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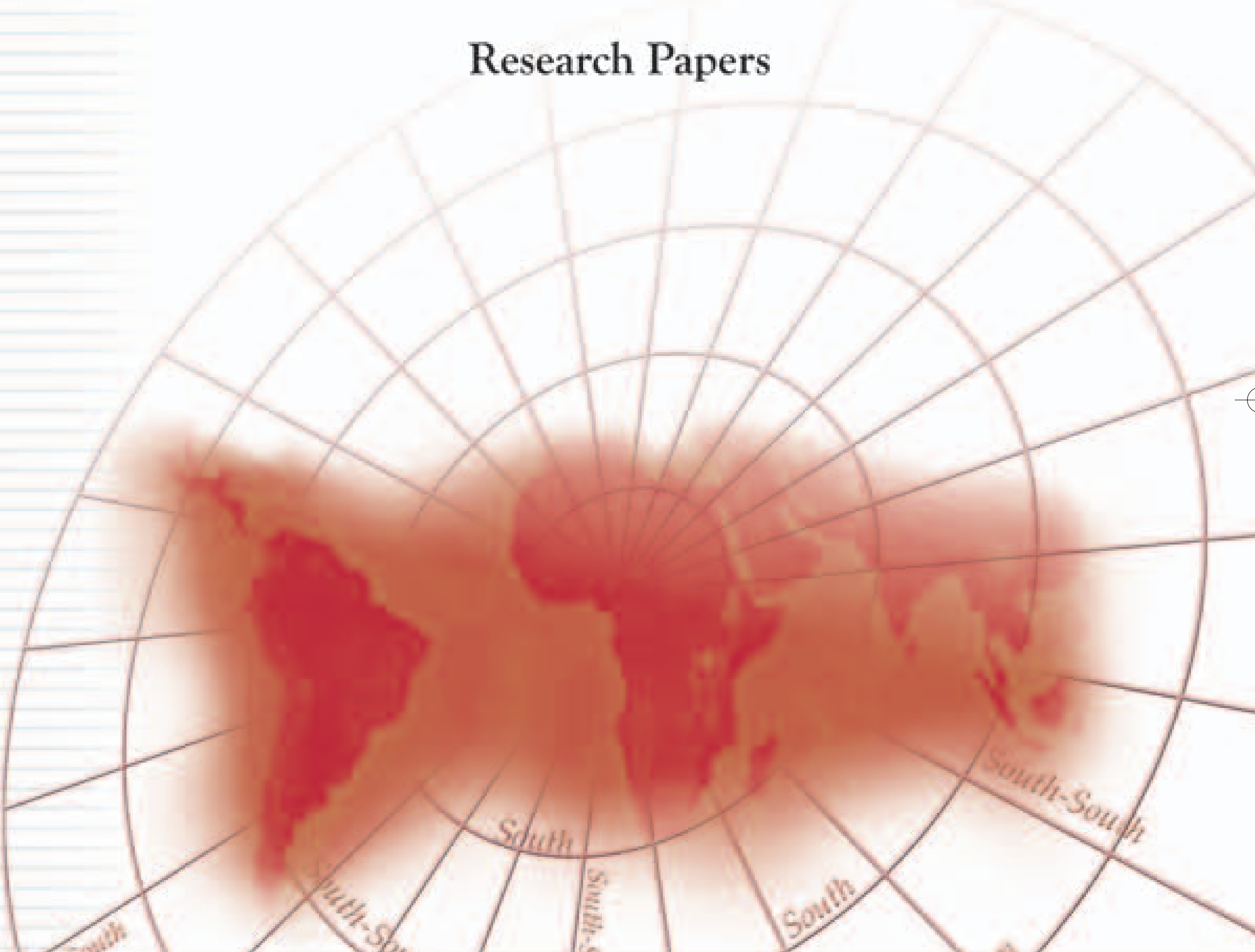

The Potential Impacts of Nano-Scale Technologies on Commodity Markets: The Implications for Commodity Dependent Developing Countries

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RESEARCH PAPERS

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THE POTENTIAL IMPACTS OF NANO-SCALE TECHNOLOGIES ON COMMODITY MARKETS: THE IMPLICATIONS FOR COMMODITY DEPENDENT DEVELOPING COUNTRIES

This working paper was written by

ETC Group*

SOUTH CENTRE

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THE SOUTH CENTRE

In August 1995, the South Centre was established as a permanent inter-Governmental organization of developing countries. In pursuing its objectives of promoting South solidarity, South-South cooperation, and coordinated participation by developing countries in international forums, the South Centre has full intellectual independence. It prepares, publishes and distributes information, strategic analyses and recommendations on international economic, social and political matters of concern to the South.

The South Centre enjoys support and cooperation from the governments of the countries of the South and is in regular working contact with the Non-Aligned Movement and the Group of 77. The Centre's studies and position papers are prepared by drawing on the technical and intellectual capacities existing within South governments and institutions and among individuals of the South. Through working group sessions and wide consultations which involve experts from different parts of the South, and sometimes from the North, common problems of the South are studied and experience and knowledge are shared.

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ACRONYMS

AITPA	Asociación Industrial Textil de Proceso Algodonero
CAS	Chinese Academy of Sciences
CBD	Convention on Biological Diversity
CSD	Commission on Sustainable Development
CSTD	UN Commission on Science and Technology for Development
ECOSOC	UN Economic and Social Council
EIU	Economist Intelligence Unit
FAO	UN Food and Agricultural Organization
GM	Genetically Modified
GDP	Gross Domestic Product
ICARRD	International Conference on Agrarian Reform and Rural Development
ICENT	International Convention on the Evaluation of New Technologies
ICI	Imperial Chemical Industries
IP	Intellectual Property
LDCs	Least Developed Countries
MIT	Massachusetts Institute of Technology
NASA	National Aeronautics and Space Administration
NNI	National Nanotechnology Initiative
PVC	polyvinyl chloride
R&D	Research and Development
TRIPs	Trade-Related Aspects of Intellectual Property
UNAM	Universidad Autónoma de México (Autonomous University of Mexico)
UNICAMP	State University of Campinas (Brazil)
US PTO	US Patent & Trademark Office
UV	ultraviolet

Organizations

ILO	International Labour Organization
ISO	International Organization for Standardization
OECD	Office for the Economic Cooperation and Development
UNCTAD	United Nations Conference on Trade and Development
WIPO	World Intellectual Property Organization
WTO	World Trade Organization

EXECUTIVE SUMMARY

For the majority of developing countries, commodity production is the backbone of the economy. Commodity dependence and poverty are closely intertwined. Commodities provide the primary source of income for the South's rural poor. Ninety-five out of 141 developing countries depend on commodities for at least 50 per cent of their export earnings; 46 developing countries depend on three or fewer commodities for more than half of their total export earnings.[1] The challenges posed by commodity dependence are myriad and complex. The defining feature of commodity dependence is a high degree of economic vulnerability due primarily to the persistent problems of price declines and volatility, trade-distorting subsidies, unfair trade barriers and a high degree of market concentration.

Historically, advances in science and technology have also had profound impacts on commodity production and trade. Rapid technological change can bring major disruption and dislocation, a process that some economists refer to as "creative destruction." In general, technology-driven shifts in commodity production and demand for raw materials have been rapid and unpredictable. The developers of new technologies are better prepared for sudden shifts in supply and demand, while the producers of primary commodities are unaware of imminent changes and less able to make timely adjustments in the face of rapidly changing markets. Science historians and economists frequently describe the introduction of major new technologies as "waves" that have relatively predictable phases of ascendancy and decline.

Today, rapid advances in nano-scale science and technologies pose additional challenges for commodity dependent developing countries. Nanotechnology refers to the manipulation of matter on the scale of atoms and molecules – where size is measured in billionths of meters. Nanotechnology's potential impacts on the world economy are breathtaking. Because of its unparalleled breadth and scale, the introduction of nanotech has been metaphorically described – not as a wave – but as a "technological tsunami." The introduction of nanotechnology is compared to a tsunami because it travels at great speed and it remains below the surface and goes virtually unnoticed before impact. When the nanotech-wave comes to shore, it will bring rapid, monumental, inescapable and potentially devastating change. Nanotechnology is a "platform technology" – meaning that it has the potential to alter or completely transform the current state of the art in every major industrial sector, not just one (e.g. medicine, food and agriculture, electronics and computing, materials and manufacturing). In the coming years, technologies converging at the nano-scale will revolutionize the design and manufacture of new materials across all industrial sectors. A 2004 report by industry analysts, Lux Research, Inc., highlights the potential of nanotech to "ultimately displace market shares, supply chains, and jobs in nearly every industry."

Worldwide, industry and governments invested more than US$10 billion in nanotech R&D in 2004. The European Union, Japan and the United States are the leading nano-investors with funding levels running neck-and-neck. At least 60 countries have established national nanotech research programmes, about half of which are in Europe. The United States National Science Foundation predicts that the nanotech market will surpass US$1 trillion by 2011 or 2012.[2] Industry sources predict the value of commercial products incorporating nanotechnology will reach US$2.6 trillion (15 per cent of global manufacturing output) by 2014 – 10 times biotech and equaling the combined informatics and

[1] Common Fund for Commodities, "Basic Facts," May 2005, p. 4.

[2] The United States National Science Foundation has predicted the market for nanoproducts would exceed US$1 trillion by 2015. In 2004, the NSF revised its forecast, estimating the US$1 trillion mark would come and go in 2011. See, for example, www.memsnet.org/news/1032299214-3

telecom industries.[3] In 2000, IBM was the only major corporation funding a nanotechnology initiative. Today, virtually all Fortune 500 companies invest in nanotech R&D.

Spending on nanotech R&D is accelerating rapidly in OECD countries and over 700 products employing nanotech have already been commercialized. But products have come to market in the absence of regulatory oversight. It is important to note that a growing number of scientific studies and government reports have recently warned that engineered nanoparticles could pose risks to human health and the environment due to their size and unique properties.

Many experts in development maintain that nano-scale technologies will address the South's most pressing needs. The UN Millennium Project's Task Force on Science, Technology and Innovation identifies nanotechnology as an important tool for addressing poverty and achieving the Millennium Development Goals.[4] In particular, nanotech research devoted to addressing energy and water problems is frequently cited to demonstrate nanotech's potential contributions to environmental sustainability and human development. Researchers are developing both nanofilters and engineered nanoparticles to clean contaminated water. Nano-scale technology is also being employed to develop inexpensive, flexible and efficient solar cells as a source of renewable energy.

Governments, industry and scientists in 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. South Africa's Minister of Science and Technology, Mosibudi Mangena, warned in February 2005: "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 assure that our natural resources do not become redundant, especially because our economy is still very much dependent on them."[5]

This report examines the potential impacts of nanotechnology on two sectors – agriculture and mining – in commodity dependent developing countries. Case studies on rubber, textiles, platinum and copper provide early examples of how economies and workers in the global South could be affected by nanotech's emerging R&D and products. In most cases it is too early to predict with certainty which commodities or workers will be affected and how quickly. However, if a new nano-engineered material outperforms a conventional material and can be produced at a comparable cost, it is likely to replace the conventional commodity. 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 or manufactured by new processes closer to home. Nanotech's new designer materials could topple commodity markets, disrupt trade and eliminate jobs. Worker-displacement brought on by commodity-obsolescence 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.

It is also important to note that nano-scale technologies could offer potential for developing countries to innovate and add value to current commodities. In addition, proponents of nanotechnol-

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[3] For the number of nano-companies, Ann M. Thayer, "Nanotech Investing," *Chemical & Engineering News*, Vol. 83, No. 18, May 2, 2005, p. 17 and Lux Research, Inc. For IBM's early role in nano-investing: Bruce Lieberman, "Nanotech: Rapidly advancing science is forecast to transform society," *San Diego Union Tribune*, March 14, 2005. Market predictions for nanotech are from Anonymous, Lux Research, "Revenue from nanotechnology-enabled products to equal IT and telecom by 2014, exceed biotech by 10 times," October 25, 2004.

[4] Calestous Juma and Lee Yee-Cheong, "Innovation: applying knowledge in development," UN Millennium Project Task Force on Science, Technology, and Innovation, 2005, pp. 69 ff., available on the Internet: http://bcsia.ksg.harvard.edu/BCSIA_content/documents/TF-Advance2.pdf.

[5] Opening Address By The Minister Of Science And Technology, Mr. Mosibudi Mangena, Minister Of Science And Technology at a Project Autek Progress Report Function, Cape Town International Convention Centre, 8th February 2005.

ogy point to future environmental benefits of revolutionary manufacturing processes associated with "bottom-up" construction that will minimize waste and offer the potential to recycle raw materials. The potential impacts of nanotech for the South cannot be categorized as monolithically "good" or "bad." However, it is clear that commodity dependent developing nations are the poorest, most vulnerable and will likely face the greatest socio-economic disruptions.[6]

Currently, nanotech innovations and intellectual property are being driven from the North (especially the United States, Japan and Europe) and promote the interests of dominant economic groups. The world's largest transnational companies, leading academic laboratories nanotech start-ups are aggressively seeking intellectual property on nanotech's novel materials, devices and manufacturing processes. The issue of control and ownership of nanotechnology is a vital issue for all governments because a single nano-scale innovation can be relevant for widely divergent applications across many industry sectors. As the *Wall St. Journal* put it, "companies that hold pioneering patents could potentially put up tolls on entire industries."[7] Intellectual property (IP) 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."[8]

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.

Commodity dependent developing countries must gain a fuller understanding of the direction and impacts of nanotechnology-induced technological transformations, and participate in determining how emerging technologies could affect their futures. To keep pace with technological change, innovative approaches are needed to monitor and assess the introduction of new technologies. This report concludes with a number of specific policy recommendations to assist commodity dependent developing countries confront the challenges and opportunities posed by rapidly emerging nano-scale science and technologies. Early warning and early listening strategies must be developed to keep pace with technological change.

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[6] While there is disagreement on the causal relationship between poverty and commodity dependence, there is agreement that the most commodity dependent countries are the poorest. See for example, Nancy Birdsall and Amar Hamoudi, "Commodity Dependence, Trade and Growth: When 'openness' is not enough," Center for Global Development, Working Paper Number 7, May, 2002, p. 17.

[7] Ibid.

[8] Mark A. Lemley, William H. Neukom Professor of Law, Stanford University, "Patenting Nanotechnology," unpublished manuscript sent to ETC Group by the author, March, 2005, p. 20.

I. INTRODUCTION

Note: Specialized terms related to nano-scale technologies are underlined in this document and are defined in the glossary.

Commodity production is the mainstay of the economy in most developing countries. According to UNCTAD, commodity dependence is measured by the share of the three leading commodities in a given country's total exports.[9] The bigger the share, the more dependent the country is. Commodity dependence and poverty are closely intertwined. Commodities provide the primary source of income for the South's rural poor. According to the Common Fund for Commodities, of the two and a half billion people engaged in agriculture in developing countries, an estimated one billion derive a significant part of their income from the production of export commodities.[10] Ninety-five out of 141 developing countries depend on commodities for at least 50 per cent of their export earnings; 46 developing countries depend on three or fewer commodities for more than half of their total export earnings.[11] (See Appendix, Table 1, for ranking of countries based on leading three export commodities.) The challenges posed by commodity dependence are myriad and complex. The defining feature of commodity dependence is a high degree of economic vulnerability due primarily to the persistent problems of price declines and volatility, trade-distorting subsidies, unfair trade barriers and a high degree of market concentration.

Strategies to address the economic vulnerability of commodity dependent developing countries frequently centre on efforts to reduce trade barriers and promote a fairer international trading system. However, the emphasis on trade alone is not sufficient, particularly in the light of rapid advances in nano-scale science and technologies. In a very real sense, technology is poised to trump trade as the defining feature of comparative advantage in the 21st century. In the coming decades, nano-scale technologies could make geography, raw materials, and even labour, irrelevant.

