

NANOTECHNOLOGY and the POOR:  
OPPORTUNITIES and RISKS



Closing the **g a p s**  
within and between  
Sectors of Society

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Our work focuses on a wide range of issues related to environment and sustainability, science and technology, agriculture, security, and health care. We work at the local, national and international levels. Meridian Institute has offices in Dillon, Colorado and Washington, DC.

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Highly Branched Dendrimers: Center for Biological Nanotechnology, University Of Michigan (<http://nano.med.umich.edu/>).

Ecotoxicology Lab: Australian Government, Department of the Environment and Heritage (<http://www.deh.gov.au/ssd/wetlands/assessment/ecotoxicology.html>).

Water from Tap: Food and Agriculture Organization of the United Nations ([http://www.fao.org/media\\_user/\\_home.html](http://www.fao.org/media_user/_home.html)).

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Vaccination: International Federation of Red Cross and Red Crescent Societies (<http://www.ifrc.org/docs/news/03/03052702/>).

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## Executive Summary

Skyrocketing private and public investments, growing numbers of publications, and increasing public dialogue all suggest that nanotechnology has become a huge phenomenon. Yet few institutions or people are considering the potential opportunities or risks that nanotechnology presents for poor people and developing countries.

This paper is intended to raise interest and awareness about the implications of nanotechnology for poor people in developing countries. The feedback it generates will help focus and inform deliberations of a multi-stakeholder dialogue group, the Global Dialogue on Nanotechnology and the Poor: Opportunities and Risks (GDNP), which will meet for the first time in the spring of 2005. The GDNP will be convened and facilitated by Meridian Institute, an organization that specializes in helping diverse groups deal with complex and controversial issues (<http://www.merid.org>).

The goals of the GDNP are to: (1) raise awareness about the implications of nanotechnology for the poor; (2) close the gaps within and between sectors of society to develop an action plan that addresses opportunities and risks; and (3) identify ways that science and technology can play an appropriate role in the development process. More information about the GDNP is available at <http://www.nanoandthepoor.org>.

In the following pages, we provide a brief overview of nanotechnology, focusing in particular on the reasons that nanotechnology is generating so much interest from governments, academics, companies, and nongovernmental organizations (NGOs).

We then describe, as illustrative examples, possible opportunities and risks presented by nanotechnology for poor people. What opportunities might nanotechnology present in regard to safe drinking water, energy, health care, information technology and communications, and food and agriculture? What human health and environmental risks might nanotechnology products present? What are the challenges in linking nanotechnology and development?

Following sections on opportunities and risks, we devote a substantial portion of the paper to exploring the potential roles and responsibilities of stakeholders – government, academia, business, and NGOs – in linkages between nanotechnology and poor people. We describe the traditional role these sectors have played with other technologies and in development processes and suggest reasons why nanotechnology may require new approaches.

We end by asking whether stakeholders can begin now to “engage upstream” to shape the direction of nanotechnology research and development efforts in a manner that helps to meet the needs of the poor and to raise issues related to risk in a transparent fashion. We challenge each sector with specific questions about their involvement in this rapidly evolving global dialogue on nanotechnology.

We believe the pieces for the responsible use of nanotechnology for development are on the table. There is an urgent need to begin putting them together.



“...most fundamentally, the challenge here is the global governance of science and technology. There is at the moment no global focal point to commission and collect research results, promote awareness of the potential applications of nanotechnology for development,...and engage the voices of people in developing countries.”<sup>1</sup>

Peter Singer

## 1. Introduction

This paper<sup>2</sup> seeks links between the opportunities and risks associated with nanotechnology and the needs of poor people in poor nations.

Millions of people lack access to safe water, efficient sources of energy, health care, and education. The United Nations has set goals for meeting these needs. Nanotechnologies may promise effective solutions in these areas. Yet there appears to be very little effort among the various sectors of society – government, nongovernmental, business, donors, and academia – to connect the development of nanotechnology with the development of poor nations and neighborhoods.

Meridian Institute, an organization that helps diverse groups address controversial and complex issues, will convene and facilitate a dialogue of representatives from governments, companies, academic institutions, NGOs, and donor agencies to develop collaborative partnerships that lead to projects and activities that address both the benefits and risks of the technology for the poor. We hope the dialogue process, referred to as the Global Dialogue on Nanotechnology and the Poor: Opportunities and Risks (GDNP), will result in an action plan that stakeholders can pursue together or independently.<sup>3</sup>

This paper was written to raise awareness of the importance of examining both the potential benefits and risks of nanotechnology for the poor. It is also meant to focus and

inform the discussions of the GDNP. While its subject is nanotechnology, it raises issues related to the roles of science and technology in the development process. And it borrows examples from efforts to make new technologies available to poor communities.

In this paper we offer a brief overview of the basics of nanotechnology. We lay out some examples of how it could benefit poor people in poor countries and of how it could accelerate the development process and make it more sustainable. We also look at some of the potential human health and environmental risks and other challenges for linking nanotechnology and development. We look at different sectors of society, the roles they play – and do not play – in the development of nanotechnology. We conclude with some questions that must be answered by the different players if nanotechnology is going to be developed effectively and responsibly and if its benefits are going to reach the majority of the world’s population.

We have written this paper to raise awareness and stimulate discussion, not because we have a particular view about the potential opportunities and risks that nanotechnology presents for developing countries. Our role is to encourage dialogue between stakeholders in developing and industrialized countries, among stakeholders in the South, and among sectors that will lead to constructive approaches for addressing the implications of nanotechnology for the poor.

<sup>1</sup> P.A. Singer et al. 2004. *Will Prince Charles et al. Diminish the Opportunities of Developing Countries in Nanotechnology?* Available at: <http://www.nanotechweb.org/articles/society/3/1/1/1>.

<sup>2</sup> Drafted by the Meridian Institute as part of a project funded by The Rockefeller Foundation and International Development Research Centre.

