude Treaty negotiations and the ratification process – meaning that ICENT’s work is unlikely to get underway until 2015 or later. Given the tremendous developments expected in technological convergence at the nano-scale and, in particular, developments in nanobiotechnology (synthetic biology), it is important that negotiations begin as soon as possible. ICENT’s work horizon should run 10-20 years ahead of the likely introduction/commercialization of significant new technologies.

Elements: The Member States will form a Conference of the Parties to the Convention. COP will be supported by a modest Secretariat and enabled by a Bureau comprised of regionally determined representative states. COP will meet biennially while the Bureau will meet semi-annually. Two expert permanent committees, consisting of all members, will convene annually and will ordinarily report to COP through the Bureau.

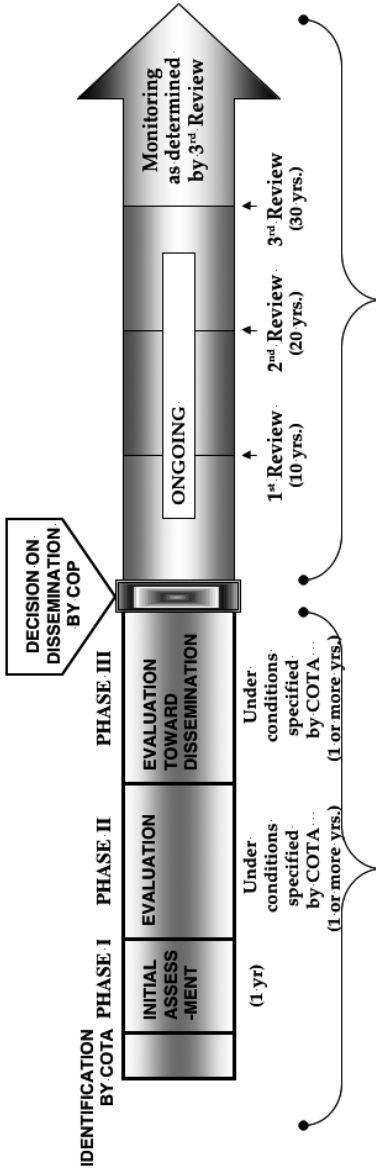
COTA, the Committee on Technology Assessment, will identify significant new technologies; establish appropriate evaluation processes for each identified technology; review progress; and recommend each technology’s dismissal, delay or diffusion to COP.

COTDAC, the Committee on Technological Diffusion and Conservation, will promote the conservation and enhancement of conventional/cultural technologies; encourage technological diversification; promote public participation and understanding; and support the diffusion of appropriate new technologies. COTDAC will have the financial resources to support national capacity-building in science and technology, and to encourage broad and equitable dissemination.

Although it will function financially and politically as an independent non-governmental agency, **ACSENT** (Advisory Committee for the Socio-Economic and Ecological Evaluation of New Technologies) will be a centre of scientific excellence dedicated to the independent monitoring of science and technology and will have the necessary resources to offer the international community an alternative or additional perspective on technologies and their dissemination.

Process: Assuming an effective early listening process, the intent is to identify potentially significant new technologies as the science is emerging so that the assessment process runs parallel to – and need not constrain – the research and development process. Preferably, even “high-impact” technologies would clear the assessment process as or before the technology is ready for commercialization.

STANDARD TECHNOLOGY ASSESSMENT PROCEDURE



Assessment issues

- → Evaluation takes place as scientific development continues unless otherwise required by COTA;
- → Each phase requires COTA approval;
- → Specific conditions for each phase to be set by COTA;
- → Promoter's projections to be received for each phase;
- → Diffusion approval by COP;
- → Monitoring, following diffusion, at three, 10-year intervals