This report provides a brief introduction to nano-scale technologies and examines their potential impacts on commodity dependent developing countries. Nanotechnology refers to the manipulation of matter on the scale of atoms and molecules – where size is measured in billionths of metres. Below about 100 nanometres (nm) materials can have different or enhanced properties compared with the same materials at a larger scale. The UK's Royal Society and Royal Academy of Engineering describe nanotechnologies as "the design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometer scale."[12]

It is important for commodity dependent developing countries to examine the rapid emergence of nano-scale technologies and the implications of this "technological tsunami." Some observers are enthusiastic about the potential of nanotech to address the South's most pressing needs. However, the potential disruptive impacts of nanotech on developing economies, particularly commodity dependent economies, have received far less attention. In short, nano-scale technologies will revolutionize traditional manufacturing processes across all industry sectors. Nano-scale engineering offers the potential to transform existing materials and design entirely new ones. New, nano-engineered materials could mean that industrial manufacturers will have multiple raw material options, which could radically alter the demand for raw materials from commodity dependent developing countries.

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[9] http://r0.unctad.org/infocomm/yearbook/coverpageen.htm

[10] Mr. Rolf W. Boehnke, Managing Director, Common Fund for Commodities, to the XIth Session of the UNCTAD, Sao Paulo, 16 June 2004. http://www.unctadxi.org/sections/u11/docs/GeneralDebate/16com_eng.pdf

[11] Common Fund for Commodities, "Basic Facts," May 2005, p. 4.

[12] The Royal Society & The Royal Academy of Engineering, *Nanoscience and nanotechnologies*, July 2004, p. 5. On the Internet: http://www.nanotec.org.uk/finalReport.htm

Case studies presented in this report on agricultural commodities (rubber) and mining (platinum and copper) offer early examples of how emerging R&D in nanotechnology could have profound impacts on workers and economies in commodity dependent nations.

Society is not prepared for the titanic socio-economic disruptions that nanotechnologies are likely to bring, especially in the developing world. This report attempts to give commodity dependent developing countries a fuller understanding of the direction and impacts of nanotechnology-induced technological transformations and, prepare these countries to participate in determining how emerging technologies should affect their futures. New and innovative early warning and early listening strategies must be developed to keep pace with technological change.

II. TECHNOLOGY AND COMMODITY TRADE: A HISTORICAL PERSPECTIVE

Advances in science and technology have always had a profound impact on commodity production, international demand and trade. Since the beginning of European expansion over 500 years ago, it is possible to identify five distinct waves of technology transfer. Each is summarized below.

II.1 The Food Exchanges

Necessity (constraints to Europe-Asian trade in the 15th century) and new navigation technologies encouraged Europe to move into the Western Hemisphere, the Indian Ocean, and East Asia five centuries ago. European expansion accelerated the flow of important food plants and livestock between continents and peoples. Maize, cassava and groundnuts, via Portuguese and Spanish sailors, were quickly adopted in many parts of Africa. Similarly, maize and sweet potatoes found welcome homes in East Asia and the Pacific islands. Eurasia's cereals (including rice, wheat and barley) – and Africa's and Asia's bananas – were taken up in Latin America – as were cattle, poultry, sheep and horses. Meanwhile, through a variety of accidental and intentional steps, potatoes, maize and tomatoes found their way into Europe's cuisine. As important (and often strategic) as this food exchange was, it was rarely the result of geopolitical design. The successful introduction of new food plants can mostly be attributed to farmer-to-farmer transfers. While it is logical that the introduction of new food staples, especially potatoes, should have had a major impact on the food security of Europeans – and even to have made urban migration and the industrial revolution viable – the actual record is not so clear and certainly, there is no evidence of an economic strategy.

II.2 Multi-sourcing Biodiversity

The pace of technology transfer accelerated with the construction of colonial botanical gardens in two waves: the first, between 1760 and 1820 saw the establishment of research and collection gardens from Jamaica and St. Vincent to Malaysia and Java. A second wave of garden constructions took place as European colonial powers moved into Africa in the final quarter of the 19th century. By the close of the 19th century, the United Kingdom's Kew Gardens held over one million plant species and conducted an active exchange involving 54 other gardens around the world. In contrast to the food plant transfers of earlier centuries, the gardens, supported by avid amateur collectors and taxonomists, worked systematically to chronicle and commercialize the species they gathered. However, it was not until the invention of the Wardian Case in 1829 that the wholesale movement of alien species between continents became technically possible. The cases (terrariums), for example, made it much easier to transfer Ethiopia's coffee (which had already spread across the Indian Ocean and as far as Indonesia) to be transferred first to Paris and Amsterdam and then onward into Central and South America; China's tea was transferred to South Asia and (much later) East Africa; and Andean chinchona and Amazonian rubber were pirated through London to plantations in South and Southeast Asia. Oil palms from West and Central Africa became plantation crops in Southeast Asia while cottons from Africa and Asia were planted in the southern United States, the Caribbean, and further south. Spices and ornamentals were also commercially-important. The Dutch for example, attempted to monopolize the spice trade from Asia by concentrating production on a few small islands while destroying groves on other islands. Some species that were benignly transferred between farmers eventually became important plantation crops. These include bananas in Latin America transferred from Africa and Asia; Latin American cocoa and groundnuts transferred to West Africa. Later still, soybeans from China and the Korean peninsular became important in Brazil and Argentina where the crop was grown for both domestic and export livestock feed.[13]

During this second wave of technology transfer, the colonial powers controlled the flow of crops and germplasm and also monopolized the production and processing technologies important to commercialization. In most cases, the technology transfers created economic dependence in the colonized countries.

II.3 Dyeing Harvests

Toward the end of the 19th century, developments in chemistry – particularly in Germany but also in France and the United Kingdom – led to a new technology wave that significantly reduced and/or altered the demand for developing country raw materials. Aniline and other dyes from Germany, for example, quickly replaced natural dyes such as the madder root. Turkish farmers exported 15,000 tonnes a year to British textile firms between 1850 and 1870 when the root yielded to alizarin. By 1900, the market was gone. Similarly, one of Liberia's most valued exports, a red dye from camwood, became commercially irrelevant almost overnight – as did Mexico's carmine dye (from the cochineal beetle), black from the West Indian logwood tree, red from Indian lac, crimson and purple from brazilwood, and green from China's lokao tree. Along with the natural dyes went the natural "plastics" like shellac, and gutta-percha from Southeast Asia.[14]

Most famously, when blue synthetic dyes went into large-scale production in Germany in 1897, India had 574,000 hectares of indigo in cultivation in Bengal and Bihar. By 1911, the area had dropped to 86,600 hectares.[15] By 1920, the crop had virtually disappeared from India. Half a century later, rural sociologists in the United States insisted that areas in the heart of India's indigo-producing region had not recovered completely from the devastation that came with the loss of the indigo crop.[16]

II.4 Synthetic Reductions

Following World War II, synthetic petroleum-based fibres ate into the global market for not only silk and cotton, but also for hard fibers customarily used in everything from carpets to car mats and harvest (baler) twine. In the 1930s, polymer science led to the synthesis of polyvinyl chloride (PVC) by DuPont and I. G. Farben for floor tiles, phonograph records, pipes, dentures, furniture, and insulation. Next, polystyrene, manufactured by Dow Chemical and I. G. Farben was used as a foam, adhesive, and emulsion, as well as a hard plastic. By 1945, the United States was producing 60,000 tonnes of PVC and 7.5 million tonnes of polystyrene each year. Polyethylene from Imperial Chemical Industries

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[13] This transfer is described in detail in Lucile H. Brockway, *Science and Colonial Expansion*: *The Role of the British Royal Botanic Gardens* (New York, 1979).

[14] The replacement of natural dyes and the later use of synthetic fibers is well described in Daniel R. Headrick, *The Tentacles of Progress: Technology Transfer in the Age of Imperialism, 1850–1940* (New York, 1988).

[15] Hugh Martin-Leakee, "A Historic Memoir of the Indigo Industry of Bihar," *Economic Botany*, 29:361-371, Oct.-Dec., 1975, (File 264).

[16] Fred Buttel, Martin Kinney and Jack Kloppenburg Jr., "Socio- economic Impact of Project Dislocation," ATAS Bulletin No. 1: Tissue Culture Technology, 1984. UN Centre for Science and Technology for Development, New York.

(ICI) was used to insulate cables and radar wires, packaging, materials and countless other household products. By 1978 world plastics production surpassed iron and steel. [17]

Slightly earlier, synthetic rubber (produced as a strategic military commodity by Germany and the United States on the eve of World War II) looked to be on the verge of eliminating the natural rubber market that had grown critical to the economies of Southeast Asia. Extensive research in plant breeding led to massively increased productivity of natural rubber plants and rescued the natural rubber industry from extinction.

II.5. Multi-Material Sourcing

Technological convergence at the nano-scale now introduces a significant new phase in multi-sourcing raw materials for manufacturing. Because each of the elements of the Periodic Table experiences alterations in its characteristics/properties at different sizes below 100 nanometres, there will be market uncertainty for sometime to come. Copper wiring may be replaced by carbon nanotubes and platinum may be overtaken by a compound of nano-scale nickel and cobalt. However, as this new technological transformation progresses, new uses may be found for both copper and platinum. Rubber and cotton appear particularly vulnerable through nanotechnology but both commodities have been threatened before and have survived – if not thrived. Clearly, developing country raw material exporters are entering a period of extreme economic uncertainty.

II.6 Lessons Learned?

Trends and traumas: In general, technology-driven shifts in commodity demand have been rapid and unpredictable. Also, in general, the beneficiaries of sudden shifts have been the developers of the new technology, who were in a position to see the changes coming, while the "losers" were the producers of primary commodities who were unaware of the imminent changes and/or those who could not make rapid adjustments in the face of new demands.

Successful failures: It is not always – or immediately – evident that a new technology is superior to that which it replaces. The large machines associated with the domestic British textile industry for example, were not initially an improvement over the efficiency of the "putting-out" manufacturing system they subverted. However, the large machines did make it possible for a smaller number of manufacturers to capture a larger share of the market. In fact, quality was initially poor and prices were not especially competitive with foreign imports. The textile manufacturers of the United Kingdom and the United States quickly grew to rank among the wealthiest families in their countries and exercised considerable influence over government policies relevant to their domestic manufacturing and imports. Historically, new technologies thrive in an initial, temporary regulatory vacuum (and/or when regulators look the other way) or, when regulators cooperate in de-commissioning competing older technologies (ostensibly for health, environmental or other reasons).

Critics of new agricultural biotechnologies would argue for example, that genetically modified plant varieties entered the market in the mid-1990s with a momentum that made their dominance (at least in North America) almost inevitable. The "hype" surrounding GM seeds meant that:

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[17] Daniel Headrick, "Botany, Chemistry, and Tropical Development," *Journal of World History* 7, no. 1 Reading 3 (Spring 1996): 1–20. in *Bridging World History*, 1, The Annenberg Foundation copyright, 2004

- Public breeders (universities and governments) were persuaded that the R&D costs were prohibitive and therefore, yielded the market to major enterprises;
- The courts adapted intellectual property laws and other seed- and food-related regulations to accommodate the new technology;
- Family seed enterprises – also assuming prohibitive expense and inevitability – were persuaded to sell or withdraw from the market.

In a space of twenty years, the seed market shifted from many thousands of breeding enterprises (public and private) to a market where the leading ten companies currently control half of global commercial seed sales;[18] where amended intellectual property laws give the leading companies research dominance; and, where the traditionally distinct seed supply and pesticide sectors have merged. This, to facilitate a technology that its critics regard as – at least – unproven and immature.

Manufacturing waves: In recent decades, science historians and economists have come to describe the introduction of major new technologies not as "revolutions" but as "waves" with relatively predictable phases of ascendancy and decline, including a discernible pattern of piracy and partnership. At least from Britain's Industrial Revolution to today, many observers share an understanding of the sequence of waves that moved from textile machinery through the use of steam in manufacturing machinery, steamships, and locomotives, through to steel and heavy machinery, onward to electricity followed by chemicals and communications technologies. History shows that each of these waves arose from a gradual accumulation of knowledge sparked less by radically new science than by new opportunities. Each wave was manufactured. More significantly, these waves have been as successful at suppressing certain new technologies as they have been at advancing others. Technology waves are the "creative destruction" many economists regard as an inevitable component of progress.

> "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, *Technological Revolutions and Financial Capital,* pp. 4-5.

Winners and losers: It is also almost inevitable that these manufactured waves will bring greater benefits to their manufacturers than to society at large. Because they make older technologies and market obsolete, those who do not see the wave coming or, cannot evade its path, are likely to suffer from the process. Thus, Britain's industrial workers in the first 50–75 years of the Industrial Revolution actually lost ground, in real health terms, relative to the generation before. As textile workers in the United Kingdom suffered, so did the weavers and spinners of South Asia where per capita life expectancy and food availability also declined. Many might agree that, at least initially, the new technology waves lift the rich and drown the poor who cannot easily manage sudden economic disruption.

Because of its unparalleled breadth and scale, nanotech has been described metaphorically – not as a wave – but as a "technological tsunami." Tsunamis exhibit several important features that highlight nanotech's potential to bring immense socio-economic disruption and upheaval. The introduction of nanotechnology is compared to a technological tsunami because it will cause disruptions far from

[18] ETC Group, "Global Seed Industry Concentration – 2005," September/October 2005. On the Internet: http://www.etcgroup.org

its origin. Though it is traveling at great speed and propelled by immense energy, its potential negative impacts are below the surface and go virtually unnoticed before impact. Its force may not reach the global South immediately but, when the nanotech-wave comes to shore, it will bring rapid, monumental, inescapable and potentially devastating change. With the depth and energy of a tsunami, nanotech will have a powerful impact on every industrial sector. Every commodity used in industry today, including food, will potentially be displaced.

III. NANOTECHNOLOGY

III.1 What is Nanotechnology?

Nanotechnology refers to those areas of science and engineering where phenomena that take place at the nanometre scale are used in the design, characterization, production and application of materials, structures, devices and systems. Only in the last quarter of a century has it been possible to intentionally modify matter within this size range. It is this manipulation at the nanometre scale that distinguishes nanotechnologies from other areas of technology.

Worldwide, industry and governments invested more than US$10 billion in nanotechnology R&D in 2004.[19] The European Union, Japan and the United States are the leading investors, at roughly equivalent levels. China's government spends more money on nanotech research "at purchasing-power parity" than any other country except the United StatesS.[20] Approximately 60 countries have established national nanotech research programmes, about half of which are in Europe.[21] The United States 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 endeavor since the Apollo Project (moon-landing). United States Government funding committed for nanotech more than doubled between 2001 and 2006. The United States Government's NNI distributes nanotech R&D funds to 11 federal agencies; over the course of the NNI's history, the Department of Defense has received a greater share of nanotech funding than any other agency.[22]

There are an estimated 1,200-nanotech start-up companies, half of which are United States-based.[23] In 2000, IBM was the only major corporation funding a nanotechnology initiative.[24] Today, virtually all Fortune 500 companies invest in nanotech R&D. The National Science Foundation in the United States estimates that the nanotech market will surpass US$1 trillion by 2011 or 12.[25] Industry sources predict the value of commercial products incorporating nanotechnology will reach US$2.6 trillion (15 per cent of global manufacturing output) by 2014 – 10 times the value of biotech products and as large as the value of products of informatics and telecommunications technologies combined.[26]

Levels of R&D funding are one indicator of the financial commitment by the world's public and private sectors. In order to fully appreciate nanotechnology's power, potential and novelty however, it is important to understand three critical components of nano-scale science:

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[19] Stacy Lawrence, "Nanotech Grows Up," *Technology Review*, June 2005, p. 31.