<sup>3</sup> More information about the GDNP is available at: <http://www.nanoandthepoor.org>.

## 2. What Is Nanotechnology?

Nanotechnology involves the study and manipulation of matter on a very small scale: generally in the range of 1-100 nanometers (1 meter = 1 billion nanometers). By way of comparison, viruses range in size from 20 to 300 nanometers.

Nanotechnology is not one technology, but many, all writ small. The UK Royal Society and Royal Academy of Engineering entitled its 2004 report *Nanoscience and Nanotechnologies: Opportunities and Uncertainties* to emphasize the range of technologies in play. It defined nanoscience as “the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale.” It defined *nanotechnologies* as “the design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometer scale.”<sup>4</sup>

Nanoparticles exist all around us – in sea air, cigarette smoke, and diesel exhaust. We have manipulated matter through chemistry, physics, and plant and animal breeding at the nano-scale (atoms, molecules, cells) for hundreds if not thousands of years. So, what is different today? Why is the issue of nanotechnology generating so much discussion?

Many observers argue that it is because today’s knowledge and scientific tools enable scientists to begin to do what has been previously impossible: building new products and compounds atom by atom. This in time may decrease costs as the needs for many raw materials and agricultural products decrease, and it may be so precise it will virtually eliminate waste and pollution.

Many see nanotechnology as the next “transformative technology,” like the Internet or electricity. Just as electricity changed society in ways that society could not imagine in the early days of that technology, so too will nanotechnology, they argue. By combining nanotechnology with other technologies such as biotechnology and information technology at the nanoscale, the potential effects may be more significant than with any other new technology.

The transformative aspects of nanotechnology and its convergence with other technologies mean it will have impacts across multiple industrial sectors and products. One UN publication on technology and development noted that some of the advantages of nanotechnology include production using little labor, land, or maintenance, high productivity, low cost, and modest requirements for materials and energy. It added that nanotechnology products would themselves be extremely productive as energy producers, as material collectors, and as manufacturing equipment.<sup>5</sup>

Potential benefits include improved water purification systems, energy systems, health care, food production, and information and communications technologies.

Some nanotechnology products have already been developed and commercialized. Others are only now in the research phase, while others are concepts that are years or decades away from development. The table on the next page lists some of the existing and near-term applications across 12 different sectors.<sup>6</sup>

<sup>4</sup> The Royal Society and the Royal Academy of Engineering. 2004. *Nanoscience and Nanotechnologies: Opportunities and Uncertainties*. Available at: <http://www.nanotec.org.uk/finalReport.htm>.

<sup>5</sup> Task Force on Science, Technology and Innovation, UN Millennium Project. 2004. *Forging Ahead: Technological Innovation and the Millennium Development Goals*. (Draft used with permission).

<sup>6</sup> Adapted from: W. Luther (ed). 2004. *Industrial Application of Nanomaterials: Chances and Risks*. Dusseldorf, Germany, Future Technologies Division of the VDI Technologiezentrum (completed with support from the European Commission).

## Automotive Industry

Lightweight construction  
Painting  
Catalysts  
Tires (fillers)  
Sensors  
Coatings for windshields and auto bodies

## Chemical Industry

Fillers for paints  
Composite materials  
Impregnation of papers  
Adhesives  
Magnetic fluids

## Engineering

Protective coatings for tools  
and machines  
Lubricant-free bearings

## Electronics

Displays  
Data memory  
Laser diodes  
Fiber optics  
Optical switches  
Filters  
Conductive, antistatic coatings

## Construction

Materials  
Insulation  
Flame retardants  
Surface coatings for wood, floors,  
stone, tiles, roofing, etc.  
Mortar

## Medicine

Drug delivery systems  
Contrast medium  
Rapid testing systems  
Prostheses and implants  
Antimicrobial agents  
In-body diagnostic systems

## Textiles

Surface coatings  
Smart textiles

## Energy

Fuel cells  
Solar cells  
Batteries  
Capacitors

## Cosmetics

Sunscreens  
Lipsticks  
Skin creams  
Toothpaste

## Food and Drinks

Packaging  
Sensors for storage life  
Additives  
Clarifiers (for juices)

## Household

Ceramic coatings for irons  
Odor removers  
Cleaners for glass, ceramics, metals, etc.

## Sports/Outdoors

Ski wax  
Tennis rackets, golf clubs  
Tennis balls  
Antifouling coatings for boats  
Antifogging coatings for glasses/goggles

The massive investments by governments and companies, the acceleration of patenting, and the growing numbers of scientific literature citations all suggest that nanotechnology is a huge phenomenon.

After seven years, the total US federal government investment in nanotechnology is approaching the total federal investment in the Human Genome Project, and the annual investment is now twice that of the Human Genome Project in its peak year.<sup>7</sup> This trend is expected to continue. The 21st Century Nanotechnology Research and Development Act, passed by the US Congress in 2003, commits the federal government to invest another \$3.7 billion<sup>8</sup> over the next four years.<sup>9</sup>

In Europe, overall levels of public expenditure in nanotechnology amounted to a total of €860 million (\$1.15 billion) in 2003, with the European Commission providing €260 million (\$350 million) and member and associated states investing €600 million (\$800 million) in funding.<sup>10</sup>

The European Union has set aside considerable funding for nanotechnology in its Sixth Framework Programme (FP6) for research, which runs from 2002 to 2006. Some €1.3 billion (\$1.74 billion) has been earmarked for FP6's third thematic priority area: "nanotechnology and nanosciences, knowledge-based multifunctional materials and new production processes and devices."<sup>11</sup> The total budget for FP6 is €17.5 billion (\$23.5 billion).<sup>12</sup>

<sup>7</sup> M.C. Roco. 2004. *Nanoscale Science and Engineering: Unifying and Transforming Tools*. AIChE Journal, Vol. 50, Issue 5, pp. 890-897.

<sup>8</sup> All dollars (\$) in this paper are US\$.