Diffusion Issues

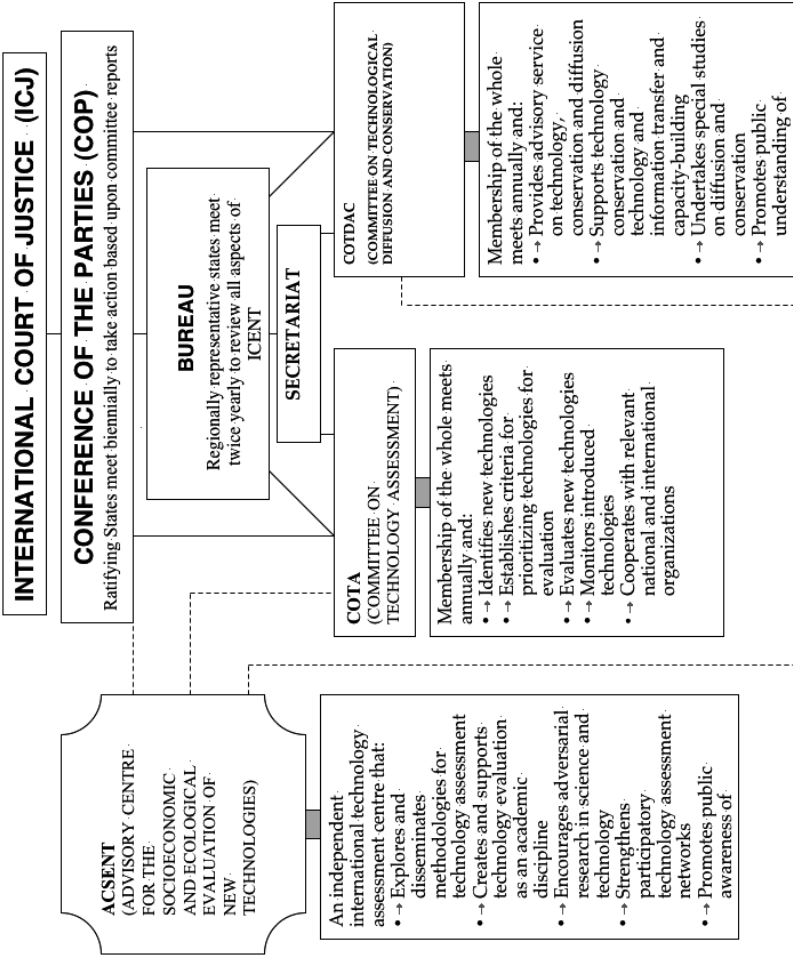
- → Credible impact/recall scenarios provided;
- → Socio-economic benefits;
- → Environmental safety;
- → Technological diversity enhanced;
- → Ecosystem applicability assured

TECHNOLOGY DEVELOPMENT PATH

DISCOVERY & RESEARCH

DIFFUSION

ICENT CHART



Appendix B:

Glossary of Terms

Artemisinin – a natural product extracted from the leaves of the sweet wormwood plant that has successfully treated all known strains of malaria. Using synthetic biology, researchers are now attempting to develop a microbe-derived version of artemisinin.

Assembler – a chemical device that, given certain atomic or molecular starting materials, can produce a specific molecular structure. K. Eric Drexler believes that Molecular Manufacture will be made possible with assemblers.

Atom – a particle of matter that uniquely defines a chemical element. It consists of a nucleus surrounded by one or more electrons. Each electron is negatively charged; the nucleus is positively charged and contains particles known as protons and neutrons.

Atomic Force Microscope (AFM) – is an example of **Scanning Probe Microscopy**. An AFM allows interaction with matter on a very small scale, at the level of molecules. The tip of the AFM is attached to the end of a highly sensitive cantilevered arm and touches the surface of the sample to be examined. The force of contact is very small. The AFM records and measures the small upward and downward movements that are needed to maintain a constant force on the sample. The tip “feels” the surface the way a finger might stroke a cheek. Because the touch must be delicate in order not to destroy the sample, several different methods have been developed, including one that gently taps the sample at unimaginably tiny intervals as it moves across its surface. The **AFM** followed the **Scanning Tunneling Microscope** and differs from it by making contact with the material rather than relying on an electrical current running between them, making it possible to see non-conducting materials at the nano-scale.

BANG – an acronym referring to a convergence of technologies whose operative units are Bits, Atoms, Neurons and Genes. The technologies are IT, nanotechnologies, cognitive neuro-sciences and biotechnology. **BANG** is also known as **NBIC** (nano-bio-info-cogno) by the US government and **CTEKS** in Europe (Converging Technologies for the European Knowledge Society).

Buckyball – full name is buckminsterfullerene (commonly called fullerene), named for the architect who invented the geodesic dome. Discovered in 1985 by Robert Curl, Harold Kroto, and Richard Smalley, buckyballs are made of sixty carbon atoms arranged like the hexagons and pentagons of a soccer ball (and not unlike a geodesic dome). Curl, Kroto and Smalley shared the Nobel Prize in Chemistry (1996) for their discovery. The buckyball is the precursor to the nanotube discovered in 1991 by Sumio Iijima.