[20] Lux Research news release, "Nanotechnology Winners and Losers Emerging among Competing Nations, Says Lux Research," November 3, 2005.

[21] Mihail Roco, Senior Adviser for Nanotechnology, National Science Foundation, telephone conversation, 30 September 2005.

[22] *The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry, Supplement to the President's FY 2006 Budget*, Washington, DC, March 2005; President's Council of Advisors on Science and Technology, "The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel," Washington, DC, May 2005.

[23] Ann M. Thayer, "Nanotech Investing," *Chemical & Engineering News*, 2 May 2005, p. 17, and from Lux Research, Inc.

[24] Bruce Lieberman, "Nanotech: Rapidly Advancing Science Is Forecast to Transform Society," *San Diego Union Tribune*, 14 March 2005.

[25] M. Roco, interview on the National Nanotechnology Initiative website: http://www.nano.gov/html/interviews/MRoco.htm

[26] Lux Research, "Revenue from Nanotechnology-enabled Products to Equal IT and Telecom by 2014, Exceed Biotech by 10 Times" press release (New York: 25 October 2004).

III.1.1 The scale of matter manipulated using nano-scale technologies

Nanotechnology refers, not to one discreet branch of applied science but, to a set of diverse techniques that involve a variety of scientific disciplines. Nanotechnologies have one thing in common: They all involve matter that is on the scale of the nanometre (nm). Atoms and molecules are nano-scale materials. 1 nanometre is one-thousandth of a micron (μm) and 1 μm is one-thousandth of a millimetre. The nano-scale refers generally to measurements between 1 and 100 nm. A molecule of DNA, for example, is 2.5 nm wide. An atom of hydrogen is .1 nm in diameter. Chemical elements (e.g. gold, silver, carbon) and compounds (e.g. titanium dioxide) can now be processed in nanoparticle form (less than 100 nm in diameter) and these nanoparticles are currently used in hundreds of products, with thousands more products in the pipeline. Everything on the nano-scale is invisible except with the aid of "scanning tunneling" and "atomic force" microscopes.

Without these fundamental tools, first developed and patented by IBM in the 1980s, it would be impossible to "see" and manipulate matter on the nano-scale. Rather than magnify a sample until it is big enough to be seen with an unaided eye, as conventional optical microscopes do, these specialized instruments scan across the surface of a nano-scale sample with an extremely sharp tip. The contours of the sample are measured and recorded and then translated into a graphic image. Under certain conditions, an individual atom can attach to the needle-like tip. Using scanning tunneling microscopes, researchers now have the capacity to move individual atoms. The invention of the scanning tunneling microscope earned IBM researchers a Nobel Prize in 1986.[27]

III.1.2 The changed behaviour of matter at the nano-scale

At the nano-scale, the rules of classical physics no longer apply and, instead, quantum effects are observable. This means that a substance in nano-scale form can behave dramatically differently from the same substance at a larger scale. With only a reduction in size, and no change in substance, properties related to electrical conductivity, elasticity, strength, colour and chemical reactivity can all change. For example:

- Carbon in the form of graphite (i.e. pencil lead) is soft and malleable but, at the nano-scale, carbon can be stronger than steel and is six times lighter.
- Zinc oxide, which appears white and opaque on the micron-scale, is transparent at the nano-scale.
- Nano-scale copper is a highly elastic metal at room temperature, stretching to 50 times its original length without breaking.
- Nano-scale aluminum can combust spontaneously.[28]

Everything in our universe – living and non-living – is made from the "raw materials" that are the chemical elements of the Periodic Table. In effect, nanotechnology provides scientists with an expanded Periodic Table, and the expansion is exponential. It is not simply the case that every substance

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[27] In light of this advance, some researchers envision that atoms and molecules will one day be arranged at will to create or build any desired material or object, including houses and food; other researchers are skeptical that large-scale "molecular manufacturing" will ever become a reality. A special issue of *Scientific American* (September 2001) devoted to nanotechnology first aired the debate between believers in "molecular manufacturing" and skeptics.

[28] For nano-aluminum: Steve, Jurvetson, "Transcending Moore's Law with Molecular Electronics," *Nanotechnology Law & Business Journal*, Vol. 1, No. 1, article 9, p. 9. For nano-copper: Chunli Bai, "Ascent of Nanoscience in China," *Science*, Vol. 309, 1 July 2005, p. 62.

exhibits one set of properties associated with the realm of classical physics and a second set of quantum properties associated with the nano-scale. Within the nano-scale realm too, a substance's fundamental properties can change. Some nanoparticles of gold are inert for example, while other nano-scale gold, of a different size, is highly reactive.

III.1.3 Nano-scale technologies enable technological convergence

Engineering on the nano-scale enables scientists to transform existing materials, design entirely new ones and enhance conventional materials by incorporating nano-scale materials (nano-composites). Because nano-scale manipulations are now possible and, because the basic components of both living and non-living matter exist on the nano-scale (e.g., atoms, molecules and DNA), it is now possible to converge technologies – and to converge scientific disciplines – to an unprecedented degree. Technological convergence, enabled by nanotechnology and its tools, can involve biology and biotechnology, physics, material sciences, chemistry, cognitive sciences, informatics, applied mathematics, electronics and robotics, among others. At the nano-scale there is no difference between living and non-living matter. For example, nuclear physicists in Chiang Mai, Thailand have "atomically modified" the characteristics of local rice varieties by blasting nitrogen atoms into the membrane of a rice cell – to stimulate the rearrangement of the rice's DNA.[29] Chemists are entering the realm of biology by trying to create electronic components out of viruses and bacteria.[30] A professor of mechanical and aerospace engineering has created a living, millimetre-long device out of silicon and muscle grown from the cells of a rat's heart.[31] With possible applications across all industry sectors, nano-enabled technological convergence is poised to become the strategic platform for 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

Hundreds of products that employ nanotechnology are already on the market:

- Exploiting the anti-bacterial properties of nano-scale silver, Smith & Nephew developed wound dressings (bandages) coated with silver nanoparticles designed to prevent infection.

- Nanoparticles of titanium dioxide (TiO_2) are transparent and block ultraviolet (UV) light. Nano-scale TiO_2 is now being used in sunscreens and in clear plastic food wraps for UV protection.

- Nano-Tex sells "Stain Defender" for khaki pants and other fabrics – a molecular coating that adheres to cotton fibre, forming an impenetrable barrier that causes liquids to bead and roll off. (See below, p. 34.)

- 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 bo-

[29] ETC Group News Release, "Atomically Modified Rice in Asia?" 25 March 2004. Available on the Internet: http://www.etcgroup.org/article.asp?newsid=444

[30] Alan Leo, "The State of Nanotechnology," *Technology Review*, June 2002.

[31] Roland Pease, "'Living' robots powered by muscle," BBC News, 17 January, 2005, available on the Internet: http://news.bbc.co.uk/1/hi/sci/tech/4181197.stm

dy). 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. 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 fishponds and swimming pools. It incorporates nano-scale particles of a lanthanum-based (La) compound that absorbs phosphates from the water and prevents algae growth.[32]

III.1.4 "Bottom-Up" Manufacturing

In addition to nanoparticles and nano-composite materials, nanotechnology also makes possible bottom-up manufacturing where, under the right conditions, molecules (clusters of atoms) snap into useful configurations on their own. The process by which the molecules fall into the desired place is called "self-assembly." The resulting self-assembled structures can become modules for constructing nano-scale devices. Building molecular devices based on self-assembly is still in the early stages. For example, products are being developed for use as electronic circuitry. 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 circuitry works, carbon nanotubes could replace silicon, yielding ultra-fast computers that perform "orders of magnitude" beyond silicon. 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.[33]

Other nano-engineered devices include invisible and highly-sensitive sensors, which are being developed for a wide range of applications. For example:

- The United States Department of Agriculture has identified "smart fields" laced with wireless sensors as one of its nanotech-related research priorities.[34] The agency is developing and promoting a total "smart field system" that automatically detects, locates, reports and applies water, fertilizers and pesticides – going beyond sensing to automatic application.[35] Computer chip maker Intel, whose chips have nano-scale features, has installed larger wireless sensor nodes (called 'motes') throughout a vineyard in Oregon, the United States.[36] The sensors measure temperature once every minute and are the first step towards fully automating the vineyard.

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[32] For nano-pesticides: Syngenta's Banner MAXX brochure on the Internet: http://www.engageagro.com/media/pdf/brochure/ bannermaxx_brochure_english.pdf. For nano-algae prevention: Anonymous, "Altair Nanotechnologies' Algae Prevention Treatment Confirmed Effective in Testing," Altair Press Release, March 11, 2004.

[33] Charles Lieber used the phrase "orders of magnitude;" quoted by David Rotman, "The Nanotube Computer," *Technology Review*, March, 2002, p. 38. For targeted tumor cells: David Mooney, "One step at a time," *Nature*, Vol. 436, 28 July 2005, p. 468.

[34] http://www.news.uiuc.edu/scitips/01/05farmlab.html

[35] Draft version of *Nano-Scale Science and Engineering for Agriculture and Food Systems: A Report Submitted to Cooperative State Research, Education, Education and Extension Service*, based on a National Planning Workshop, November 18-19, 2002, Washington, D.C., September 2003; the draft is revision B, 14 February 2003.

[36] Gerry Blackwell, "The Wireless Winery," September 23, 2004, on the Internet: www.wi-fiplanet.com/columns/article/php/3412061

- Fish farming companies in the United States are experimenting with mass vaccination of fish using ultrasound.[37] Nanocapsules containing short strands of DNA are added to a fish-pond where they are absorbed into the cells of the fish. Ultrasound is then used to rupture the capsules, releasing the DNA and eliciting an immune response from the fish. The technology has been tested by Clear Springs Foods (Idaho, United States) – a major aquaculture company that accounts for about one-third of all United States farmed trout.

- Scientists at Kraft Foods, as well as researchers at Rutgers University and the University of Connecticut, are working on nanoparticle 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 colour-change in food packaging to alert the consumer if a food is contaminated or has begun to spoil.

- MIT’s Institute for Soldier Nanotechnologies, created in 2002 with a US$50 million grant from the United States Department of Defense, aims to create a “21st century battlesuit” to enhance “soldier survivability.” One research team is using nanotech to develop a battlesuit that incorporates: 1) highly sensitive chemical and biological sensing technologies; 2) protective 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.[38]

Box 1
Nanotech’s new molecular materials:
nanotubes, buckyballs and quantum dots

Carbon nanotubes and buckyballs are pure crystalline carbon molecules – as are diamond and graphite, the only other known forms of crystalline carbon. 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. Nanotubes can be hollow like straws (known as single-walled) or rolled up like documents 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 much attention because they are recent discoveries (neither was known before 1985) and, because they have extraordinary properties. Since buckyballs are hollow, they make ideal nano-sized 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.[39]

Nanotubes are 100 times stronger than steel and six times lighter; they can now be produced with 1-nm diameters and several millimetres 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

[37] USDA Grant 2002-00349, “Development of an Ultrasound-mediated Delivery System for the Mass Immunization of Fish.” For more information, see: ETC Group, *Down on the Farm: The Impact of Nano-scale Technologies on Food and Agriculture*, November, 2004. On the Internet: www.etcgroup.org
[38] For the Institute of Soldier Nanotechnologies: http://web.mit.edu/isn/
[39] Marcia F. Barusiak et al., *A Positron Named Priscilla: Scientific Discovery at the Frontier*, National Academy of Sciences, 1994, pp. 285-286.

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. Quantum dots are of commercial interest because different-sized quantum dots emit distinctly different colours. 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 project aims to add quantum dots to inks or polymers used in the manufacture of paper money as a way to combat counterfeiting. Quantum dots are being used to label biological material *in vitro* and *in vivo* in animals for research purposes – they can be injected into cells or attached to proteins in order to track, label or identify specific biomolecules. The hope is that one day quantum dots could be used in humans to treat and monitor diseases such as cancer. However, researchers will have to proceed with caution because the core material in most quantum dots is highly toxic cadmium and toxicological analysis has yet to be tackled.[40]

III.2 Potential Risks of Nanoparticles

Public and private spending on nanotech R&D is accelerating and over 700 new products have already come to market but, a growing number of scientific studies and government reports have recently warned that engineered nanoparticles could pose unique risks to human health and the environment due to their size and quantum properties. Nanotech products have come to market in the absence of public awareness and regulatory oversight.

Only a handful of 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 larger scales, 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 elude 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 are reasons for concern:

- A study published in July 2004 found that buckyballs can cause rapid onset of brain damage in fish.
- In 2005 researchers at the United States National Aeronautic and Space Administration (NASA) reported that when commercially available carbon nanotubes were injected into

[40] Quantum dots to combat counterfeiting: http://www.evidenttech.com:80/applications/quantum-dot-ink.php. For biological imaging using quantum dots: Anonymous, Carnegie Mellon news release, “Carnegie Mellon Enhances Quantum Dot Corp. Technology For Long-term, Live-animal Imaging,” January 19, 2004.

the lungs of rats it caused significant lung damage. (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 United States 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.

- In 2005 University of Rochester (United States) researchers found that rabbits inhaling buckyballs demonstrated an increased susceptibility to blood clotting.

- 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.[41]

In response to heightened concerns about nanoparticles, some scientists suggest that it may be possible to mitigate potential toxic effects by controlling the surface chemistry of nano-scale materials, or by coating them in protective substances. These efforts are complicated by the fact that there is currently no standardized 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.[42]

Given the knowledge gaps, experts are urging caution, and recommending that release of nanoparticles be restricted or prohibited. In 2002, civil society organizations called for a moratorium on the release of manufactured nanoparticles until laboratory protocols are established to protect workers and, until regulations are in place to protect consumers and the environment.[43] A July 2004 report by the United Kingdom's Royal Society and Royal Academy of Engineering recommended that the environmental release of manufactured nanoparticles and nanotubes be avoided as much as possible until more is known about their impact. Specifically, they recommended "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."[44]

Currently, nano-scale chemicals are escaping regulatory oversight if the same substance has been approved at the micro- or macro-scale. For example, manufacturers of carbon nanotubes sometimes simply identify their product as "graphite" – another 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 do not trigger new regulatory action – even though, by definition, nano-scale ingredients can have dramatically different properties, including different toxicological effects. Although some companies claim that they have conducted their own toxicological studies on nanoparti-

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[41] Eva Oberdörster, "Manufactured Nanomaterials (Fullerenes, C60) Induce Oxidative Stress in the Brain of Juvenile Large-Mouth Bass," *Environmental Health Perspectives*, Vol. 112, No. 10, July 2004. Janet Raloff, "Nano Hazards: Exposure to minute particles harms lungs, circulatory system," Science News Online, Week of March 19, 2005; Vol. 167, No. 12. For the solubility of buckyballs: Anonymous, "CBEN: Buckyball aggregates are soluble, antibacterial," June 22, 2005, available on the Internet: http://www.eurekalert.org/pub_releases/2005-06/ru-cba062205.php.

[42] On controlling surface-chemistry to reduce toxicity of nanoparticles: Anonymous, "Rice Finds 'On-Off Switch' for Buckyball Toxicity," September 24, 2004.http://www.physorg.com/news1308.html

[43] ETC Group, Greenpeace International, GeneEthics, ICTA and Corporate Watch have supported a call for a moratorium.

[44] Royal Society and Royal Academy of Engineering, "Nanoscience and Nanotechnologies: Opportunities and Uncertainties," July 2004.

cles, those studies are rarely in the public domain.[45] While the United States and European governments are belatedly conceding that some type of regulation is needed, it remains to be seen if nanotech regulations will be cobbled together using existing regulations for chemicals or, if a new precautionary approach will prevail.