<sup>9</sup> 21st Century Nanotechnology Research and Development Act. 15 USC 7501.

<sup>10</sup> Commission of the European Communities. 12 May 2004. *Communication from the Commission: Towards a European Strategy for Nanotechnology*. Available at: [ftp://ftp.cordis.lu/pub/nanotechnology/docs/nano\\_com\\_en.pdf](ftp://ftp.cordis.lu/pub/nanotechnology/docs/nano_com_en.pdf).

<sup>11</sup> Commission of the European Communities. 10 March 2003. Available at: [http://europa.eu.int/comm/research/infocentre/export/03-2003\\_454.html](http://europa.eu.int/comm/research/infocentre/export/03-2003_454.html).

<sup>12</sup> Commission of the European Communities. *Sixth Framework Programme Frequently Asked Questions*. Accessed on 20 December 2004. Available at: [http://europa.eu.int/comm/research/fp6/pdf/faq\\_en.pdf](http://europa.eu.int/comm/research/fp6/pdf/faq_en.pdf).

Japan identified nanotechnology as one of its main research priorities in 2001. The funding levels increased sharply from 41.7 billion Japanese Yen (\$400 million) in 2001 to around 88.3 billion Yen (\$800 million) in 2003.<sup>13</sup>

China is devoting increasing resources to nanotechnology. Its share of worldwide publications is increasing rapidly with a growth rate of 200% in the late 1990s.<sup>14</sup>

The US, Europe, Japan, and China are not alone in their enthusiasm for nanotechnology. Over 20 countries now have national nanotechnology programs resulting in an annual collective investment approaching \$4 billion globally.<sup>16</sup>

Brazil has three “millennium institutes” and four cooperative networks in nanotechnology. There are about 300 PhD-level scientists working in nanotechnology in Brazil. The total government budget for nanotechnology in 2004 is about 18.7 million Brazil Reais (\$7 million). The budget for the period 2004 - 2007 is predicted to grow to about 66.9 million Reais (\$25 million).<sup>17</sup>

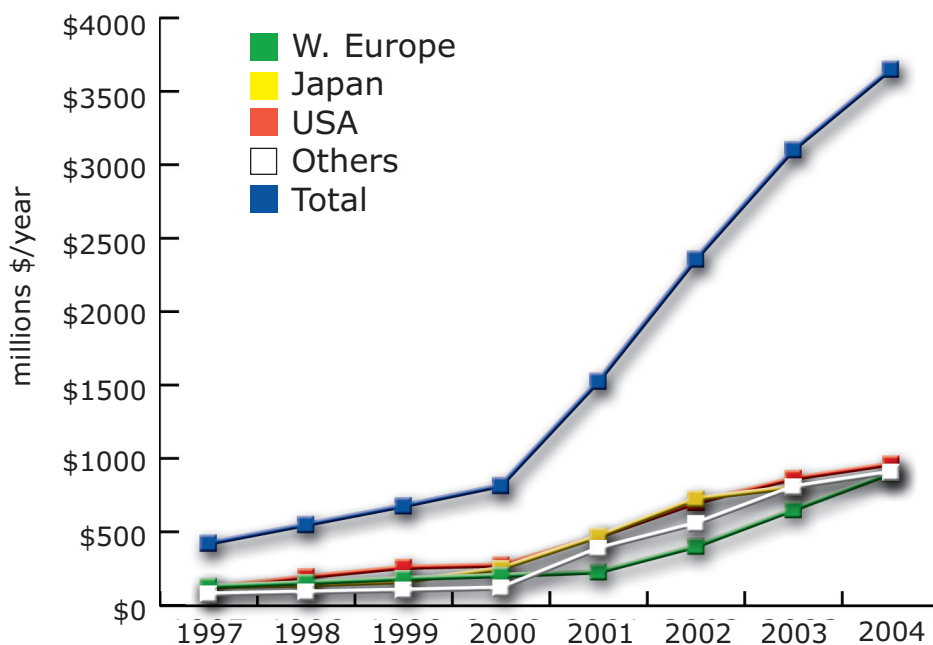
Taiwan plans to spend 21.4 billion Taiwan New Dollars (\$663 million) over six years to advance nanotechnology and nanotechnology-related industries.<sup>18</sup>

In India, more than 30 institutions are involved in research and teaching/training programs in nanotechnology. The government of India has allocated 1 billion India Rupees (\$22.8 million) under its 10th five year plan (2002-2007).<sup>19</sup>

In South Africa, about a dozen universities, four science councils, and several companies are active in nanotechnology R&D. As of July 2003, nanotechnology spending was estimated at 14.2 million South Africa Rand (\$2.25 million), with government R&D grants and student support at 2.8 million Rand (\$500,000), science council grants at 5.7 million Rand (\$1 million), and private sector funding estimated at 6.8 million Rand (\$1.2 million).<sup>20</sup>

Despite these levels of expenditure and the increased interest in nanotechnology shown by regulatory agencies, industries, NGOs, and other stakeholders, we are still in the very early days of this phenomenon. There is still time and space for stakeholders to examine the issues and chart a collective path forward to ensure human development needs are considered as the technology evolves.

### Investments in Nanotechnology by Governments (1997 – 2004)<sup>15</sup>



<sup>13</sup>K. Shimizu. 4 April 2004. *Opening Statement at the International Dialogue on Responsible Research and Development of Nanotechnology*.

<sup>14</sup>Commission of the European Communities. 12 May 2004. *Communication from the Commission: Towards a European strategy for nanotechnology*. Available at: [ftp://ftp.cordis.lu/pub/nanotechnology/docs/nano\\_com\\_en.pdf](ftp://ftp.cordis.lu/pub/nanotechnology/docs/nano_com_en.pdf).

<sup>15</sup>M.C. Roco. 2004. *Nanoscale Science and Engineering: Unifying and Transforming Tools*. AIChE Journal, Vol. 50, Issue 5, pp. 890-897. Note: U.S. fiscal year begins in October, six months in advance of EU and Japan (in March/April).