Catalyst – a substance able to perform catalysis, which is the acceleration of a chemical reaction by lowering the energy barrier. The strict definition of catalysis requires that the catalyst not be affected by the overall reaction.

Cell line – A population of cells propagated in a growth medium (i.e., culture), which is totally derived from, and therefore genetically identical to, a single common ancestor cell.

Composite – in general, refers to anything made up of disparate parts or elements. Nanocomposites are a new class of materials derived from the incorporation of nano-scale particles into **polymers**.

Computational physics – is the study and implementation of numerical algorithms in order to solve problems in physics for which a quantitative theory already exists.

CTEKS – See **BANG**.

Dendrimer Chemistry – In analogy with “smart” biological large molecules such as enzymes and proteins, which have precisely defined three-dimensional structures, scientists are developing a wide range of strategies for the synthesis, characterization, and applications of synthetic three-dimensional molecules called dendrimers (so named because the structures resemble a tree with branches [dendrons]). During the last decade, dendrimer chemistry has expanded dramatically. The development was driven by the practical applications of dendrimers in inkjet toners, *in vitro* diagnostics and MRI contrast agents. The envisaged applications are wider-ranging, including use in the manufacture of advanced microelectronics and magnetic storage devices. The proven capability of dendrimers to host, either in the internal cavities or on the surface, smaller molecules that can be later released over time makes dendrimers promising drug delivery agents, as well as slow delivery agents for perfumes and herbicides.

Gray Goo – Eric Drexler introduced the term in his 1986 book *Engines of Creation: The Coming Era of Nanotechnology*. Gray Goo refers to the obliteration of life that could result from the accidental and uncontrollable spread of self-replicating assemblers. Bill Joy and others have cautioned that the self-replicating miniature robots, though invisible to the human eye, could result in a kind of Gray Goo if their multiplication ever got out of control.

Green Goo – Coined by ETC Group, it is a variation of Drexler’s **Gray Goo**, but the destruction of the planet is not caused by self-replicating machines, but by inadvertent release of a living or hybrid organism engineered at the nano-scale, a product of nanobiotechnology or synthetic biology.

Informatics – the software tools that allow scientists to capture, organize and analyze information data.

Microbicide – a pharmaceutical agent capable of killing viruses or pathogens.

MicroElectroMechanical Systems (MEMS) – integrated mechanical elements on a common silicon substrate. MEMS is a relatively new technology that exploits the existing microelectronics infrastructure to create complex machines with micron-sized feature sizes (a micron is 1000 nm). These machines have many applications, including sensing and communication.

Micron – a measurement equal to one thousand nanometers.

Molecule – a collection of atoms held together by strong bonds. It usually refers to a particle with a number of atoms small enough to be counted (a few to a few thousand).

Molecular Manufacturing/ Molecular Nanotechnology – method of creating products by means of molecular machinery, allowing molecule-by-molecule control of products and by-products through positional chemical synthesis.

Nano – from the Greek “nanos” meaning dwarf; destined to become one of the most popular (and over-used) prefixes of the 21st century. Nano implies the scale of the nanometer, one billionth of a meter.

Nanobiotechnology – The integration of biological materials with synthetic materials on the nano-scale to build new molecular structures. See also **Synthetic Biology**.

Nanometer (nm) – a measurement equal to one billionth of a meter.

Nanoparticle – a small piece of matter, composed of an individual element or a simple compound of elements, typically less than 100 nanometers in diameter. The term can refer to a wide range of materials, including the particulate matter that is expelled as car exhaust. In this document we refer to an industry that has been developing over the last decade to manufacture a range of particles, all on the nano-scale, that exhibit desirable properties. A compound created through traditional chemistry will have one set of properties. If that same compound is engineered to form nanoparticles, it may exhibit enhanced capabilities or even brand new properties. Nanoparticles can be manufactured, in the case of compounds, by vaporizing a solid, adding a reactive gas and cooling the vaporized molecules, which condense into nanoparticles. Pure metal nanoparticles can be also be made by evaporation-condensation techniques, but more creative methods, such as extracting the nano-scale gold that has been taken up by alfalfa plants, are being developed.