III.3 Trends in Intellectual Property and Nanotechnology: Implications for Developing Countries

> "When you control the atoms, you control just about everything." – Dr. Richard Smalley, 1996 Nobel laureate for his discovery of fullerenes (buckyballs).[46]

It is impossible to assess the potential challenges and opportunities nanotech poses for developing countries without examining the larger context of technology transfer and intellectual property.

The issue of control and ownership of nanotechnology is a vital issue for all governments because a single nano-scale innovation (materials, devices and processes) can be relevant for widely divergent applications across all industry sectors. As the *Wall St. Journal* put it, "companies that hold pioneering patents could potentially put up tolls on entire industries."[47] The current nanotech patent grab is reminiscent of the early days of biotechnology – "it's like biotech on steroids" in the words of one patent attorney. 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, atomic engineering provides new opportunities for sweeping monopoly control over both animate and inanimate matter.[48] Intellectual property (IP) 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."[49]

Over the past two decades the role of intellectual property in all areas of science and technology has exploded globally – primarily due to rules prescribed by the World Trade Organization's Trade-Related Aspects of Intellectual Property (TRIPs) and by bilateral/regional trade agreements. The TRIPs agreement obligates all WTO member countries to adopt and enforce minimum standards of intellectual property. WTO has 150 members, and claims that it accounts for over 97 per cent of all world trade.[50]

The TRIPs Agreement requires member countries to make patents available for inventions, whether products or processes, in all fields of technology without discrimination, subject to the stan-

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[45] ETC Group, *Down on the Farm: The Impact of Nano-scale Technologies on Food and Agriculture*, November 2004, pp. 46-49. On the Internet: http:www.etcgroup.org

[46] Smalley is quoted in interview with Sonia E. Miller, "Measuring Nanotechnology's Effect on the Law," *New York Law Journal*, 02-04-2005 (online). Smalley died October 28, 2005.

[47] Ibid.

[48] For nanotech as biotech on steroids: Antonio Regalado, "Nanotechnology Patents Surge as Companies Vie to Stake Claim," *Wall Street Journal*, June 18, 2004, p. 1.

[49] Mark A. Lemley, William H. Neukom Professor of Law, Stanford University, "Patenting Nanotechnology," unpublished manuscript sent to ETC Group by the author, March, 2005, p. 20.

[50] From "The WTO in brief," available on the Internet at http://www.wto.org/english/thewto_e/whatis_e/inbrief_e/inbr00_e.htm

dard patent criteria (novelty, inventiveness and industrial applicability).[51] However, during the negotiations on the TRIPs Agreement, consensus was not reached on the controversial area of biotechnological inventions. The United States and some other developed countries pushed for no exclusions to patentability, while some developing country members preferred to exclude all biological diversity-related inventions from IP laws. For many developing countries the patenting of life forms and the legal right to obtain exclusive monopoly protection on biological products and processes that originate in developing countries (or that are based on traditional knowledge) continues to be controversial. Article 27.3(b) of the TRIPs Agreement is the text that ultimately prevailed on biological products and processes. It states that plants and animals as well as essentially biological processes may be excluded from patentability. However, WTO members must offer protection for plant varieties either by patents and/or by an effective *sui generis* system. Developing countries were given until 2000 to pass laws in this direction, and least developed countries (LDCs) were given until 2006. Because of the difficulty in reaching consensus on this issue, it was agreed that the controversial sub-paragraph TRIPs Article 27.3(b) would be reviewed in 1999. The review has not happened.

The controversy and debate surrounding the patentability of biotechnological inventions at WTO is relevant today because nano-scale materials and processes – especially those inventions that claim both living and non-living matter – raise many of the same fundamental questions (see below, nanobiotech patents). Broad nanotech patents are already being granted that span multiple industry sectors and include sweeping claims on entire classes of the Periodic Table. Should exclusive monopoly patents be granted on the fundamental building blocks of nature? Does the TRIPs Agreement obligate all developing countries to recognize and enforce patents on nanotechnology inventions, even those that incorporate plants and animals as well as essentially biological processes? Will overly broad patents or "patent thickets" on emerging nano-scale materials, processes and devices prevent developing countries from participating in the nanotech revolution?

Over the past decade, some governments, the UN Human Rights Commission as well as civil society and social movements have warned of the inequities of IP for the global South. Recently, even at WIPO – the UN body whose mission is to promote and protect intellectual property – the uneven IP playing field and the negative impacts of TRIPs have become undeniable and untenable for many developing nations. In September 2004 the "Geneva Declaration on the Future of the World Intellectual Property Organization" warned that current IP regimes are having negative impacts in the developing world, resulting in lack of access to essential medicines, anti-competitive practices that hinder innovation and the misappropriation of social and public goods.[52] At WIPO's General Assembly meeting (September 27-October 5, 2004), Brazil and Argentina, supported by 14 developing country co-sponsors, proposed that WIPO adopt a "development agenda," stating that

> Intellectual property protection cannot be seen as an end in itself, nor can the harmonization of intellectual property laws leading to higher protection standards in all countries, irrespective of their levels of development. The role of intellectual property and its impact on development must be carefully assessed on a case-by-case basis. IP protection is a policy instrument the operation of which may, in actual practice, produce benefits as well as costs, which may vary in accordance with a country's level of development. Action is therefore needed to ensure, in all countries, that the costs do not outweigh the benefits of IP protection.

WIPO's General Assembly adopted the decision to welcome a development agenda. But the United States, the United Kingdom and other industrialized nations have objected to proposals that would

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[51] For additional background on the controversy over TRIPs Article 27.3(b) and the patenting of biotechnological inventions, see: *Seeding Solutions*, Volume 1, Published by the International Development Research Centre, et al., 2000.

[52] The Declaration, translated into six languages, can be found on the Consumer Project on Technology website at http://www.cptech.org/ip/wipo/genevadeclaration.html.

give development concerns a higher profile within WIPO, acknowledging only that WIPO should give greater technical assistance to developing countries.[53] At WIPO's General Assembly in October 2005 members agreed to continue discussions.[54]

III.3.1 Nanotech Patent Trends

The world's largest transnational companies, leading academic laboratoriesand nanotech start-ups are all racing to win monopoly control of nanotech's colossal market. A study conducted by the University of Arizona and the United States National Science Foundation found that 8,630 nanotech-related patents were issued by the United States Patent & Trademark Office (US PTO) in 2003 alone, an increase of 50 per cent between 2000 and 2003 (as compared to about 4 per cent for patents in all technology fields). The top five countries represented were: the United States (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 the University of California (89).[55]

According to industry analysts, many broad patents on nanotech-related materials, tools and processes have been granted too early and too often. In 2002, the United States-based industry trade group, Nanotechnology Business Alliance, was already warning in testimony before the United States Congress, "…several early nanotech patents are given such broad coverage, the industry is potentially in real danger of experiencing unnecessary legal slowdowns."[56]

More recently, nanotech industry analysts observe that the "euphoria for patenting" in the United States combined with the United States Patent & Trademark Office's inability to handle a flood of patent applications, has resulted in "the rejection of valid claims, the issuance of broad and overlapping claims, and a fragmented and somewhat chaotic IP landscape." The writers warn, "These IP roadblocks could severely retard development of nanotechnology."[57] Many intellectual property experts in the United States are predicting that large-scale nanotech patent litigation is inevitable. Because of the large number of over-lapping and conflicting patents being granted, nanotech companies must be prepared to vigorously defend their patents in court. In most patent battles, the largest enterprises – not the most innovative ones –will prevail. According to authors Josh Lerner and Adam Jaffe, "the firm with the best lawyers or the greatest capacity to withstand the risk of litigation wins the innovation wars – rather than the company with the brightest scientists or most original, valuable ideas."[58]

In October 2004, the United States PTO created a new classification for nanotechnology patents – Class 977 – which serves as a cross-reference to help examiners, among others, search prior art. Before Class 977 existed, examiners relied on keyword searches to find relevant information and related patents.[59] As defined by the United States PTO, nanotechnology patents in Class 977 must meet the following criteria:

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[53] William New, "Nations Clash On Future Of WIPO Development Agenda," *Intellectual Property Watch*, April 11, 2005. Available on the Internet: http://www.ip-watch.org

[54] WIPO's decision is available on the Internet: http://www.cptech.org/ip/wipo/wipo10042004.html

[55] Zan Huang, et al., "International nanotechnology development in 2003: Country, institution and technology field analysis based on US PTO patent database," *Journal of Nanoparticle Research*, Vol. 6, No. 4, 325-354, 2004.

[56] Mark Modzelewski, Executive Director, NanoBusiness Alliance, September 17, 2002, in testimony to the United States Congress.

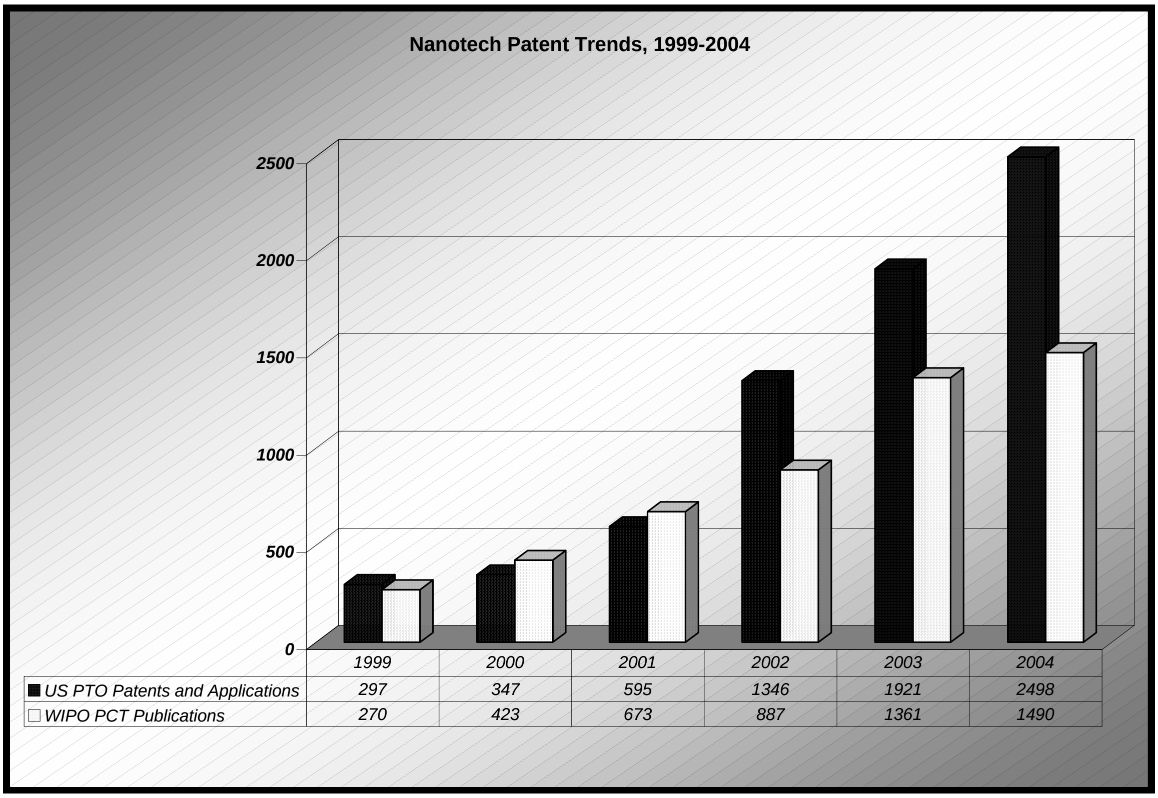
[57] John C. Miller, Ruben Serrato, Jose Miguel Represas-Cardenas, Griffith Kundahl, The *Handbook of Nanotechnology: Business, Policy and Intellectual Property Law*, John Wiley & Sons, 2005, p. 65.

[58] Adam B. Jaffe and Josh Lerner, *Innovation and its Discontents: How Our Broken Patent System is Endangering Innovation and Progress, and What to Do About It*, Princeton University Press, Princeton, 2004, p. 6.

[59] Juliana Gruenwald, "Patent office struggles to stay ahead of nanotech industry," *Small Times* on-line, April 20, 2004. Available on the Internet: http://www.smalltimes.com/document_display.cfm?document_id=7743

- relate to research and technology development in the length scale of approximately 1-100 nm in at least one dimension
- provide a fundamental understanding of phenomena and materials at the nano-scale and create and use structures, devices, and systems that have size-dependent novel properties and functions.[60]

Chart 1
Nanotech Patent Trends, 1999-2004



III.3.2 Patents on nanotech's fundamental building blocks and tools

Stanford University law professor Mark Lemley asserts that nanotechnology "is the first new field in a century in which people started patenting the basic ideas at the outset."[61] In contrast to most other major enabling technologies of the 20th century (such as computer hardware, software, the Internet, and even biotechnology), writes Lemley, the most basic ideas and fundamental building blocks in nanotechnology "are either already patented or may well end up being patented."[62]

[60] The USPTO class definition is available online: http://www.uspto.gov/web/patents/classification/uspc977/defs977.htm
[61] Mark A. Lemley, William H. Neukom Professor of Law, Stanford University, "Patenting Nanotechnology," unpublished manuscript sent to ETC Group by the author, March 2005, p. 1.
[62] Ibid., p. 14.

In the nanotech arena, it is not just the opportunity to patent the most basic enabling tools but, the ability to patent the nanomaterials themselves, the products they are used in and the methods of making them. At the United States PTO for example, there are three primary types of patent claims:[63]

1) composition of matter claims (that is, nanomaterials such as nanotubes, nanowires and nanoparticles)

2) device, apparatus or system claims (including for example, tools used to characterize and control nanomaterials – or devices incorporating nanomaterials)

3) method claims (processes for synthesizing nanomaterials or constructing nano-scale devices)

Nanomaterials are chemical elements or compounds less than 100 nm in size. Taking advantage of quantum physics, nanotech companies are engineering novel materials that may have entirely new properties never before identified in nature. As discussed above, the "raw materials" for creating nanomaterials and devices are the chemical elements of the Periodic Table – the building blocks of *everything* – both living and non-living. Whereas biotechnology patents make claims on biological products and processes – nanotechnology patents may literally stake claim to chemical elements, as well as the compounds and the devices that incorporate them. With nano-scale technologies the issue is not just patents on life – but on all of nature. In short, atomic-level manufacturing provides new opportunities for sweeping monopoly control over both animate and inanimate matter. In essence, patenting at the nano-scale could mean monopolizing the basic elements that make life possible.

Exclusive monopoly patents on chemical elements are not new. Glenn Seaborg, the 1951 Nobel Prize-winning physicist, registered United States patent #3,156,523 for the chemical element *Americium* (element no. 95 on the periodic table) on November 10, 1964. Seaborg's patent is recognized for having the shortest patent claim on record: "What is claimed is Element 95." Seaborg's second patented element was Curium #96 – United States patent # 3,161,462 granted on December 15, 1964.