<sup>16</sup>M.C. Roco. 2004. *Questionnaire Response for the International Dialogue on Responsible Research and Development of Nanotechnology*. Available at: <http://www.nanodialogues.org/international.php>.

<sup>17</sup>J.R. Leite. 5 April 2004. *Questionnaire Response for the International Dialogue on Responsible Research and Development of Nanotechnology*. Available at: <http://www.nanodialogues.org/international.php>.

<sup>18</sup><http://english.www.gov.tw/index.jsp?action=cna&cnaid=5346>.

<sup>19</sup>K.K. Dwivedi. 7 June 2004. *Questionnaire Response for the International Dialogue on Responsible Research and Development of Nanotechnology*. Available at: <http://www.nanodialogues.org/international.php>.

<sup>20</sup>P. Maruping. 10 May 2004. *Questionnaire Response for the International Dialogue on Responsible Research and Development of Nanotechnology*. Available at: <http://www.nanodialogues.org/international.php>.

## 3. Opportunities – Nanotechnology and Development

Calls for economic development have been superseded by calls for *sustainable development* – best defined as forms of development that meet the needs of the present without compromising the ability of future generations to meet their needs.<sup>21</sup> Given nanotechnology’s potential to be much more sparing of resources, to produce cheap solar electricity, to “build anything out of anything,” the technology could make possible the efficient use of resources necessary for this and future generations.

The very scale of the “needs of the present” makes sustainable development a fairly radical goal. The World Bank estimates that some 1.1 billion people are trying to survive on the equivalent of \$1 per day. The Bank has also estimated that about 11% of the global population is well off, 11% is middle income, and 78% is poor – about 4.8 billion people.<sup>22</sup>

For the first time in human history, society has outlined a series of quantitative goals for improving the lives of poor people in developing countries (see Appendix). These UN Millennium Development Goals (MDGs) were agreed to in 2000 and refined at the 2002 World Summit on Sustainable Development.<sup>23</sup> Some are centered on poverty generally, such as reducing by half the proportion of people living on less than a dollar a day. Others deal with more specific challenges, such as reducing by half the proportion of people who suffer from hunger, achieving universal primary education, reducing by two-thirds the mortality rate among children under five, reducing the prevalence of certain diseases, and reducing by half the proportion of people without access to safe drinking water and basic sanitation. Most goals have a deadline of 2015.

These are ambitious goals, and society is already behind schedule in meeting many of them. While achieving these goals depends on numerous factors, any helpful technologies should be brought into service if the goals are to be realized. We describe below some roles that nanotechnology might play. A report from the Task Force on Science, Technology and Innovation, part of the UN Millennium Project, noted: “It is now understood that meeting the MDGs will require a substantial

reorientation of development policies to focus on key sources of economic growth, including those associated with the use of new and established scientific and technological knowledge, and related institutional adjustments.”<sup>24</sup>

### Water

One of nanotechnology’s most immediate and compelling promises may be in the area of access to safe drinking water. None of the MDGs will be met unless this goal is met. It not only affects all the poverty and health goals, but children hauling water for their families all day are not going to school.

Waterborne diseases and water-related illnesses kill more than five million people a year worldwide, 85% of these being children, according to the World Health Organization.<sup>25</sup> Most of the deaths are caused by diarrhea due to fecal contamination of drinking water. Some 1.1 billion people were still using water from “unimproved” sources in 2002, and 42% of the population of sub-Saharan Africa remained without safe drinking water.

There are a number of filter systems based on nanotechnology that could save lives in the developing world. A product called NanoCeram, developed by the Argonide Company with backing from the US National Aeronautics and Space Administration (NASA), is said to filter bacteria and even viruses out of water, not by forcing it through tiny holes but by using a positive charge to attract these negatively charged viruses and bacteria, which measure in the range of 20 to 100 nm.<sup>26</sup>

Seldon Laboratories of Vermont has developed a “nanomesh” fabric made of fused carbon nanotubes that it says can filter out all bacteria, viruses, and other waterborne pathogens to US Environmental Protection Agency (EPA) potable water standards.<sup>27</sup> The company claims that the mesh also removes lead, arsenic, and uranium.

Researchers at Rensselaer Polytechnic Institute (US) and Banaras Hindu University (India), working in collaboration, claim to have devised a simple method of producing carbon

<sup>21</sup>World Commission on Environment and Development. 1987. *Our Common Future*. Oxford, UK.

<sup>22</sup>World Bank. 2004. *World Development Indicators*. Washington, DC. Available at: <http://www.worldbank.org/data/wdi2004/>.

<sup>23</sup>United Nations. *Millennium Development Goals*. Available at: <http://www.un.org/millenniumgoals/>.

<sup>24</sup>Task Force on Science, Technology and Innovation, UN Millennium Project. 2004. op. cit.

<sup>25</sup>Task Force 7 on Water and Sanitation, UN Millennium Project. 2004. *Interim Full Report*. Available at: <http://www.unmillenniumproject.org/documents/TF7interim.pdf>.

<sup>26</sup>More information is available at: <http://www.argonide.com>. Accessed 28 November 2004

<sup>27</sup>More information is available at: <http://www.seldontechnologies.com/products/>. Accessed 28 November 2004.