Nanotube – cylinder-shaped molecule resembling rolled-up chicken wire. Nanotubes can be made of different substances, but most nanotube research focuses on tubes of pure carbon atoms. Carbon nanotubes are 100 times stronger than steel, impervious to temperatures up to 6,500 degrees Fahrenheit and only one to a few nanometers in width. Carbon nanotubes can be good conductors of electricity and heat. If a carbon nanotube is rolled up evenly, like a sheet of paper with the top and bottom edges lined up, it acts like a metallic conductor, efficiently carrying electricity. If a carbon nanotube is rolled up askew, like a mis-buttoned shirt, then its electrical properties change to those of a silicon-like semiconductor where current can be switched on and off. A transistor requires semiconducting nanotubes. (Kenneth Chang, *New York Times*, 3/27/01).

Periodic Table – a complete list of all known chemical elements (approximately 115, at present) arranged in columns and rows according to chemical properties. Russian chemist Dimitri Mendeleev produced the first list in 1869. Mendeleev's list proposed about 60 elements.

Polymer – a substance, either natural or artificial, consisting of long-chain molecules, derived either by the addition of many smaller molecules or by the condensation of many smaller molecules with the elimination of water, alcohol, or the like. Plastic is the most well-known artificial polymer.

Quantum Dot – is a nano-scale particle (a few hundred to a few thousand atoms) with extraordinary optical properties that can be customized by changing the size or composition of the particle. Quantum dots absorb light, then quickly re-emit the light but in a different colour, which can be “tuned” to any chosen wavelength simply by changing the size of the dots, useful for biological labeling in diagnostics and drug development.

Quantum Mechanics – a system of mechanics based on quantum theory that explains phenomena observable at the atomic level (<50 nm), phenomena that differ from those observable on larger scales.

Quantum Modeling – computer simulations that allow researchers to predict how materials will perform at the nano-scale, governed by the laws of quantum mechanics.

Replicator – a system able to build copies of itself when raw materials and energy are provided.

Scanning Probe Microscopy – a general term that refers to scanning a needle-like tip across the surface of a sample in order to create a graphic image of the sample’s contours.

Scanning Tunneling Microscope – an STM brings a sharp, electrically conducting needle-like tip up to an electrically conducting surface, almost touching it. The tip and the surface are electrically connected so that a current will flow if they touch, like closing a switch. A detectable current flows when just two atoms are in tenuous contact, one on the surface and one on the tip of the needle. By delicately maneuvering the needle over the surface, keeping the current flowing at a tiny, constant rate, the STM can map the contours of the surface with great precision. The STM was developed in an IBM research lab, Zurich, Switzerland, throughout the 70s and 80s and can be used to “pick up” and relocate atoms. If the voltage is increased when the needle is placed exactly over an atom, then the atom will stick to the needle tip; the atom can be moved and positioned while stuck to the needle tip, the voltage lowered and the atom released from the tip and put in the desired spot (K. Eric Drexler, *Unbounding the Future*, pp. 92-94).

Self-Assembly – A method of integration in which the components spontaneously come together, typically by bouncing around in a solution or gas phase until a stable structure of minimum energy is reached. Components in self-assembled structures find their appropriate location based solely on their structural properties (or chemical properties in the case of atomic or molecular self-assembly), with an energy difference between the starting and finished state being the driving force.

Synthetic Biology – Refers to the construction of new living systems in the laboratory that can be programmed to perform specific tasks. When synthetic biology involves the integration of living and non-living parts at the nano-scale, it's synonymous with nanobiotechnology.

Table of Elements – See **Periodic Table**.

Appendix C:

A Case Study of Patents on Carbon Nanotubes

Multinational corporations, universities and nanotech start-ups (primarily in OECD countries) have already secured numerous patents on essential nanotech tools, materials and processes. To the extent that these are “foundational” patents – that is, seminal breakthrough inventions upon which later innovations are built, researchers in the global South could be shut-out. Nanotech patent thickets are already causing concern in the US and Europe.

Nanotech’s “Miracle Molecules” Monopolized?