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

When Harvard University's Charles Lieber obtained a key patent (United States 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 a metal oxide selected from up to 33 chemical elements. Harvard's claims on nanorods include those comprised of titanium, zirconium, hafnium, vanadium, niobium, tantalum, chromium, molybdenum, tungsten, manganese, technetium, rhenium, iron, osmium, cobalt, nickel, copper, zinc, cadmium, scandium, yttrium, lanthanum, a lanthanide series element, boron, gallium, indium, thallium, germanium, tin, lead, magnesium, calcium, strontium, and barium. In a single patent, Lieber's claims extend to nearly one-third of the chemical elements in the Periodic Table – spanning 11 of the 18 Groups. Patent lawyers have identified Harvard's patent (licenced to Nanosys, Inc.) as one of the top 10 patents that could influence the development of nanotechnology.[64]

Similarly, a key patent on semiconductor nanocrystals (quantum dots) held by the University of California (licenced to Nanosys, Inc. and Quantum Dot Corp.) claims semiconductor nanoparticles

[63] Lux Research Inc., *The Nanotech Report 2004*, Volume 1, 2004, p. 242.
[64] Steve Maebius, "Ten Patents that Could Impact the Development of Nanotechnology," an article appearing in Lux Research, Inc., *The Nanotech Report 2004*, p. 242-247.

from elements in Groups III-V of the Periodic Table. The claims in United States patent number 5,505,928 extend to boron, aluminium, gallium, indium, nitrogen, phosphorus, arsenic, antimony as well as those compound semiconductors that result from combining elements in Groups III-V (such as gallium arsenide).

III.3.3 Cross-industry Patent Claims

Nanotechnology is not only cross-disciplinary; a single nano-scale innovation may have diverse applications that span multiple industry sectors. Mark Lemley of Stanford Law School observes, "a significant number of nanotechnology patentees will own rights not just in the industry in which they participate but, in other industries as well."[65]

Consider the following examples from the United States PTO's Class 977 (patents identified as nanotechnology patents):

- US5,874,029 – University of Kansas, 23 February 1999: Methods for particle micronization and nanonization by recrystallization from organic solutions sprayed into a compressed antisolvent: ***The invention can be used in the pharmaceutical, food, chemical, electronics, catalyst, polymer, pesticide, explosives, and coating industries, all of which have a need for small-diameter particles.***

- US6,667,099 – Creavis Gesellschaft für Technologie und Innovation mbH, 23 December 2003: Meso-and nanotubes: The invention relates to mesotubes and nanotubes (hollow fibres) having an inner diameter of 10 nm-50 µm and to a method for the production thereof …***The hollow fibers are used in separation technology, catalysis, micro-electronics, medical technology, material technology or in the clothing industry.***

- US6,641,773 – The United States, as represented by the Secretary of the Army, 11 November, 2004: Electro spinning of submicron diameter polymer filaments: An electro spinning process yields uniform, nanometer diameter polymer filaments…***The filament is particularly useful for weaving body armour, for chemical/biological protective clothing, as a biomedical tissue growth support, for fabricating micro sieves and for microelectronics fabrication.***

The reason that the same invention can be used inside the human body, in clothing and in computers (as illustrated in the third example above) is that at the molecular level biological and non-biological material can be integrated. Whether this is a seamless integration is a matter yet to be determined by toxicological research.

III.3.4 Nanobiotech Patents

While biotech's raw materials are biological, nano-scale technologies involve the manipulation of both living and non-living materials, sometimes in combination. When this is the case, the discipline is known as <u>nanobiotechnology</u>. A nanostructured material used inside the body as a bone replacement is one example of nanobiotechnology, but so is a hybrid organism created from living and non-living materials, such as the nano-scale silicon and muscle-tissue hybrid announced by researchers in early 2005.[66] Closely related to and sometimes overlapping nanobiotech is the new field of "<u>synthetic biology</u>", in which living systems are built to order and then programmed to perform specific tasks. These

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[65] Lemley, p. 1.

[66] Roland Pease, "'Living' robots powered by muscle," BBC News, January 17, 2005. Available on the Internet at http://news.bbc.co.uk/go/pr/fr/-/1/hi/sci/tech/4181197.stm

too, often combine biological and non-biological parts. Patents on the products of nanobiotechnology provide the opportunity to monopolize the basic elements that are the building blocks of the entire natural world, bringing a whole new dimension to the notion of "life patenting."

The table below provides examples of the possible range of nanobiotechnology and synthetic biology patents recently issued by the United States PTO. It includes, for example: hybrid devices combining a nanomaterial and muscle tissue, which generate electrical power and which the inventor has described as "absolutely alive"[67] (Montemagno [1]); membranes made from biological and non-biological materials to be used in electricity production or water purification (Montemagno [2]); a method for controlling the properties of semiconductor nanoparticles by creating them with the help of biological material (Belcher); synthetic DNA base pairs that do not occur in nature (Benner); a method for genetically modifying cells by pricking them with carbon nanotube "needles" and injecting foreign DNA (McKnight); a gene switch that uses "switching agents" to control gene expression by turning them on or off.

Table 1
A Sample of Recent Nanobiotechnology/Synthetic Biology Patents

Inventor	**Patent/ Application Number**	**Publication Date**	**Description**
Carlo Montemagno, UCLA, United States [1]	US20040101819A1	27 May 2004	Self-assembled muscle-powered micro-devices
Carlo Montemagno, UCLA, United States [2]	US20040049230A1	11 March 2004	Biomimetic membranes
Angela Belcher, MIT, United States	US20030113714A1	19 June 2003	Biological control of nanoparticles
Angela Belcher, MIT, United States	US20030073104A1	17 April 2003	Nanoscaling ordering of hybrid materials using genetically engineered mesoscale virus
Steven Benner, UF-Gainesville	US6617106	9 September 2003	Methods for preparing oligonucleotides containing non-standard nucleotides
James J. Collins, Cellicon Technologies, United States	US6841376	11 January 2005	Bistable genetic toggle switch
Timothy McKnight, Oak Ridge National Laboratory	US20040197909A1	7 October 2004	Parallel macromolecular delivery and biochemical/electrochemical interface to cells employing nanostructures

III.3.5 Role of Public Sector Universities in Nanotech IP

One of the unique features of nanotechnology, according to Mark Lemley, is that universities and public research foundations hold "a grossly disproportionate share of nanotech patents" that he believes are critically important to downstream nanotech products.

[67] Ibid.

In 2004 a patent attorney specializing in nanotechnology identified 10 key United States patents that he believed could have the greatest impact on the development of nanotechnology. Seven of the 10 patents are owned by universities.[68]

Because they conduct basic research, it is not surprising that universities are the early-stage engines for nanotechnology. But unlike early-stage researchers 25 years ago, the new generation of United States public researchers has become "extremely aggressive patenters" largely because of the Bayh-Dole Act of 1980 – United States legislation designed to encourage technology transfer by permitting universities to patent their federally funded research projects. Before 1980, universities worldwide were granted about 250 United States patents per year. By 2003, the number of university-owned patents increased almost 16-fold, to 3,933.[69]

From 2003 to early 2005 the *Nanotechnology Law & Business Journal* identified 55 publicly announced nanotech patent licence agreements – 20 of which involved a university or public research entity as the licensor. Of the 20 licence agreements involving university or research entities as licensor, all but one was granted on exclusive terms (and its terms were not disclosed).

Early assessment of nanotech IP indicates that it will be important for developing countries to monitor intellectual property trends and their potential impacts on technology transfer and trade. 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.[70]

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[68] Steve Maebius, "Ten Patents that Could Impact the Development of Nanotechnology," an article appearing in Lux Research, Inc., *The Nanotech Report 2004,* p. 242-247.

[69] Mark A. Lemley, p. 19.

[70] ETC Group, *Nanotech's Second Nature Patents: Implications for the Global South*, June 2005. On the Internet: http://www.etcgroup.org

IV. THE POTENTIAL IMPACTS OF NANOTECHNOLOGY FOR COMMODITY DEPENDENT DEVELOPING COUNTRIES

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

Nanotechnology's potential impacts on the world economy are breathtaking. A 2005 report from the United Nations University, *State of the Future*, warns that the accelerated introduction of new technologies – including nanotechnology – is outrunning governments' capacity to understand them.[71] New, nano-engineered materials could mean that industrial manufacturers will have multiple raw material options, with the potential to turn traditional commodity markets upside-down. New "bottom-up" manufacturing platforms could mean that the quantity of raw materials required will be sharply reduced. Nano-scale technologies could make geography, raw materials, and even labour, irrelevant. The remainder of this report will consider these possible impacts in more depth.

The late Nobel laureate and chemist Richard Smalley predicted that the "impact of nanotechnology on the health, wealth, and lives of people will be at least the equivalent of the combined influences of microelectronics, medical imaging, computer-aided engineering and man-made polymers."[72] Others believe that nanotech's impacts will rival those brought about by the steam engine, electricity, the transistor and the Internet.[73] Still others, such as the United States Undersecretary of Commerce for Technology, Phillip Bond, see nanotech's potential impact 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."[74] Even allowing for hype and hyperbole, it is likely that nanotech will deliver dramatic and global disruptions across several industrial sectors.

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[71] United Nations University, *The State of the Future* 2005, United Nations University Millennium Project, June 28, 2005, See http://www.acunu.org/millennium/

[72] Congressional testimony, "Nanotechnology: Prepared Written Statement and Supplemental Material of R. E. Smalley," Rice University, May 12, 1999; available on the Internet: http://www.house.gov/science/smalley_062299.htm

[73] Thomas A. Kalil, writing in the foreword to John C. Miller, Ruben Serrato, José Miguel Represas-Cardenas, Griffith Kundahl, *The Handbook of Nanotechnology: Business, Policy and Intellectual Property Law*, John Wiley & Sons, 2005 p. xi. Kalil was science and technology advisor in the Clinton administration.

[74] Remarks by Phillip J. Bond, Under Secretary of Commerce for Technology, United States Department of Commerce, *Delivered September 9, 2003* to the World Nano-Economic Congress, The Fairmont Hotel, Washington, DC.

"Quite simply, the world is about to be rebuilt (and improved) from the atom up. That means tens of trillions of dollars to be spent on everything: clothing... food... cars... housing... medicine...the devices we use to communicate and recreate...the quality of the air we breathe...and the water we drink, are all about to undergo profound and fundamental change. And as a result, so will the socio and economic structure of the world. Nanotechnology will shake up just about every business on the planet." – Josh Wolfe, editor of the Forbes/Wolfe Nanotech Report.

In recent years much has been written about the potential of nanotech to improve the conditions of poor and marginalized populations in the developing world.[75] The UN Millennium Project's Task Force on Science, Technology and Innovation for example, identifies nanotechnology as an important tool for addressing poverty and achieving the United Nations Millennium Development Goals. In particular, nanotech research devoted to addressing energy and water problems is frequently cited to illustrate nanotech's potential contributions to environmental sustainability and human development.[76]

IV.1 Will Nanotech Address Human Development Needs in the Developing World?

Recent studies (2005) examine the potential role of nanotechnology in the developing world and, in particular, the possible use of nano-scale technologies to address the needs of poor and marginalized populations. Fabio Salamanca-Buentello and colleagues at the University of Toronto Joint Centre for Bioethics (Toronto, Canada) surveyed 63 scientific experts in nanotechnology in the South and North in order to identify and rank the ten applications of nanotechnology most likely to achieve the Millennium Development Goals.[77] The authors conclude that nanotech can be harnessed to "to address some of the world's most critical development problems," and they advocate the creation of a new global funding initiative to accelerate the use of nanotech to address critical sustainable development challenges.

Noela Invernizzi (UNICAMP, Brazil) and Guillermo Foladori (UNAM, Mexico) offer a different perspective in the *Nanotechnology Law & Business Journal*.[78] They conclude that, "In order to serve the needs of the poor, technology has to be used in a favorable socio-economic context." In direct response to Salamanca-Buentello, et al., Invernizzi and Foladori write:

"Despite the optimistic assessments recently offered, experience suggests that nanotechnology could follow the mainstream economic trends that increase inequality. First, the development of

[75] See, for example, Gordon Conway, Minutes of Evidence to House of Commons Select Committee on Science and Technology (United Kingdom), 23 March 2005, http://www.publications.parliament.uk/pa/cm200405/cmselect/cmsctech/487/5032303.htm, and Mohamed H. A. Hassan, "Nanotechnology: Small Things and Big Changes in the Developing World," *Science*, Vol. 309, Issue 5731, pp. 65-66, 1 July 2005

[76] Fabio Salamanca-Buentello, Deepa L. Persad, Erin B. Court, Douglas K. Martin, Abdallah S. Daar, Peter A. Singer, "Nanotechnology and the Developing World," April 12, 2005. On nanotechnology and the UN Millennium goals, see Calestous Juma and Lee Yee-Cheong, lead authors, "Innovation: applying knowledge in development," UN Millennium Project Task Force on Science, Technology, and Innovation 2005, p. 69 ff.

[77] Salamanca-Buentello F, Persad DL, Court EB, Martin DK, Daar AS, et al. (2005) Nanotechnology and the Developing World. PLoS Med 2(5): e97. On the Internet: http://medicine.plosjournals.org/perlserv/?request=get-document&doi=10.1371/journal.pmed.0020097

[78] Noela Invernizzi and Guillermo Foladori, "Nanotechnology and the Developing World: Will Nanotechnology Overcome Poverty or Widen Disparities?" *Nanotechnology Law & Business Journal*, Vol. 2, Issue 3, 2005.

nanotechnology faces many of the same problems faced by prior technological developments because large multinational corporations are patenting the majority of the nanotechnology products. Patents are monopolistic guarantees of earnings for twenty years – something that certainly works against the rapid diffusion of the beneficial potentials of this technology for the poor."[79]

Donald Maclurcan, a researcher at the Institute for Nanoscale Technology in Sydney, Australia, recently published two papers on developing country engagement with nanotechnology.[80] Maclurcan concludes:

"Overall, there are some encouraging signs that certain developing countries could play a significant role in the global development of nanotechnology. Yet, in light of increasing, market-based barriers and limited country participation on a number of levels, early signs are that nanotechnology will promote a greater global technological divide."[81]

IV.1.1 Nano-Water

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. Researchers are developing both nanofilters and engineered nanoparticles to clean contaminated water:[82] 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-nanomters wide. Their goal is to develop a low-cost water filter that can be cleaned and re-used.[83]

- With funding from the United States Air Force, Vermont-based Seldon Technologies is developing 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. The company claims that its patented, prototype filter, also based on carbon nanotube technology, provides "an absolute barrier against passage of microbial contaminants."[84]

- In countries like Bangladesh, naturally occurring arsenic in wells is a major threat to public health, afflicting an estimated 10-20 per cent 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. At Oklahoma State University, chemists are experimenting with the use of zinc oxide nanoparticles to clean up arsenic in water.

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[79] Ibid.
[80] Donald C. Maclurcan, "Nanotechnology and Developing Countries, Part 2: What Realities?" AZoNano – Online Journal of Nanotechnology, October 19, 2005. On the Internet:
http://www.azonano.com/Details.asp?ArticleID=1429
[81] Ibid.
[82] William J. Broad, "With a Push From the U.N., Water Reveals its Secrets," *New York Times*, July 26, 2005, p. D1.
[83] David Cotriss, "Nanofilters," *Technology Review*, November 2004, p.
[84] Matt Kelly, "Vermont's Seldon Labs wants to keep soldiers' water pure," *Small Times,* April 26, 2004. On the Internet: http://smalltimes.com/document_display.cfm?document_id=7764.
See also: http://www.seldontechnologies.com/products/

Research on applications of nano-scale technologies to improve access to clean water may prove beneficial. The potential health and environmental impacts must be thoroughly evaluated, however, before any application is introduced. For example, the United Kingdom's Royal Society and Royal Academy of Engineering has recommended that the use of engineered nanoparticles in groundwater remediation be prohibited until toxicological and environmental impact issues are clarified.[85] The intellectual property landscape will also play a role in determining the conditions under which nanotech innovations for clean water would become widely accessible to low-income communities.