<sup>28</sup>PhysOrg.com. 12 August 2004. Available at: <http://www.physorg.com/preview803.html>.

nanotube filters that remove microscale to nanoscale contaminants from water. They say that the filters are easily manufactured using a novel method for controlling the cylindrical geometry of the structure and can remove 25-nanometer-sized polio viruses from water, as well as larger pathogens such as *E. coli* and *Staphylococcus aureus* bacteria.<sup>28</sup>

Natural arsenic in wells is a big problem in Bangladesh and some other nations. Researchers at Oklahoma State University in the US say they have used nanoparticles of zinc oxide to remove arsenic from water, even though bulk-scale zinc oxide particles cannot absorb arsenic.<sup>29</sup> They produced the zinc oxide in a porous aggregate form that is suitable for water treatment. They say that the zinc oxide product could be used in “at-the-tap water purification devices, and the process could also be used to create a range of metal, metal oxide, and metal sulfide nanoparticle aggregates that could be used in a number of pollution-prevention, water-treatment and catalytic applications.”<sup>30</sup>

European companies such as FluXXion in the Netherlands<sup>31</sup> and Berghof<sup>32</sup> in Germany, as well as companies in Asia (e.g., Saehan in Korea<sup>33</sup>), are developing nanofiltration membrane products, primarily for liquid filtration in industrial processes. On the detection front, NanoSight in the UK has a system that it says can detect waterborne nanoparticles and viruses in real time.<sup>34</sup>

## Energy

Access to electricity is not specifically among the MDGs, but it could help with most of them: pumping water for human use and for agriculture, powering rural clinics and refrigerating medicines, lighting schools, and helping people earn sustainable livings in their own businesses.

“Access to basic, clean energy services is essential for sustainable development and poverty eradication, and provides major benefits in the areas of health, literacy, and equity. However, over two billion people today have no access to modern energy services,” according to the Intermediate Technology Development Group (ITDG).<sup>35</sup>

Cheap solar-powered electricity has long been an aspiration for tropical countries, but glass photovoltaic panels remain too expensive and delicate. Nanotechnology may allow for the production of cheap photovoltaic films that can be unrolled across the roofs of buildings. It may even be possible to paint solar power films onto surfaces.

Some 2.4 billion people use traditional biomass energy – wood, crop residues, and dung – for cooking and heating, a number that is increasing rather than decreasing. This is inefficient for most purposes; it can cause burns and respiratory problems due to indoor pollution and, depending on the source of the biomass, can degrade environmental systems and resource bases.

Nanosys Inc. and its collaborators received funding from the US Defense Advanced Research Projects Agency (DARPA) to develop nanotechnology-based, high-efficiency, flexible, light-weight, low-cost solar cells to provide power generation solutions for military applications.<sup>36</sup> The ultimate goal, which could have civilian applications, is to use nanotechnology to produce a photovoltaic material that can be spread like plastic wrap or be painted onto surfaces.

The British company Hydrogen Solar claims to have doubled the performance of its technology, which converts light and water directly into hydrogen fuel, a breakthrough based on a nanocrystalline material the company developed that it says will dramatically improve the production of hydrogen by using solar energy to split water more efficiently into its elemental parts.<sup>37</sup> The company expects its technology to be used as a clean, CO<sub>2</sub>-free fuel for transport and home energy installations.

Energy storage systems can store energy produced at off-peak times to be used at peak times; they can help provide photovoltaic energy throughout the day and night. Nanotechnology approaches include using nanoparticles and nanotubes for batteries and fuel cells. Nanotechnology can improve the performance of rechargeable batteries; new lithium ion batteries that use nano-sized lithium titanate can provide 10-100 times faster charging/discharging rates than conventional batteries.<sup>38</sup>

<sup>29</sup>NanotechWeb. 25 May 2004. *Nanoparticles Clean Up Arsenic*. Available at: <http://www.nanotechweb.org/articles/news/3/5/15/1>.

<sup>30</sup>S. Kuriyavar. 2004. As quoted on NanotechWeb in *Nanoparticles Clean Up Arsenic*. Published 25 May 2004 at: <http://www.nanotechweb.org/articles/news/3/5/15/1>.

<sup>31</sup>More information about FluXXion is available at: <http://www.fluxion.com/index2.htm>.

<sup>32</sup>More information about Berghof is available at: <http://www.berghof.com>.

<sup>33</sup>More information about Saehan is available at: <http://www.saehansm.com>.

<sup>34</sup>More information about NanoSight is available at: <http://www.nano-sight.com>.

<sup>35</sup>Intermediate Technology Development Group. *Power to the People*. [http://www.itdg.org/html/advocacy/power\\_to\\_the\\_people\\_paper.htm](http://www.itdg.org/html/advocacy/power_to_the_people_paper.htm). Accessed 28 November 2004.

<sup>36</sup>Nanosys Inc. 18 August 2004. Available at: [http://www.nanosysinc.com/news/Press%20Release%20html/2004/081804\\_darpaGrant.html](http://www.nanosysinc.com/news/Press%20Release%20html/2004/081804_darpaGrant.html).

<sup>37</sup>PhysOrg.com. 24 September 2004. *Nanotechnology to Create Green Hydrogen*. Available at: <http://www.physorg.com/news1309.html>.

<sup>38</sup>Institute of Nanotechnology. *Introduction to Nanotechnology CD ROM*. As cited in *Energy Nanocubes and Nanotechnology Enabled Energy Storage* by Azonano.com. <http://www.azonano.com/details.asp?ArticleID=895>. Accessed 28 November 2004.

<sup>39</sup>L. Moldofsky. 28 October 2004. *Biotechnology: Smarter Products with Nanotechnology*. Financial Times Australia.

## Health

Nanotechnology offers possibilities for health breakthroughs, yet many of these developments seem so high-tech that it is hard to imagine their being used as health interventions among the poor.

An exception could be a product such as VivaGel microbicide, under development by Starpharma, a Melbourne-based biotechnology company that claims its topic gel could reduce the risk of HIV infection in women.<sup>39</sup> It is said to be the world's first drug based on nanoscale polymers known as dendrimers, which according to a company spokesman “stick to the AIDS virus surface like molecular Velcro and prevent it from attaching to the cells it is trying to infect.”

Other exceptions could be simple, accurate, small, and stable diagnostic test units based on nanotechnology. The Central Scientific Instruments Organization of India has announced plans to develop a nanotechnology-based TB diagnostic kit that would work more quickly, use less blood, and cost less per test.<sup>40</sup>

Nanoporous membranes may help with disease treatment in the developing world. They are a new way of slowly releasing a drug, important for people far from hospitals. Making the nanopores only slightly larger than the molecules of drugs can control the rate of diffusion of the molecules, keeping it constant regardless of the amount of drug remaining inside a capsule.