“Patents concern me greatly, particularly in nanotubes. There are so many patents being issued. I fear that we are setting ourselves up for many years of IP lawsuits. This will have a chilling effect on innovation.”
– **James R. Von Ehr II**, founder and chairman of Zyvex Corporation.¹⁹⁰

What are carbon nanotubes? Carbon nanotubes are large molecules of pure carbon that are long and thin and shaped like tubes, about 1-3 nanometers (1 nm = 1 billionth of a meter) in diameter, and hundreds to thousands of nanometers long. As individual molecules, nanotubes are 100 times stronger-than-steel and one-sixth its weight. Some carbon nanotubes can be extremely efficient conductors of electricity and heat; depending on their configuration, some act as semi-conductors.

Why are they important? Some people believe that nanotubes are one of nanotech’s most promising molecular building blocks because they exhibit unique properties with a wide range of potential commercial applications. Industry enthusiasts believe that carbon nanotubes will radically improve the performance of tiny sensors, electronic and optical devices, catalysts, batteries, fuel cells, solar cells and drug delivery vehicles. Currently 50% of all lithium batteries incorporate carbon nanofibers (wires spun from carbon nanotubes), which double their energy capacity. Some predict that nano-scale carbon transistors will replace silicon transistors within the next decade. Nanotubes are already used in tennis rackets to make them stronger and lighter. Fortifying a bulletproof vest with a small quantity of nanotubes could double its ability to absorb the energy of a bullet.¹⁹¹

One company is developing carbon nanotubes to make plastics fire retardant. Carbon nanotubes are capable of storing up to 65% of their weight in hydrogen – a capacity that could someday make hydrogen fuel cells a cheap and efficient alternative to fossil fuels.¹⁹² Scientists at Rice University are developing a new type of wire made of carbon nanotubes that conducts electricity much better than copper, and could transform the electrical power grid.

The huge potential market for carbon nanotubes hinges on industry's ability to figure out how to produce large quantities of them more cheaply and uniformly. Today, there are at least three major processes for producing carbon nanotubes, but most companies measure output in only grams per day. According to a 2005 report from nanotech industry analysts, Cientifica, the nanotube market is poised for big changes. "Massive improvements in capacity are now such that demand for nanotubes will no longer be constrained by production," predicts Cientifica. A total of 65 tonnes of nanotubes and nanofibers were produced in 2004 with a market value of roughly €144 million. Cientifica predicts that by 2010 carbon nanotube prices will decrease by a factor of 10-100, the global market for nanotubes will surpass €3 billion and Korea will be the major supplier of all types of nanotubes.¹⁹³

Nano Hazards? Despite the huge amount of interest and investment in carbon nanotubes, the toxicological impacts of these and other engineered nanoparticles are still unknown. A handful of toxicological studies reported thus far indicate that there is reason for concern. 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.¹⁹⁴ (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.¹⁹⁵

The Nanotube Patent Thicket: Although nanotech is often described as a nascent industry – patent offices have already granted hundreds of patents on carbon nanotubes. As a result, in those countries where the patents are recognized, it is virtually impossible to make or use materials, devices and systems based on carbon nanotubes without infringing a swarm of existing patents – whose claims are often broad, overlapping and conflicting.

The quagmire is known as a “patent thicket” and it means that any researchers hoping to develop new technology based on carbon nanotubes must first negotiate licenses from multiple patent owners. (And there’s no guarantee that a company will agree to license its patent – especially if it aims to curb competition.) A 2004 review of US patents related to carbon nanotubes conducted by John Miller *et al.* uncovered 306 patents on nanotubes and the methods used to produce them.¹⁹⁶ The survey identified at least ten patents claiming nanotubes, 38 patents on nanotube production methods, 20 patents on general-purpose tools and processes, and over 238 patents on various applications of carbon nanotubes. The authors point out that, even if a company developed a revolutionary new product or process involving carbon nanotubes, the new innovation would undoubtedly infringe existing patents. The authors conclude, “As nanotechnology continues to develop, the minefields of patents will become more difficult to traverse.”¹⁹⁷

Who Owns Patents on Nanotubes? Single-wall carbon nanotubes were discovered in 1991 by Sumio Iijima of Japan, a researcher for Japanese computer giant, **NEC Corporation**. In 2004, the company asserted that any company that wants to manufacture or sell carbon nanotubes must first negotiate a license on NEC’s two seminal patents.¹⁹⁸ NEC is expected to license its carbon nanotube patents widely; in 2004, Japan’s **Sumitomo Corporation** was the first company to negotiate a license.¹⁹⁹ **IBM** also holds an early and fundamental patent on single-wall carbon nanotubes. US Patent No. 5,424,054 has been identified by patent lawyers as one of the ten most important patents that could have an impact on the future development of nanotech. IBM’s patent was licensed to **Carbon Nanotechnologies Incorporated (CNI)**.