IV.1.2 Nano-Energy

Access to inexpensive, safe and renewable energy is key to sustainable development worldwide. In the developing world, an estimated two billion people lack access to modern energy sources. Cheap, flexible and efficient solar cells are often highlighted as one of the most promising areas of "green nanotechnology."[86]

In 2004, the United States 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) are developing a new generation of lightweight, flexible solar cells that are based on semi-conducting nanoparticles.[87] 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 wrap 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."[88]

IV.2 What Roles 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 recent survey conducted by 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 fourteen countries have expressed interest in engaging in nanotechnology research. Of these countries, one is categorized as transitional and 13 as developing, including three LDCs. Maclurcan's findings are presented in the table below.

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[85] CBEN, "Sorption of Contaminants onto Engineered Nanomaterials," on the CBEN website: http://cohesion.rice.edu/centersandinst/cben/research.cfm?doc_id=5100; Liz Kalaugher, "Nanoparticles clean up arsenic," *nanotechweb.org*, 25 May 2004. Royal Society and Royal Academy of Engineering, *Nanoscience and Nanotechnologies: Opportunities and Uncertainties*, July 2004.

[86] Anonymous, "Nanotech vs. the Green Gang," *Forbes/Wolfe Nanotech Report*, March 2005, p. 4.

[87] Paul Carlstrom, "As solar gets smaller, its future gets brighter," San Francisco Chronicle, July 11, 2005.

[88] Anonymous, "Nanotech vs. the Green Gang," *Forbes/Wolfe Nanotech Report*, March 2005, p. 4.

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; Viet Nam	Belarus; Bulgaria; Cyprus; Czech Republic; Estonia; Hong Kong, China; Hungary; Israel; Latvia; Lithuania; Poland, Romania; Russian Federation; Singapore; Slovak Republic; Slovenia; Republic of Korea; Ukraine	Australia; Austria; Belgium; Canada; Denmark; Finland; France; Germany; Greece; Iceland; Republic of Ireland; Italy; Japan; Luxembourg; Netherlands; New Zealand; Norway; Portugal; Puerto Rico; Spain; Sweden; Switzerland; TaiwanProvince of China; 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. http://www.azonano.com/Details.asp? ArticleID=1429

IV.3 Impacts on Trade and Commodity Markets

While governments, industry and scientists in OECD countries are quick to point out the potential contributions of nano-scale technology to development in the South, the potential disruptive impacts of nanotech on developing economies, particularly commodity dependent economies, have received far less attention. At the first North-South dialogue on nanotechnology sponsored by the United Nations Industrial Development Organization in February 2005, scientists from developing countries pondered the opportunities and challenges posed by nano-scale science and technology. While most of the discussion focused on promoting nanotech R&D and preventing a "nano-divide" between South and

North, representatives from India and South Africa warned that raw materials and labour in developing economies risk becoming "redundant in the nano-age." According to South Africa's Minister of Science and Technology: "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." 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.[89]

IV.3.1 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 dependent 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.[90] The consortium involves fifteen universities and public research laboratories. None of the scientists involved in the consortium are food scientists by training; rather, they are a diverse group of molecular chemists, material scientists, engineers and physicists. Kraft and other companies are working on using nano-scale technologies to create "interactive foods" that operate using "on-demand" delivery. One project of Kraft's NanoteK consortium is 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.[91] Increasing the shelf-life of food and beverages is another goal of formulating ingredients at the nano-scale.[92] (The health effects of dormant ingredients or un-opened nanocapsules would also need to be evaluated.)

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[89] The North-South Dialogue on Nanotechnology: Challenges and Opportunities, 10-12 February 2005, Trieste, Italy, was sponsored by the International Centre for Science and High Technology (ICS), part of UNIDO (United Nations Industrial Development Organization). At the Trieste meeting, comments by Pontsho Maruping of the Science and Engineering Research Council in Pretoria, South Africa and Roop L. Mahajan, University of Colorado, Boulder. Opening Address By The Minister Of Science And Technology, Mr. Mosibudi Mangena, Minister of Science and Technology at a Project Autek Progress Report Function, Cape Town International Convention Centre, 8th February 2005.
[90] Elizabeth Gardner, "Brainy Food: academia, industry sink their teeth into edible nano," *Small Times*, June 21, 2002.
[91] Eric Russell, "Foods of Tomorrow: The Nuts and Bolts of Nanoscience," International Food Ingredients, *ifi-online.com*. On the Internet: http://www.ifi-online.com/Tmpl_Article.asp?contentType=3&ContentID=225
[92] For example, BASF sells synthetic, nano-scale lycopene for use in lemonades, fruit juices and margarines. According to BASF, nano-scale formulation makes the lycopene more easily absorbed by the body and also increases shelf-life. For discussion, see: ETC Group, *Down on the Farm: The Impact of Nano-Scale Technologies on Food and Agriculture,* November, 2004. On the Internet: www.etcgroup.org

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 commodity dependent developing countries. Consider, for example, that coffee represents 75 per cent of Burundi's total exports, 62 per cent of Ethiopia's, 54 per cent of Uganda's and 24 per cent of Guatemala's; cocoa represents 36 per cent of Côte d'Ivoire's total exports and 24 per cent of Ghana's.[93]

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.[94] When United States 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.[95] The gift demonstrated China's prowess in cutting-edge technologies. However, as the world's largest producer of both cotton and silk, , China must closely follow developments in nano-scale technologies that could dramatically affect the demand for natural fibres.

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.[96] 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.[97] (In April 2005 Nano-Tex announced a new version of Coolest Comfort designed for use with wrinkle-free cotton garments.)

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."[98] 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 discoloured.[99] 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.[100]

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[93] Common Fund for Commodities, "Basic Facts," May 2005, p. 4.
[94] A partial list of clothing manufacturers includes Gap, Eddie Bauer, Old Navy and Lee.
[95] Anonymous, "A Chinese nano-society?" *Nature Materials*, editorial, vol. 4 no. 5 May 2005, p. 355.
[96] Anonymous, Nano-Tex news release, "Nano-Tex Secures US$35 Million Series-A Round To Drive Development, Marketing, Global Expansion of Fabric Innovations," March 7, 2005, available on the Internet: http://www.nano-tex.com/news&media/news.html
[97] Email correspondence with Dan Stevens of Nano-Tex, October 12, 2005.
[98] Anonymous, "China Uses Nanotechnology for Clothing," China Education and Research Network, September 2001.
[99] Ibid.
[100] Ibid.

Nanotech-fabrics are already influencing the textile sector, a topic that has been the focus of international conferences for the past two years, in Europe and in Asia.[101] This year's European conference was co-sponsored by AITPA, Asociación Industrial Textil de Proceso Algodonero (Spanish cotton textiles industry association). It is not hard to understand why: In addition to information-sharing on nano-scale fabric treatments, the conference organizers promised to address how Europe can "respond to the twin threats of high tech 'knowledge enabled' textiles and low cost Asian production."[102]

Although the full implications are not clear, it is critical for commodity-dependent developing countries 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 accounts for 38 per cent of the global fibre market. Though China, India, and Pakistan, together with the United States, account for approximately two-thirds of world output, cotton is grown in over 100 countries.[103]

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.[104] Cotton is also the main cash crop in the Central African Republic, where cash crop production accounts for only per cent of GDP but is the principal source of income for most of the rural population.[105] Cotton accounts for 39 per cent of Burkina Faso's exports, 37 per cent of Chad's and 33 per cent of Benin's.[106] 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.[107]

"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.

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[101] EuroFutureTex, November 2005, in Padua, Italy and AsiaFutureTex, October 2005, Singapore. Both conferences are sponsored by Cientifica, a consulting and business information firm.

[102] http://www.eurofuturetex.com/about.html

[103] Info Comm: Market Information in the Commodities Area: Cotton, available on the Internet: http://r0.unctad.org/infocomm/anglais/cotton/market.htm

[104] Zambia Country Profile, *The Economist Intelligence Unit*, 2005.

[105] Central African Republic Country Profile, *The Economist Intelligence Unit*, 2005.

[106] Common Fund for Commodities, "Basic Facts," May 2005, p. 4.

[107] Gérald Estur, "Cotton: Commodity Profile," International Cotton Advisory Committee, Washington, D.C., June 2004, pp. 1-2.

IV.3.2 Case Studies

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 case studies were conducted on rubber and strategic minerals (platinum and copper) because: 1) these cases provide early indications of nano-scale R&D currently underway that has the potential to alter demand for traditional commodities produced in developing countries; 2) researchers associated with the R&D have clearly stated that the objective of developing a nano-scale material or manufacturing process is to ultimately substitute for or change the uses of the traditional commodity or raw material.

Case Study # 1: 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.[108] 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. 79 per cent of all natural rubber was produced in South-East Asia in 2004.[109]

At this point, it is difficult to evaluate how the market for natural rubber will be affected by future developments in nano-scale technologies. For instance, it is possiblethat 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.[110] Researchers in the United States, 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.[111]

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 tires. As Bob Nelson, sales manager at Goodyear Chemical Corporation, puts it: "The rubber industry goes as the tyre industry goes."[112] Currently, around 40 per cent 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 tires 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 per cent reduction in abrasion, promising a tyre with significantly improved durability.[113] 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

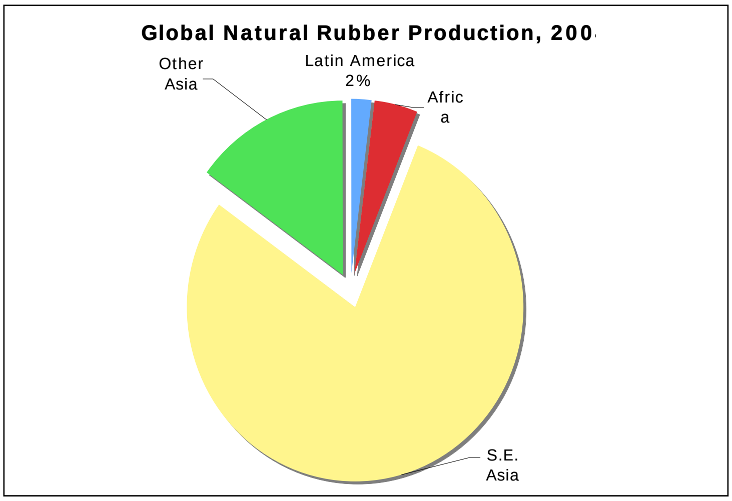
[108] http://en.wikipedia.org/wiki/Rubber
[109] http://www.rubberstudy.com/statistics-quarstat.aspx
[110] Toru Noguchi et al., English Abstract of "Carbon Nanotubes as Fillers," *The Journal of the Society of Rubber Industry, Japan*, 78(6), 2005, pp. 205-210.
[111] nanoScience Engineering Corporation press release, "New company's technology creates performance-enhancing nano-fillers for polymers," April 29, 2005.
[112] Bob Nelson quoted in Alexander H. Tullo, "Synthetic Rubber: Amid a faltering economy, North American producers struggle to hang on in some sectors, while other segments post modest gains," *Chemical & Engineering News*, Volume 81, Number 15, April 14, 2003, pp. 23-26.
[113] NanoProducts press release, "Nanotechnology creates safer, more durable tires," July 2003; available on the Internet: http://www.nanoproducts.com/site/content_page.php?p=new_developments

since late 2001. The technology was originally developed in the late 1990s in a joint R&D project of Michelin and Hoechst Celanese.[114]

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.[115]

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 2
Global Natural Rubber Production, 2004



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

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 per cent and exports by 4 per cent over the next three years.[116]

- Natural rubber is cultivated in the south of Thailand, a country where 13.6 million people – 40 per cent of the workforce – are employed in the agriculture sector.[117] Thailand sur-

[114] Sara Parsowith, “These Balls Could Bounce All the Way to Profit,” *Business News* (New Jersey), 13 November 2001.
[115] Anonymous, American Chemical Society, “New Lightweight Materials May Yield Safer Buildings, Longer-lasting Tires: Aerogels,” September 2002.
[116] *Economist Intelligence Unit*, Country Profile: Indonesia, 25 April 2005.
[117] *Economist Intelligence Unit*, Country Profile: Thailand, 1 June 2005.

passed Malaysia in 1991 to become the world's largest producer of natural rubber – almost three million tonnes in 2004, accounting for more than 34 per cent of total global production.[118] 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 two million tonnes in 2004, accounting for almost one-quarter of global production.[119] According to the *Economist Intelligence Unit*, 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 per cent of global production. In September 2005, the Malaysian Rubber Board organized 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. Malaysia expects that it will export 60,000 more tonnes of rubber to China than it did last year.[120]

Case Study # 2: 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.[121] 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 53 per cent of the total demand for platinum worldwide in 2004.[122] 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 per cent of the products' total cost.[123] In 2004, the demand for platinum for use in autocatalysts was 3.51 million ounces (reflecting a market value of almost three billion dollars).[124]

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$845.75 per ounce in 2004), and supplies are limited.[125] To make today's fuel cell

[118] International Rubber Study Group, *Summary of World Rubber Statistics*, Annual Edition, 2005, pp. 1-2.
[119] Ibid.
[120] Hanim Adnan, "Malaysian rubber riding high on China market," Malaysian Rubber Board, September 12, 2005.
[121] According to Wikipedia: The platinum group or platinum family is a group of six metal elements with similar physical and chemical properties. The family consists of ruthenium, rhodium, palladium, osmium, iridium, and platinum. Source: www.wikipedia.org
[122] Tom Kendall, *Platinum 2005: 20th Anniversary*, Johnson Matthey plc, May 2005, p. 48. The figure includes both recovered platinum and newly-mined platinum.
[123] QuantumSphere, Inc., Company News Release, "QuantumSphere Achieves Milestone: Nano-Nickel/Cobalt Alloy, Replaces Platinum," August 29, 2005. On the Internet: www.nanoinvestornews.com
[124] According to Johnson Matthey, the average price of platinum in 2004 was US$845.75.
[125] *Fuel Cell Industry Report*, Vol. 6, No. 9, September 2005, p. 1.

designs economically viable, researchers must find a substitute for the platinum catalyst – or reduce the amount of platinum used by 90 per cent.[126]

Both academic and private-sector researchers, including two California-based nanotech start-up companies, QuantumSphere, Inc.[127] and NanoStellar, Inc.,[128] 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."[129]

"Companies and governments collectively waste billions of dollars a year as a byproduct of their overreliance on using platinum as a catalyst. As a result, the annual US$10 billion platinum group metal catalyst market will inevitably be impacted by the fact that our nanonickel can be used to achieve better results, for many of the same applications that people use today, at a 75 per cent cost reduction." – Kevin Maloney, CEO, QuantumSphere, Inc., quoted in *Fuel Cell Magazine*, January 2005.[130]

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. In essence, the researchers are modeling materials one atom at a time.[131] 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.[132] 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."[133]

In 2003, Stanford University professor, Kyeongjae Cho co-founded nanotech start-up company, NanoStellar, Inc., to commercialize nano-structured catalysts. Nanostellar is in the process of prepar-

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[126] Monya Baker, Sheer Energy: Thinner, cheaper fuel cell catalysts," *Technology Review*, June 2005.
[127] On the Internet: http://www.qsinano.com/
[128] On the Internet: http://www.nanostellar.com/
[129] QuantumSphere, Inc., Company News Release, "QuantumSphere Achieves Milestone: Nano-Nickel/Cobalt Alloy, Replaces Platinum," August 29, 2005. On the Internet: www.nanoinvestornews.com
[130] Fuel Cell Magazine, E-Update, January 2005, on the Internet: http://www.fuelcell-magazine.com/fc_newsletter_1-05.htm
[131] Alexandra Goho, "Virtual Nanotech: Modeling materials one atom at a time," *Science News*, February 7, 2004, Vol. 165, No. 6, p. 87.
[132] Ibid.
[133] Telephone conversation with Noel Park, Nanostellar, Inc., October 6, 2005.

ing up to 20 patent applications, some of which claim low-cost nanocatalysts to reduce the need for platinum.[134] A May 2005 progress report on the United States 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."[135]

In separate research, scientists at the United States 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.[136] The research team reported earlier this year 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.[137] 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 Matthey-Johnson, the United Kingdom-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."[138] 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 roughly US$6,000 million worldwide (for newly mined, not recycled metal).[139] In 2004, worldwide demand for platinum was 6.58 million ounces and the average price of platinum was $845.75 per oz., a 22 per cent increase over the previous year. Production of autocatalysts was the largest single use of platinum in 2004 – accounting for 53 per cent 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.[140]

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[134] Ibid.