## Information and Communications Technology

Cheaper information and communications technology (ICT) can help society reach the MDGs in the areas of education and of general poverty alleviation, in that it can make farmers, fishermen, and small businesspeople more competitive. ICT can also help to create trained, educated, and healthy workforces that can build vibrant and successful economies.<sup>41</sup>

Nanotechnology may increase the speed and quality of connections and make computers, display devices, wires, and

connection devices much cheaper. Thus nanotechnology may help make computers, cell phones, and related tools affordable by the poor.<sup>42</sup> Such tools could even contain more than enough processing capability for an interface that can be used by illiterate people.

## Food and Agriculture

Several studies suggest that nanotechnology will have major, long-term effects on agriculture and the production of food, but it remains unclear whether effects on developing country agriculture and nutrition will be positive or negative.

Many of the promised advances for agriculture are similar to some promised advances in drug delivery in human medicine: time-controlled release; remotely regulated, pre-programmed, or self-regulated delivery of nutrients or disease treatments; transplanted cells protected by membranes; bio-separation; and rapid sampling and diagnosis of plant or animal health.<sup>43</sup>

Nanotechnology may help make food products cheaper and production more efficient and more sustainable through using less water and chemicals, which would be a great help to developing world agriculture.

The ability to manipulate the molecules and the atoms of food could allow the food industry to design food with more precision and help lower costs, claims a study by the Helmut Kaiser Consultancy.<sup>44</sup> The study argues that foods in the future will be designed by shaping molecules and atoms and predicts that nanoscale biotech and nano-bio-info will have a major impact on the food and food-processing industries.<sup>45</sup> However, this could enable developed countries to produce more food, more economically, making them less dependent on cheap agricultural products from developing countries.<sup>46</sup> As noted in the sections below, the corresponding socioeconomic effects on the economies of developing countries could prove devastating.

Identifying opportunities, anticipating potential effects, and then choosing an appropriate development-sensitive path forward are major objectives of the Global Dialogue on Nanotechnology and the Poor: Opportunities and Risks.

<sup>40</sup>The Times of India. 3 January 2004. *CSIO Develops Nanotechnology for TB Diagnosis Kit*. Available at: <http://timesofindia.indiatimes.com/articleshow/401636.cms>.

<sup>41</sup>Center for International Development. 2004. *Readiness for the Networked World: A Guide for Developing Countries*. Available at: <http://cyber.law.harvard.edu/readinessguide/guide.pdf>.

<sup>42</sup>Center for Responsible Nanotechnology. *Benefits of Molecular Manufacturing*. <http://www.crnano.org/benefits.htm>. Accessed 28 November 2004.

<sup>43</sup>M.C. Roco. 2003. *Nanotechnology: Convergence with Modern Biology and Medicine*. *Current Opinion in Biotechnology*, Volume 14, pp. 337–346. See also, N. Scott and H. Chen. 2003. *Nanoscale Science and Engineering for Agriculture and Food Systems*. Cooperative State Research, Education and Extension Service, US Department of Agriculture.

<sup>44</sup>Helmut Kaiser Consultancy. 2004. *Study: Nanotechnology in Food and Food Processing Industry Worldwide*. 2003-2006-2010-2015.

<sup>45</sup>FoodProductionDaily.com. 16 September 2004. Available at: <http://www.foodproductiondaily.com/news/news-NG.asp?n=54760-nanotechnology-a-food>.

<sup>46</sup>ETC Group. 2004. *Down on the Farm: The Impact of Nano-Scale Technologies on Food and Agriculture*. Ottawa, Canada.

## 4. Risks – Human Health and Environment

Some observers argue that the sheer momentum of efforts to develop nanotechnology could be overwhelming the need to examine and manage associated risks.

The British government Health and Safety Executive issued a report in late 2004 concluding that “there is little evidence to suggest that the exposure of workers arising from the production of nanoparticles has been adequately assessed.”<sup>47</sup>

A report from Swiss Reinsurance Company (Swiss Re) states: “Although little definitive knowledge is available on how nanotechnologically manufactured products behave in the environment, such products are already in use today and more will be launched on the market in the near future. So, the approach to the opportunities and risks involved must be worked out now, the sooner and more comprehensive, the better.”<sup>48</sup>

The *Nanoscience and Nanotechnologies* report of the Royal Society and the Royal Academy of Engineering recommended that a multi-stakeholder group examine the technology, finding where health, safety, environmental, social, ethical, and regulatory issues might lie and recommending ways of handling them. It added that this work must be made public, and public discussion of findings must be properly funded.<sup>49</sup>

Opinion as to risks is divided among those involved in nanotechnology. One end of the opinion spectrum maintains that we have manipulated matter at the nanoscale (atoms, molecules, cells) for many years, and the risks of nanotechnology are simply more of the same, not different. Since we know how to regulate and keep safe the practices of the various sciences, we also know how to regulate nanotechnology and keep it safe.

The US Food and Drug Administration (FDA) position paper on nanotechnology said: “...we must acknowledge that the cells and molecules with which FDA staff work with every day are ‘nano’ in size. In particular, every degradable medical device or injectable pharmaceutical generates particulates that pass through this size range during the processes of their absorption by the body. FDA has not experienced an adverse reaction related to the ‘nano’ size of resorbable drug or medical device products.”<sup>50</sup>

At the other end of the opinion spectrum are those who argue that manipulating matter at a scale where quantum mechanics begins to operate is completely new to human experience. We know little or nothing about how these tiny new constructs are going to interact with living cells. Our existing

regulations, guidelines, norms, and ways of thinking may be mostly irrelevant to nanotechnology.