CNI is the self-described “preeminent world producer” of carbon nanotubes. The Houston, Texas-based company was founded in 2000 by Rice University Nobel Laureate and entrepreneur, Richard Smalley. According to CNI’s president, Bob Gower, the company holds a portfolio of 30 patents related to carbon nanotubes, and about 12 of them give CNI a lock on the nanotube market. In addition, CNI has 70 patent applications pending that include 4,000 claims on nanotube compositions, methods of production and end-use applications.²⁰⁰ “We expect to be the supplier in this arena,” Gower told the *Houston Chronicle*.²⁰¹

The company sees its patent portfolio as the key to the company’s survival. CNI’s chief financial officer told *Small Times*, “IP protection is critical for everything we’ve done. IP gives us the freedom to price appropriately and keep others from

nipping at the door.”²⁰² CNI’s strategy is to stake claims on the dominant methods used to manufacture carbon nanotubes. In 2005 Richard Smalley asserts that his company has “an exceptional intellectual property position in all the process routes” that are considered practical for large-scale commercial production of single-wall carbon nanotubes.²⁰³ While most of its competitors produce just grams of nanotubes per day, CNI claims that it’s the only manufacturer that can crank out 25 lbs. or more of nanotubes per day, with plans to scale-up to 100 lbs. per day in the future.²⁰⁴

In early 2005 the company also began to manufacture double-wall carbon nanotubes in gram to multiple kilogram quantities.²⁰⁵ (While 25 lbs. per day seems almost negligible, it’s important to keep in mind that CNI sells its tubes by the gram with a one-gram minimum. That means, in theory, that 25 lbs. of nanotubes could represent over 11,000 one-gram orders!) CNI has about 700 customers, including many commercial firms that are purchasing tiny amounts of nanotubes to test in products ranging from plastics, batteries, water purification systems to aerospace, defense and space exploration. One corporate client, Korean electronics titan, **Samsung**, is using CNI’s carbon nanotubes to create a new generation of energy-saving, flat-screen televisions. [In March 2007, CNI merged with Unidym, a nanotube product developer. The new company – Unidym, a subsidiary of Arrowhead Research Corporation – is developing nanotube applications for the electronics industry. Its first product is a transparent and conductive film that will replace the metal oxide films that are currently used in screens, flat panel displays and some solar cells. See www.unidym.com/products_1.html.] **Hyperion Catalysis** based in Cambridge, Massachusetts (USA) claims that its multi-wall carbon nanotubes were first synthesized in 1983, and the company holds a seminal patent issued in 1985.²⁰⁶ The company sells multi-wall nanotubes dispersed in a range of plastics for commercial automotive and electronics applications. Worldwide, there are less than 20 companies making commercial quantities of carbon nanotubes.²⁰⁷

Nanocyl S.A. (Belgium) is the leading manufacturer and developer of carbon nanotubes in Europe. Other players include, for example: **Nanoleedge** in France, **Rosseter Holdings** in Cyprus; South Korea’s **ILJIN**; Moscow’s **Nanocarblab**; **Shenzhen Nanotech Port Co.** in China and Tokyo’s **Carbon Nanotech Research Institute**.

Carbon Nanotube patents issued by US PTO (1999-2004) Top Assignees – 251 patents total		Number of patents
Samsung Electronics and Samsung SDI Co., Ltd.	Korea	23
Rice University	USA	14
Hyperion Catalysis International, Inc.	USA	10
The United States of America	USA	9
Univ. of Kentucky Research Foundation	USA	8
Industrial Technology Research Institute	Taiwan	8
NEC Corp. and Research Institute, Inc.	Japan	7
Intel Corporation	USA	6
Iljin Nanotech Co., Ltd.	Korea	5
Battelle Memorial Institute	USA	4
The Regents of the Univ. of California	USA	4
Agency of Industrial Science and Technology	Japan	4
Hitachi, Ltd.	Japan	4
LG Electronics, Inc.	UK	4
Stanford University	USA	4
The Regents of the Univ. of California	USA	4

The nanotube patent search was conducted on 25 April 2005.