[135] PCAST, "National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel, May, 2005, p. 13.
http://www.ostp.gov/pcast/PCASTreportFINALlores.pdf

[136] Monya Baker, Sheer Energy: Thinner, cheaper fuel cell catalysts," *Technology Review*, June 2005.

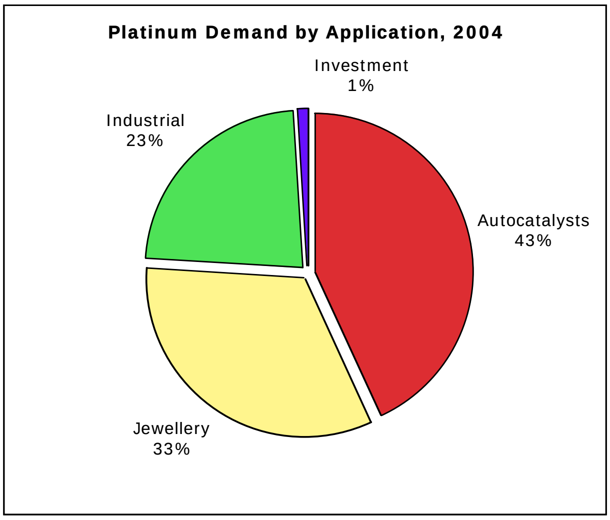
[137] PCAST, "National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel, May, 2005, p. 13.

[138] Telephone conversation with Tom Kendall, Johnson-Matthey, London, UK, 12 October 2005.

[139] Estimate provided by Tom Kendall, Johnson-Matthey, London, UK. Telephone conversation, 12 October 2005.

[140] UNCTAD, Market Information in the Commodities Area, Platinum. On the Internet: http://r0.unctad.org/infocomm/anglais/platinum/market.htm

Chart 3: Platinum Demand by Application, 2004



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 77 per cent of the total global production of platinum in 2004 and holds an estimated 87.5 per cent of the world's reserves.

- South Africa's entire mining and quarrying sector directly employs over 416,920 workers, equivalent to 2.6 per cent 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 per cent 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.

- 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 new platinum mine expected to be in full production by 2007.

- 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)

Case Study # 3: Power Cable Made of Carbon Nanotubes Aims to Replace Copper Wiring

In April 2005 the United States 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.[141] The project aims to produce a prototype wire made entirely of carbon nanotubes, which could conduct electricity up to 10 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 fibrefibres of carbon nanotubes by 2010. Rice University researchers believe that wiring made of carbon nanotubes will someday transform the electrical power grid.

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.

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

Rice University researchers have already spun carbon nanotube fibrefibres 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.[142]

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. Richard Smalley, 1996 Nobel Laureate and Director of Rice University's Carbon Nanotechnology Laboratory, described the promise and potential of quantum wires:

"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 per cent 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." – Richard E. Smalley, Nobel Laureate and Director of Rice University's Carbon Nanotube Laboratory

[141] NASA News, "NASA Awards US$11 Million 'Quantum Wire' Contract to Rice," April 22, 2005. On the Internet: http://www.nasa.gov/centers/johnson/news/releases/J05-018.html

[142] Ibid.

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 Director of Rice University's Carbon Nanotube Laboratory[143]

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.[144]

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 aluminium wires, at speeds of up to 10 gigahertz (10^9 per second).[145] 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.

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 connexions 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."[146]

In the late 1990s the semiconductor chip industry shifted from using aluminium to copper for its interconnect wiring (connexions between the transistors) because copper carries electrical signals faster than aluminium. 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."[147]

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).[148]

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[143] Testimony of Richard E. Smalley before the United States House of Representatives, Committee on Science, Energy Subcommittee, "Review of Non-Oil and Gas Research Activities in the Houston-Galveston-Gulf Coast Area," Rice University, December 4, 2003.
[144] Erika Jonietz, "Power Transmission," *Technology Review*, May, 2005.
[145] Z. Yu and P.J. Burke, Microwave Transport in Metallic Single-Walled Carbon Nanotube," *Nanoletters*, Vol. 5, No.7, 1403-1406. On the Internet: http://nano.ece.uci.edu/papers/nl050738k.pdf
[146] Burke is quoted in Henry Samueli School of Engineering, University of California, Irvine, *News Release*, "UCI Scientists Use Nanotechnology to Create World's Fastest Method for Transmitting Information in Cell Phones and Computers," June 9, 2005. On the Internet: http://www.eng.uci.edu/news_events/current/?page=188
[147] Henry Samueli School of Engineering, University of California, Irvine, News Release, "UCI Scientists Use Nanotechnology to Create World's Fastest Method for Transmitting Information in Cell Phones and Computers," June 9, 2005. On the Internet: http://www.eng.uci.edu/news_events/current/?page=188
[148] According to wikipedia.com

Copper**:** Chile, Indonesia, the United States 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.[149] 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 United States, cut back on production, despite an almost 800,000 Mt increase in global mine capacity during 2001-2003.[150]

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 per cent of Chile's GDP and for US$16,400 million, or 51 per cent, of exports. **Copper accounted for US$14,300 million, or 45 per cent of Chile's exports in 2004; an estimated 74,000 workers were employed in the Chilean mining and quarrying sectors.**

- In 2004, Chile produced 5.45 million tonnes of refined copper, representing 38 per cent 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.[151]

Employment: Chilean mining/production

Year	2000	2001	2002	2003	2004
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, Boletin Mensual.

Indonesia has rich deposits of copper. **Mining accounts for 12 per cent of the country's GDP; in 2004, an estimated 500,000 Indonesian workers were employed in the mining and quarrying sector.**[152]

- Indonesia produced 3.2 million tonnes of copper in 2003.

[149] Chile, Country Profile, *Economist Intelligence Unit*
[150] United States Geological Survey
[151] Chile Country Profile, *Economist Intelligence Unit*
[152]Indonesia Country Profile, data from Country Studies Program, Federal Research Division, Library of Congress, United States of America. http://lcweb2.loc.gov/frd/cs/profiles.html

- The world's second-largest copper mine is at Grasberg in Papua and employs 18,000 people.

- A new copper mine, operated by Newmont Nusa Tenggara, a subsidiary of the United States 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 per cent of its foreign exchange earnings (see Appendix 1), 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 per cent higher than in 2000.

- Proceeds from copper and cobalt mining dominate Zambia's foreign-exchange earnings, typically contributing 55-70 per cent of the total.

- For 2005 Zambia expects a small trade surplus as a whole, largely owing to copper exports, of US$35 million.

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, IMF, Zambia: Selected issues and Statistical Appendix; EIU

A note on Congo (Democratic Republic): While the entire mining sector contributed just nine per cent 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.[153] 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 in 2005.[154]

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 de-

[153] Congo Country Profile, *Economist Intelligence Unit*, 2005.
[154] Congo Country Report, *Economist Intelligence Unit*, September 2005.

veloping countries to innovate and add value to current commodities. The potential impacts cannot be dismissed as “good” or “bad.” However, it is clear that commodity dependent developing nations are the poorest, most vulnerable and will likely face the greatest disruptions.[155] Currently, nanotech innovations and intellectual property are being driven from the North (especially the United States, 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 do not 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 favour 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 to determine research priorities based on human needs and development.

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[155] While there is disagreement on the causal relationship between poverty and commodity dependence, there is agreement that the most commodity dependent countries are the poorest. See for example, Nancy Birdsall and Amar Hamoudi, “Commodity Dependence, Trade and Growth: When ‘openness’ is not enough,” Center for Global Development, Working Paper Number 7, May, 2002, p. 17.

V. CONCLUSION

History shows that technology-driven shifts in commodity demands are rapid and unpredictable. The beneficiaries of sudden shifts tend to be the developers of the new technology, who are in a position to see the changes coming, while the "losers" are the producers of primary commodities who were unaware of the imminent changes and/or, those who could not make rapid adjustments in the face of new market configurations.

There is little doubt that "tiny tech" is the next big thing on the science and technology horizon. Nano-scale technologies are gaining a critical mass of investment and innovation from both the public and private sectors. Globally, billions of dollars are pouring into basic research and the number of nanotech-related scientific articles and published patents is surging. A number of middle-income developing countries are already developing nanotechnology R&D programmes.

Some commodity dependent developing countries will soon find themselves under pressure to "get on the nanotech bandwagon" – either as testing grounds for research, as markets for nanotech-based products or, as possible jurisdictions for patent protection. Without critical planning and assessment, commodity dependent developing countries are more likely to be on the receiving end of nanotech's potentially adverse impacts – rather than active participants in shaping nanotech's role in society. Development experts are already warning of the threat of a "nano-divide." However, it is important for commodity dependent developing countries to recall that new technologies have rarely provided simple solutions to complex problems rooted in poverty and social inequities. It is also true that there are many good technologies currently available that have never been applied to the South's most pressing development needs.

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 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 nanotech wave – not human development needs. Will poor communities or countries gain access to nanotech's proprietary products? Will nanotech patents 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.

Genetically modified crops came to market one decade ago with virtually no public discussion of their risks, and within regulatory frameworks that some critics 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 still unresolved, and millions of people have spurned GM products. Today, five multinational agrochemical firms dominate the global agbiotech market. There is growing evidence that unwanted gene flow from GM plants is causing contamination of non-GM crops in many areas (including centres of genetic diversity in developing countries), with unknown consequences for biodiversity.[156] The United Nations' Cartagena Protocol on Biosafety, which establishes rules for the introduction of genetically modified organisms across national borders, entered into force in 2003 – eight years after the first GM crops were commercialized. The parallels between the introduction of agbiotech and nanotech are undeniable. In the case of nanotech, however,

[156] Scott Miller and Scott Kilman, Biotech Crop Battle Heats Up as Strains Mix With Others, *Wall St. Journal*, November 8, 2005, p. 1.

the impacts will cut across all industry sectors, and multinational firms are involved at a much earlier stage.

In 2006, corporate funding for nanotech R&D is expected to exceed publicly supported research for the first time. [157] The fate of converging technologies at the nano-scale will likely be sealed in the immediate years ahead. Unfortunately, many OECD 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 nations – especially the United States, Europe and Japan – 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.

Governments negotiating at the WTO for market access should bear in mind that converging technologies are poised to trump trade as the defining feature of comparative advantage in the 21st century. The current context for trade negotiations at the WTO (or in bilateral agreements) could be transformed by emerging technologies that alter markets for traditional commodities.

At a time when truly transforming technologies are emerging far faster than public policies can evolve to address them, how can society assert democratic control over new technologies, and participate in assessing research priorities? It is critical to broaden the participation of developing nations in assessing how emerging technologies should affect their future. Society must gain a fuller understanding of the direction and impacts of science and technology innovation in a broader socio-political context. To keep pace with technological change, innovative approaches are needed to monitor and assess the introduction of new technologies. The following section outlines policy recommendations to address the needs of commodity dependent developing countries.

[157] For private funding outpacing public: Marc Airhart, "How Much for Nano?" Earth & Sky Radio Series, posted April 2005 at http://www.earthsky.com/shows/articles/2005-04_howMuch4Nano.php

VI. POLICY RECOMMENDATIONS

VI.1 Promote Early Warning/Early Listening Strategies in Technology Monitoring and Assessment

Early Warning Research and Information for Commodity Dependent Developing Countries

The case studies included in this report on nanotech-induced impacts on commodities are the first hint of the power of nanotech's technological tsunami – they are early projections of possible impacts. The nanotech revolution will span multiple industry sectors with potential impacts on virtually all commodities. Additional, in-depth research is urgently needed to provide early warning information to commodity dependent developing nations.

The Common Fund for Commodities, an intergovernmental financial institution based in Amsterdam, could play an important role in facilitating and funding further research. The current five-year action plan of the Common Fund directs its activities to commodities of interest to Least Developed Countries and the poor strata of their populations. Governments should request that the Common Fund for Commodities undertake research on the implications of nano-scale technologies on commodities with special attention to sectors that are vulnerable in commodity dependent developing countries – including textiles, agricultural commodities (tropical beverages, rubber) and strategic minerals. According to the Commodity Fund's guidelines, all project proposals must be submitted to the Commodity Fund through an International Commodity Body. Co-financing by governments and UN agencies is possible and should be encouraged. Governments should consult with International Commodity Bodies and request that project proposals be submitted to the Common Fund to investigate the opportunities and challenges of nano-scale technologies for commodity dependent developing countries.

Reinvigorate the Capacity of the UN System to Conduct Technology Assessment for Development

Emerging nano-scale technologies require scientific, socioeconomic and societal evaluation in order for governments to make informed decisions about their risks/benefits and ultimate value. This is particularly the case for commodity dependent developing countries. Unfortunately, at the very time when society is most in need of technology assessment and monitoring, there are few resources devoted to these goals. Currently, nanotechnologies and emerging technologies in general, are developing below the radar of the UN system.

In recent decades, the United Nations system has lost its capacity to conduct technology monitoring and assessment. For instance, in 1992 the UN Commission on Science and Technology for Development became a subsidiary body of the Economic and Social Council, where it operates with greatly reduced staff and funding. (CSTD's administrative services are handled by the Science and Technology Development Network within UNCTAD.) There is a need for new capacity in the areas of technology assessment and monitoring, especially for commodity dependent developing nations. Governments should request that the United Nations reinvigorate its capacity to assist its members in the area of technology assessment and monitoring. In order to prevent international regulatory gaps or distortions, governments must work together through the specialized agencies of the United Nations to ensure worker and consumer health and safety; to safeguard the environment and biological diversity; and to ensure the socio-economic well -being of people in every country.

Corporate Technology Oversight

If present trends continue, multinational firms will soon dominate global investment, R&D and product sales in nano-scale technologies across multiple industry sectors. As such, it is also important to monitor technology business practices and trends. In 1974 the UN created the Centre on Transnational Corporations, but its programme withered and the Centre ceased operations in 1993. Following its closure, global corporate mergers rose sevenfold (from half a trillion dollars per annum to US $3.4 trillion) and the global technology sector boomed. Because of the enormous potential impacts on society and development, the international community must re-gain the capacity to monitor the activities of transnational enterprises, particularly in regard to technology platform control and monopoly power.

Technology and Diversity

Just as dependence on a few commodities places developing countries in a vulnerable economic position, dependence on new, untested technologies also poses potential risks. Ultimately, society must actively maintain and use a diversity of viable technologies that are socially, economically and environmentally appropriate. If technologies are to be used to address diverse societal needs in diverse cultural contexts, it is important that both foreign aid donors and recipients are aware of the need to maintain diverse technologies (both old and new) and to recognize and encourage indigenous technology innovation that is often overlooked in the face of pressures to accept dominant technology introductions.

Nanotech and Intellectual Property

Intellectual property plays a large role in science and technology development today, and the race to win monopoly control of nanotech's colossal market is underway. Studies are needed to examine the implications of intellectual property and nano-scale technologies. Governments should request that WIPO initiate studies to examine the special implications of nanotech-related intellectual property on monopoly practices, technology transfer and trade – especially for developing countries.