The US National Nanotechnology Initiative (NNI) has explained that its specific goal is to create novelty: “to create and use materials, devices and systems with fundamentally new properties and functions because of their small structure.” The NNI encourages research that results in “novel phenomena, properties, and functions which do not transfer outside of the nanometer realm.”<sup>51</sup> This would suggest that the official US government view is that nanotechnology is fundamentally different – in “phenomena, properties, and functions” – from what has gone before.

The definition of nanoscience quoted earlier from the *Nanoscience and Nanotechnologies* report referred to the “atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale.” Thus there is a serious school of thought that holds that nanotechnology is by definition full of uncertainty and the unknown, both of which are difficult to regulate.

At a size smaller than about 50nm, particles begin to follow the laws of quantum physics rather than classical physics, and properties such as magnetism and electric charge change radically. Also, the smaller a particle, the larger the surface area compared to the mass, and thus the more reactive the particle. Smaller particles may be more toxic because of their smaller size or may do harm just because of their size.

As noted earlier, nanoparticles exist in nature. However, in nature they tend to clump together quickly into microscale particles. Many nanoparticles produced commercially for various purposes are treated so that they will not clump together and thus lose whatever effectiveness their smaller size gives them.<sup>52</sup>

Numerous papers urge their readers to balance possible risks against possible benefits when assessing nanotechnology. However, it is difficult if not impossible to balance largely unknown risks against largely unknown benefits. It is not the role of this paper to attempt such a balancing act, but we provide a brief summary of human health and environmental risks that will have to be addressed, particularly in efforts to bring nanotechnology benefits to the poorest.<sup>53</sup> We note that, while many of the examples below are focused on nanoparticles, questions about risks should be considered for near-term and long-term nanoproducts, including those resulting from the convergence of technologies at the nanoscale.

<sup>47</sup>Institute of Occupational Medicine. 2004. *Nanoparticles: An Occupational Hygiene Review*. Health and Safety Executive Research Report 274.

<sup>48</sup>Swiss Re. 2004. *Nanotechnology: Small Matter, Many Unknowns*. Zurich, Switzerland.

<sup>49</sup>The Royal Society and the Royal Academy of Engineering. 2004. op. cit.

<sup>50</sup>US Food and Drug Administration. 2004. *FDA Regulation of Nanotechnology Products*. Washington, DC.

<sup>51</sup>D. Rejeski, Director, Foresight and Governance Project, Woodrow Wilson International Center for Scholars. Pers. Comm., 1 November 2004.

<sup>52</sup>Swiss Re. 2004. *Nanotechnology: Small Matter, Many Unknowns*. Zurich, Switzerland.

<sup>53</sup>For an example of a detailed survey of worldwide studies dealing with safety and risk assessment issues, please visit the website of TEMAS AG, Switzerland at: <http://www.ethrat.ch/topnano21>.

## Human Health

Several groups have raised concerns about the potential health risks of manufactured nanomaterials.

A report from Swiss Re about nanotechnology states: “Human contact with nanoparticles takes various forms: they are inhaled with air, swallowed, and may possibly enter the body via the skin. How do these particles behave on or in the organism?”<sup>54</sup>

A 2004 report by the ETC Group, an international NGO, warned that “a handful of food and nutrition products containing invisible nano-scale additives are already commercially available. Hundreds of companies are conducting research and development on the use of nanotechnology to engineer, process, package, and deliver food and nutrients to our shopping baskets and our plates.”<sup>55</sup> This is happening, ETC argues, when “no government has developed a regulatory regime that addresses the nano-scale or the societal impacts of the very small.”

If inhaled, nanomaterials may end up in the deep lungs, and the extremely small size of nanoparticles may allow them to enter into cells. Potential for exposure exists in research laboratories, in the workplace, and through environmental exposure. The nanotechnology report from Swiss Re states: “In general, if equal quantities of nanoparticles – or larger particles of the same substance – are inhaled, the smaller particles cause a reaction in the lung tissue that is many times stronger. The surface reactivity of the nanoparticles can, depending on the type of coating, cause chemical damage to the surrounding tissue.”<sup>56</sup>

Unprocessed nanotubes are very light and could become airborne and thus reach people’s lungs. Only a few studies have been published regarding the toxicity of nanotubes, and these initial studies are limited in scope and show mixed results.

A study conducted in mice at NASA Johnson Space Center concluded that carbon nanotubes in the lungs are more toxic than carbon black (soot) and can be more toxic than quartz, which is considered a serious occupational health hazard in chronic inhalation exposures.<sup>57</sup> A study in rats by DuPont Haskell Laboratory for Health and Environmental Sciences, however, concluded that nanotubes are less toxic than quartz dust.<sup>58</sup>

Some observers have pointed out that these studies, in which nanotubes were injected, should be followed by

inhalation studies, which may yield more reliable results. They also point out that other types of manufactured carbon nanoparticles exist that have not been included in these studies.

Nanoparticles of titanium dioxide and zinc oxide are being used in sunscreens and cosmetic products, respectively. The Scientific Committee on Cosmetic and Non-food Products (SCCNFP), which advises the European Commission, considered the safety of nanoparticles of titanium dioxide when used as a UV filter and declared them safe for use at any size.<sup>59</sup> Much of the data underlying this study, however, are not publicly available.

Other human health concerns include the largely unknown effects of using nanomaterials in pharmaceutical applications, such as to deliver drugs to specific parts of the body.

In addition to concerns over the possible negative health impacts of manufactured nanomaterials, scientists, regulators, and others have expressed concerns over the lack of standard risk assessment procedures and have pointed at the difficulty of detecting manufactured nanoparticles once they are released.

## Environment

What happens to nanoparticles once they are no longer embedded in today’s self-cleaning windows or flat-screen computer displays? Are nanoparticles persistent (do they take a long time to decay)? Do they accumulate in animals’ fatty tissue? Are they toxic? And are they toxic because they are small?