The Bottom Line:

- To the extent that carbon nanotubes represent an important component in nanotech-related materials, they will affect traditional commodity markets and demands for raw materials. Concerns about ownership and control of carbon nanotubes are especially relevant to the global South.
- ETC Group's list of top patent assignees (see chart page 79) of US patents related to carbon nanotubes reveals that ownership of carbon nanotube patents is highly fragmented – there are numerous players in diverse industries.
- There were 140 different primary patent examiners for the 257 patents on nanotubes issued by the US PTO. The lack of uniform handling increases the likelihood that different examiners in different departments reviewed different prior art and this could result in overlapping patent claims.
- ETC Group agrees with analysts who conclude that there currently exists a nanotube patent thicket. A swarm of existing patents, whose claims are often broad, overlapping and conflicting, means that researchers hoping to develop new technology based on carbon nanotubes must first negotiate licenses from multiple patent owners.
- Lux Research, a nanotechnology consulting firm, recently conducted its own study of the IP nanotech landscape. The Lux report concludes that “nanotube patents look messy in electronics,” but they found that carbon nanotube patents are not a problem in all areas (especially energy, healthcare and cosmetics).²⁰⁸
- Since patent databases do not always reveal the current ownership of patents or disclose assignees, our list of leading carbon nanotube patent assignees is not a true reflection of a company or institution's dominant position. CNI claims that it has an exceptional IP position in all the process routes for producing carbon nanotubes, for example, but it is not immediately apparent by conducting patent searches. However, CNI has licensed nanotube patents from Rice University.
- The number of US patents already granted relating to carbon nanotubes is considerable, but the number of patent applications received by US PTO from 2001-2004 is far greater – suggesting that there could be increased activity in the nanotube patent area in the immediate years ahead. US PTO patent applications do not always reveal patent assignees – so it is impossible to predict which companies/institutions are most actively seeking patents in this area, or by whom the patents, if granted, will be controlled.

Appendix D:

Resources for learning more about nano-scale technologies

United Nations

The Codex Alimentarius Commission (www.codexalimentarius.net/web/index_en.jsp) was created in 1963 by FAO and WHO to develop food standards, guidelines and related texts such as codes of practice under the **Joint FAO/WHO Food Standards Programme**. In July 2007, FAO and WHO launched the **Global Initiative for Food related Scientific Advice** (GIFSA: www.fao.org/ag/agn/agns/advice_en.asp and www.who.int/foodsafety/codex/gifssa/en/index.html) to aid the Codex Commission in decision-making related to food, including the use of nanotechnology: (www.fao.org/newsroom/en/news/2007/1000624/index.html).

United Nations Environment Programme (UNEP), *Geo Yearbook 2007*, “Emerging Challenges: Nanotechnology and the Environment,” pp. 61-70; on the Internet: (www.unep.org/geo/yearbook/yb2007/PDF/7_Emerging_Challenges72dpi.pdf).

United Nations Educational, Scientific and Cultural Organization (UNESCO) *The Ethics and Politics of Nanotechnology*, 2006; on the Internet: (<http://unesdoc.unesco.org/images/0014/001459/145951e.pdf>).

WHO: Agenda item for Intergovernmental Forum on Chemical Safety, **IFCS Forum VI**: (www.who.int/ifcs/documents/forums/forum6/en/index.html).

World Health Organization *INFOSAN Note No. 1 (2008)* on Nanotechnology, available in the six WHO official languages online: (www.who.int/foodsafety/fs_management/infosan_archives/en).

World Intellectual Property Organization (WIPO): Nanotech and Patents, (www.wipo.int/patent-law/en/developments/nanotechnology.html).

ETC Group reports on nano-scale technologies, including synthetic biology; available on the Internet at www.etcgroup.org:

Extreme Genetic Engineering: An Introduction to Synthetic Biology, January 2007.

Nanotech Rx – Medical Applications of Nano-scale Technologies: What Impact on Marginalized Communities? September 2006.

NanoGeoPolitics: ETC Group Surveys the Political Landscape, July/August 2005.

Nanotech's Second Nature Patents: Implications for the Global South, June 2005.

Down on the Farm: The Impacts of Nano-scale Technologies on Food and Agriculture, November 2004.