Social and Ethical Implications of Converging Technologies

The integration of living and non-living matter at the nano-scale (nanobiotechnology, also known as "synthetic biology") is a nascent field that is creating excitement and debate within the scientific community. Today, researchers are building "biological machines" – hybrid organisms employing both biological and non-biological matter, in the absence of public scrutiny or regulatory oversight. Although the field of synthetic biology may seem distant, the merger of living and non-living materials is advancing rapidly and opens up a range of far-reaching ethical and environmental concerns that should be addressed by governments and civil society. If this effort is postponed for ten years, it will be too late. Governments should request that the Human Rights Commission undertake studies on the social and ethical implications of synthetic biology and/or nanobiotechnology, particularly for people with disabilities and other marginalized populations in the developing world.

Impacts on Biological Diversity and the Environment

Nano-scale technologies are already being developed for food and agriculture, and large-scale environmental release of nano-scale particles and devices is envisioned in the near future. Parties to the Convention on Biological Diversity, at its upcoming Conference of Parties (COP8) in Brazil (20-31 March 2006), should request that the CBD incorporate in its programme of work the issue of emerging nanobiotechnologies, and the potential impacts on the environment and biodiversity.

Agrarian Reform

The government of Brazil will host the International Conference on Agrarian Reform and Rural Development (ICARRD) during the period 7-10 March 2006 in Porto Alegre. The theme of the conference, which is being organized by FAO, is "new options and challenges for revitalizing rural communities." Governments attending the meeting should request that the topic of nano-scale technologies and potential implications for agricultural communities and commodity markets be addressed at the conference.

Legally-binding, multilateral approach

Rather than approaching technology assessment in a piece-meal fashion, governments should also consider longer-term strategies to address the introduction of significant new technologies on an ongoing basis. To break free from the cycles of crisis that accompany each new technology introduction, the international community needs an independent body that is dedicated to assessing major new technologies and providing an early warning/early listening system. One possibility is the establishment of an intergovernmental framework (for the purposes of discussion, this facility could be called the International Convention on the Evaluation of New Technologies – ICENT). The objective of ICENT would be 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 social and scientific innovation, and facilitates equitable benefit-sharing. Furthermore, the inter-governmental framework would also ensure the conservation of useful, conventional or culturally-distinct technologies and, in particular, promote technological diversification and decentralization.

ICENT could be negotiated through a Specialized Agency such as UNCTAD or the ILO or, through ECOSOC's Commission on Sustainable Development (CSD). The process of United Nations negotiations to develop an international agreement such as ICENT would also stimulate high-level and broad societal discussion, and encourage national and regional legislative and institutional initiatives that would compliment an international agreement.

VI.2 Increasing the Participation of Commodity Dependent Developing Countries in Nanotech Governance

The governance of nano-scale technologies requires transparency and broad international participation. To date, governments from only a handful of middle-income developing countries have participated in multilateral discussions on nanotech policy. The United Nations and its specialized agencies have been largely sidelined in these discussions, as has input from civil society and social movements.

Broadening the Debate beyond Health and Safety Risks

Over the past year many OECD governments and organizations have hosted meetings to discuss the potential health, safety and environmental risks associated with nanotech (and regulatory issues). Developing country governments should participate in and monitor these discussions. In collaboration with civil society and in consultation with scientists, national governments should establish a *sui generis* regulatory regime, based on the precautionary principle, specifically designed to address the unique health and environmental issues associated with nano-scale materials. The health and safety risks related to nanotech are important issues for the international community. However, it is crucial that regulatory discussions are not limited to health, safety and environmental issues – they must also include discussion of broader socio-economic impacts, particularly impacts on commodity dependent developing countries, control and ownership of the technologies, and impacts on marginalized peoples. Unless governments press for that to happen, the debate will be limited and fail to consider longer-term socio-economic impacts.

Time to prepare

Given that no government in the world has developed regulations to address nanotechnologies' unique risks, governments may require additional time and capacity building to formulate adequate regulations and social policies related to nano-scale technologies. To make wider evaluations of nano-scale science and technology, including the impacts of intellectual property, South governments may wish to consider establishing a moratorium on nanotechnology until regulations are in place to protect workers, consumers and the environment – and until wider social impacts are considered.

Because of the breadth and powerful scope of nano-scale technologies across all sectors of the economy, it is important to have a long-term and fully informed view of these trends. For that reason, governments must work not only with scientific experts, industry and other governments, but also include the participation of civil society and social movements in order to gain fuller perspectives on emerging technologies.

South/South Nanotech Planning Initiative

South governments, and commodity dependent developing countries in particular, should consider sponsoring a series of meetings that would bring together trade unions and farmer/peasant/producer organizations from developing countries to learn about and discuss the possible implications of nanotechnologies on workers and economies in the South, to share information and to strategize.

Commodity dependent developing countries must have the capacity to monitor and participate in international meetings on nanotech governance, including the development of nanotech standards (see below). The proliferation of closed-door meetings and invitation-only dialogues points to the critical need for UN involvement in this arena.

Ongoing nanotech policy and governance meetings include, for example:

The International Dialogue on Responsible Research and Development of Nanotechnology

The International Dialogue on Responsible Research and Development of Nanotechnology was an early initiative that brought together representatives of 25 national nanotech programs, plus the European Union, in June 2004 near Washington, DC. (Argentina, Brazil, China, India, the Republic of Korea, Mexico, Singapore and South Africa were among the participants.) The first closed-door meeting discussed the need for standards and societal dialogue and also proposed the creation of an international "code of conduct" for nanotech development. A second meeting of the group met in Brussels on 14-15 July 2005. The 13 countries present at the second, closed-door meeting were not able to produce a consensus statement. Because of the United States Government's opposition to a formal code of conduct on nano-scale technologies, the governments pledged to work toward a "framework of shared principles." Future meetings of the group are planned for 2006.

OECD Workshop on the Safety of Manufactured Nanomaterials

On 7-9 December 2005 the OECD will hold a workshop in Washington, DC to discuss definitions, nomenclature and characterization of nano-scale materials, and regulatory frameworks for human health, safety and environmental effects of nanotech.

International Standards

Nano-policy is so young that even the definition and standards for nano-scale technologies have yet to be determined. Most players agree that uniform standards are necessary to sustain a global nanotech industry. A common description, terminology and measurement for nano-scale materials will have a major impact on trade in commodities (e.g. carbon nanotubes), international norms for nano-patent regimes, technology transfer, liability and labeling as well as international agreements and national regulations relating to control or safety-testing of nanomaterials. The establishment of international standards is complicated and could take three years or more to finalize. Individual nations are fully aware that international standards can affect their own positions and are now jockeying to establish their standards first. China, Japan, the European Union and the United States are among the most prominent players in developing international standards. Ultimately, global standards will be settled by and harmonized by bodies such as the International Organization for Standardization (ISO). The British Standards Institute is coordinating the ISO effort on nanotechnology standards.

Global Dialogue Initiative on Nanotech and the Poor

A current initiative, the "Global Dialogue on Nanotechnology and the Poor: Opportunities and Risks," is supported by the Rockefeller Foundation, the International Development Research Centre of Canada and the United Kingdom's Department for International Development.[158] In order for the dialogue to be useful, it must have input from representatives of the developing world, particularly commodity dependent developing countries, and those populations most vulnerable to the disruptive impacts of nano-scale technologies. To insure that multi-stakeholder dialogues examine the potential impacts of nanotech from a wide and diverse group of stakeholders, it is also important that developing country representatives from trade unions, social movements and civil society are invited to participate.

[158] For background information, see: http://www.nanoandthepoor.org/

APPENDIX

Table 1
Share of three leading commodities in total exports by most commodity-dependent developing countries
(in percentages)

Rank	Country	Average 1990-1999	Three leading commodities in 1997-1999
1	Solomon Islands	97.06	Wood non-coniferous, Fishery commodities, Palmoil
2	Brunei Darussalam	95.87	Fuels, Poultry Meat, Cabbages
3	Botswana	94.59	Diamonds sorted, Bovine Meat, Hides and Skins
4	Niger	94.00	Uranium, Live Animals, Tobacco
5	Iraq	93.43	Fuels, Dates, Hides and Skins
6	Kuwait	93.10	Fuels, Sulphur, Fruit Juice nes.
7	Libyan Arab Jamahiriya	92.98	Fuels, Fishery commodities, Hides and Skins
8	Greenland	92.83	Fishery commodities, Fuels, Hides and Skins
9	Gabon	91.81	Fuels, Wood non-coniferous, Manganese ore
10	Turkmenistan	91.56	Fuels, Cotton Lint, Wine
11	Congo	91.17	Fuels, Wood non-coniferous, Sugar
12	Kiribati	89.28	Fishery commodities, Copra, Crude Materials (incl. Flowers)
13	Algeria	88.99	Fuels, Nat. Ca Phosphate, Dates
14	Saudi Arabia	88.95	Fuels, Sulphur, Dairy Products + Eggs
15	Netherlands Antilles	88.91	Fuels, Rice, Sugar
16	Dem. Rep. of the Congo (ex Zaire)	88.88	Diamonds sorted, Coffee Green + Roasted, Wood Non-coniferous
17	Suriname	88.63	Alumina (AL oxide, hydroxide), Rice, Fuels
18	Nigeria	86.94	Fuels, Cocoa + products, Natural Rubber
19	Comoros	86.75	Vanilla, Essential Oils ne., Cloves, Whole + Stems
20	Burundi	86.57	Coffee Green + Roasted, Tea, Suga,
21	Equatorial Guinea	83.88	Fuels, Wood non-coniferous, Cocoa + products
22	Yemen	83.65	Fuels, Fishery commodities, Coffee Green + Roasted
23	Guinea-Bissau	81.96	Nuts, Fishery commodities, Cotton Lint
24	Iran, Islamic Republic of	81.58	Fuels, Nuts, Oil of Soya Beans
25	Oman	81.56	Fuels, Tobacco, Fishery commodities
26	Sao Tome and Principe	81.32	Cocoa + products, Fishery commodities, Coffee Green + Roasted
27	Venezuela	81.32	Fuels, Iron ore and concentrates, Tobacco
28	Ethiopia	80.28	Coffee Green + Roased, Hides and Skins, Sesame Seed
29	Angola	79.88	Fuels, diamonds sorted, Coffee Green + Roasted
30	Qatar	78.72	Fuels, Live Animals, Sulphur
31	Ecuador	77.75	Fuels, Bananas, Fishery commodities
32	Jamaica	77.61	Alumina (AL oxide ,hydroxide), Sugar, , Bauxite
33	Malawi	76.52	Tobacco, Tea, Sugar
34	Mauritania	75.60	Iron ore and concentrates, Fishery commodities, Fuels
35	Maldives	74.92	Fishery commodities, Wood non-coniferous, Copra
36	Central African Republic	70.00	Diamonds sorted, Wood non-coniferous, Cotton Lint

Rank	Country	Average 1990-1999	Three leading commodities in 1997-1999
37	Cuba	69.49	Sugar, Tobacco, Fishery commodities
38	Uganda	68.37	Coffee Green + Roasted, Fishery commodities, Crude Materials (inc. Flowers)
39	Syrian Arab Republic	68.20	Fuels, Cotton Lint, Tomatoes
40	St. Vincent and the Grenadines	67.90	Bananas, Wheat + Flour, Rice
41	Zambia	67.83	Refined Copper, Sugar, Cotton Lint
42	Bahrain	67.81	Fuels, Iron ore and concentrates, Palmoil

Source: Based on data from UNCTAD

Table 2
Top producers of Selected Commodities

Commodity/ Reporting Year	**Top Producer (% of total production)**	**Other top producers**	**Total Production**
Buaxite/2003	Australia (38%)	Guinea (11%) Jamaica (9.2%) Brazil (9.0%) China (8.6%)	146 million metric tons
Iron Ore/2003	China (22.4%)	Brazil (18.2%) Australia (16.1%)	1.164 billion metric tons
Cocoa/2004-05	Ivory Coast (40.6%)	Ghana (19%) Indonesia (13%)	2.130 million metric tons
Copper/2002	Chile (33.7%)	Indonesia (8.5%) United States (8.4%) Australia (6.5%)	13.600 million metric tons
Cotton/2003-04	China (27%)	United States (19%) India (13%) Pakistan (9%)	94.495 million bales (480 lbs. per bale)
Gold/2003	South Africa (15%)	Australia (11%) United States (11%) China (8%) Russia (7%) Canada (5%)	2.590 million kg
Nickel/2002	Russia (23%)	Australia (16%) Canada (13%) Indonesia (9%) New Caledonia (7%)	1.340 million metric tons
Platinum/2003	South Africa (74%)	Russia (18%) Canada (4%) United States (2%) [Zimbabwe]	205,000 kg
Rubber (Natural)/2001	Thailand (32.0%)	Indonesia (22.1%) India (8.9%) Malaysia (7.7%) China (6.3%) Viet Nam (4.4%)	7.130 million metric tons
Silver/2003	Peru (15%)	Mexico (14%) China (13%) Australia (10%) United States (7%)	18,700 metric tons
Tin/2003	Indonesia (34%)	China (24%) Peru (19%)	209,000 [metric tons]
Titanium (titanium ilmenite concentrates)/2003	Australia (35%)	China (14%) Norway (14%) Ukraine (11%) India (9%)	5.910 million metric tons
Titanium (rutile)/2003	Australia (36%)	South Africa (32%) Ukraine (16%)	374,000 metric tons

The CRB Commodity Yearbook 2005 (Commodity Research Bureau, NJ: John Wiley & Sons, Inc., 2005, print source)

GLOSSARY

Aerogel – a solid-state substance similar to gel where the liquid phase is replaced with gas. Aerogels can be made of many different materials.

Alloy – a combination of two or more elements, including a combination of at least two metals. An alloy has metallic properties.

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.

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.

Catalytic converter – a device used to reduce the emissions from an internal combustion engine.

Elastomer – term often used interchangeably with rubber; refers to polymers that have undergone the chemical process of vulcanization.

Electrode – a conductor used to make contact with a nonmetallic part of a circuit.

Fuel cell – device similar to a battery but different in that it is designed for continuous replenishment of the reactants consumed; i.e. it produces electricity from an external fuel supply of hydrogen and oxygen as opposed to the limited internal energy storage capacity of a battery. Additionally, the electrodes within a battery react and change as a battery is charged or discharged, whereas a fuel cell's electrodes are catalytic and relatively stable. (source: www.wikipedia.org)

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

Micron – a measurement equal to one thousand nanometres.

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 21^{st} century. Nano implies the scale of the nanometre, one billionth of a metre.

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

Nano-composite – in general, a composite 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**.

Nanometre (nm) – a measurement equal to one billionth of a metre.

Nanoparticle – a small piece of matter, composed of an individual element or a simple compound of elements, typically less than 100 nanometres in diameter. The term can refer to a wide range of materials, including the particulate matter that is expelled as car exhaust. 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 entirely 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 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 nanometres 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*, 27 March 2001).

Palladium – a chemical element with the symbol **Pd** and atomic number 46. A rare silver-white metal of the platinum group, palladium resembles platinum chemically and is extracted from some copper and nickel ores. It is primarily used as an industrial catalyst and in jewelry.

Patent Ticket – An overlapping set of patent rights requiring those seeking to use or commercialize a new technology to obtain licences from multiple patentees.

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 Mendeleyev produced the first list in 1869. Mendeleyev's list proposed about 60 elements.

Platinum – a chemical element in the periodic table that has the symbol Pt and atomic number 78. Platinum is known for its outstanding catalytic properties.

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 – 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 It is useful for biological labeling in diagnostics and drug development.

Quantum Effects – phenomena observable at the atomic level (approx. less than 100 nm); these phenomena differ from those observable on larger scales.

Scanning Probe Microscopy – 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 laboratory in Zurich, Switzerland, throughout the 1970s 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 – 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.

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