Principles for the Oversight of Nanotechnologies and Nanomaterials, endorsed by more than 40 organizations, July 2007. Available on the Internet: <http://tinyurl.com/28j8tj>.

Friends of the Earth (Australia) Nanotechnology Project: <http://nano.foe.org.au/>.

The **Woodrow Wilson International Center for Scholars** (Washington, D.C.), Project on Emerging Nanotechnologies, including an inventory of manufacturer-identified nanotech consumer products: www.nanotechproject.org.

International Center for Bioethics, Culture and Disability provides a nanotechnology resource page with hundreds of Internet links to information about nano-scale technologies, including journal articles, blogs, news items, reports and patent publications; available on the Internet: www.bioethicsanddisability.org/nanotechnology.html.

For Information from Governments / Institutes on nano-scale technologies:

Europe: European Commission: <http://cordis.europa.eu/nanotechnology>
European Nanotechnology Gateway: www.nanoforum.org

UK: Department for Environment, Food and Rural Affairs (defra): www.defra.gov.uk/environment/nanotech/

USA: www.nano.gov

Asia: Asia Nano Forum: www.asia-nano.org
Asia Pacific Nanotechnology Forum: www.apnf.org

China: www.nanochina.cn/english

Latin America: *MINAPIM, The Micro and Nanotechnology Magazine for Latino America* (in Portuguese, Spanish and English): www.suframa.gov.br/minapim/news

Some Nanotech News Sources:

Meridian Institute Nanotechnology and Development News: www.merid.org/NDN

Science and Development Network:
www.scidev.net/quickguides/index.cfm?qguideid=5

IoP (Institute of Physics, UK): www.nanotechweb.org/cws/home

Acronyms:

ACT	Artemisinin Combination Therapy
AFM	Atomic Force Microscope
ASCENT	Advisory Committee for the Socio-Economic and Ecological Evaluation of New Technologies
BANG	Bits (information technology), Atoms (nanotechnology), Neurons (cognitive neuroscience) and Genes (biotechnology)
CAS	Chinese Academy of Sciences
CBD	Convention on Biological Diversity
CEO	Chief Executive Officer
CNI	Carbon Nanotechnologies Incorporated
COP	Conference of the Parties
COTA	Committee on Technology Assessment
COTDAC	Committee on Technological Diffusion
CSD	Commission on Sustainable Development
CTEKS	Converging Technologies for the European Knowledge Society
DNA	Deoxyribonucleic acid
DNT	Dendritic NanoTechnologies
DOE	Department of Energy (US)
ECOSOC	Economic and Social Council
EIU	Economist Intelligence Unit

EPA	Environmental Protection Agency
EPO	European Patent Office
EU	European Union
FAO	Food and Agriculture Organization (UN)
FDA	Food and Drug Administration (US)
GATT	General Agreement on Tariffs and Trade
GDP	Gross Domestic Product
GM	Genetically Modified
HIV	Human Immunodeficiency Virus
ICENT	International Convention on Evaluation of New Technologies
ICJ	International Court of Justice
ICRAF	World Agroforestry Center (Mozambique)
ILO	International Labour Organization
IMF	International Monetary Fund
IP	Intellectual Property
ITRE	Committee on Industry, Research and Energy
LDC	Least Developed Country
MDG	Millennium Development Goal
MEMS	MicroElectroMechanical Systems
MIT	Massachusetts Institute of Technology
MRI	Magnetic Resonance Imaging
Mt	Metric Tonne
NASA	National Aeronautic and Space Administration (US)
NBIC	Nanotech, Biotech, Informatics and Cognitive Neuroscience
NIH	National Institutes of Health (US)
NIOSH	National Institute of Occupational Safety and Health (US)
NM	Nanometer
NNI	National Nanotechnology Initiative (US)
OECD	Organisation for Economic Co-operation and Development
R&D	Research and Development
SAICM	Strategic Approach to International Chemicals Management
STDs	Sexually Transmitted Diseases

STM	Scanning Tunneling Microscope
TRIPS	Trade-Related Aspects of Intellectual Property Rights
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNIDO	United Nations Industrial Development Organization
US PTO	United States Patent & Trademark Office
WHO	World Health Organization
WIPO	World Intellectual Property Organization
WTO	World Trade Organization
ZCCM	Zambia Consolidated Copper Mines

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