There is a scarcity of information on the effects, if any, of nanoparticles on ecosystems, animals, plants, and microorganisms. One widely publicized pilot study looked at the potential impact of nanoparticles on marine life. The study involved exposing largemouth bass to a certain type of fullerene (a manufactured carbon molecule). The study showed an immune response to the invading nanomaterials, and there was some evidence that the materials may have breached the barrier protecting the animal’s brain and central nervous system.<sup>60</sup>

Several institutions worldwide are beginning to look into the human health and environmental effects of manufactured nanomaterials by conducting comparative risk assessments. Public funding devoted to the study of health and environmental impacts is increasing worldwide, although some NGOs see it as still being insufficient.

<sup>54</sup>Swiss Re. 2004. *Nanotechnology: Small Matter, Many Unknowns*. Zurich, Switzerland.

<sup>55</sup>ETC Group. 2004. *Down on the Farm: The Impact of Nano-scale Technologies on Food and Agriculture*. Ottawa, Canada.

<sup>56</sup>Swiss Re. 2004. *Nanotechnology: Small Matter, Many Unknowns*. Zurich, Switzerland.

<sup>57</sup>C.W. Lam et al. 2004. *Pulmonary Toxicity of Single-Wall Carbon Nanotubes in Mice 7 and 90 Days after Intratracheal Instillation*. *Toxicological Sciences*, Volume 77, Number 1, pp. 126-134. Available at: <http://toxsci.oupjournals.org/cgi/content/short/kfg243v1>.

<sup>58</sup>D.B. Warheit et al. 2004. *Comparative Pulmonary Toxicity Assessment of Single-Wall Carbon Nanotubes in Rats*. *Toxicological Sciences*, Volume 77, Number 1, pp. 117-125. Available at: <http://www.toxsci.oupjournals.org/cgi/content/full/77/1/117?ck=nck>.

<sup>59</sup>SCCNFP. 2000. *Opinion Concerning Titanium Dioxide* (Colipa n°S75), Brussels, Belgium. Available at: [www.europa.eu.int/comm/health/ph\\_risk/committees/sccp/docs/html/sccp\\_out135\\_en.htm](http://www.europa.eu.int/comm/health/ph_risk/committees/sccp/docs/html/sccp_out135_en.htm).

<sup>60</sup>Eva Oberdörster. 2004. *Manufactured Nanomaterials (Fullerenes, C60) Induce Oxidative Stress in the Brain of Juvenile Largemouth Bass*. *Environmental Health Perspectives*, Volume 112, Number 10.

## 5. Challenges in Linking Nanotechnology and Development

Even if opportunities related to nanotechnology are identified and environmental and human health risks are appropriately evaluated and managed, there is still a risk that small minorities of people will benefit from its opportunities, while large majorities, mainly in the developing world, will not. Some academics have argued that many previous technology introductions and revolutions, including the industrial revolution, have benefited the rich while further marginalizing the poor.<sup>61</sup>

In fact, nanotechnology could be a major problem for poorer countries if it makes their labor, commodities, and other exports less necessary in the global market. Several groups are calling for measures to ensure that the poor and disenfranchised are not adversely affected.<sup>62</sup>

Many of the issues identified below are familiar challenges to anyone working on economic development issues, especially in developing countries. These issues and conditions must be considered and created if development efforts, including those that include a nanotechnology component, are to succeed. We raise these issues to begin a dialogue about whether nanotechnology presents new issues that have not been seen with the introduction of other technologies in developing countries.

### Socioeconomic Issues

Some predict that molecular manufacturing will allow for the production of goods using local resources, with dramatic reductions in raw material inputs. However, others point out that this could cause severe economic disruption as a result of jobs and economic activity being lost. Developing countries might suffer from economic displacement due to the loss of markets for raw materials.<sup>63</sup>

“...tropical agricultural commodities such as rubber, cocoa, coffee and cotton – and the small-scale farmers who grow them – will find themselves quaint and irrelevant in a new nano-economy of ‘flexible matter’ in which the

properties of industrial nanoparticles can be adjusted to create cheaper, ‘smarter’ replacements,” according to the ETC Group.<sup>64</sup>

### Public Awareness and Dialogue

The risks of nanotechnology are poorly understood among developed world publics and are less well understood among developing world publics. It will be very difficult to get information to developed world publics about risks and benefits so that they can make informed decisions. It will be even more challenging to get this same information to the public in the developing world. Developing countries, like developed countries, have a hard time communicating technology risks in a way that facilitates public dialogue and decision making.

### Regulatory Capacity and Systems

Regulatory systems in many developing countries have shown themselves inadequate in dealing with much simpler technologies, such as motorized vehicles and pesticides.

Many developing countries tend to lack appropriate environmental, human health, and worker safety regulations; regulations on the books are not well enforced; and there are not enough trained regulators. Very often, these nations require assistance, particularly financial assistance, to develop the scientific and institutional capacity to adequately assess and manage risks, including the necessary infrastructure such as laboratories and technology for detection.

Many commentators feel that North-South communications about nanotechnology risks are weak among scientists and policy makers, as well as among national-level ministries and international institutions.

Difference in risks may be affected by differences in environments (natural and social) in developed and developing countries. Thus different emphases might be required.

<sup>61</sup>For example, see the following studies on the societal impacts of technology introductions: R.W. Fogel. 2004. *The Escape from Hunger and Premature Death, 1700–2100: Europe, America, and the Third World*. Cambridge University Press, Cambridge, UK.

Spar, D. L. 2001. *Ruling the Waves: Cycles of Discovery, Chaos and Wealth from the Compass to the Internet*. Harcourt. New York, New York.

<sup>62</sup>For instance, P.A. Singer et al. 2004. op. cit.

<sup>63</sup>ETC Group. 2003. *The Big Down: From Genomes to Atoms*. Atomtech – Technologies Converging at the Nano-Scale. Winnipeg, Canada.

<sup>64</sup>ETC Group. 2004. *Down on the Farm: The Impact of Nano-Scale Technologies on Food and Agriculture*. Ottawa, Canada.

## Ethical Issues

The US and European governments have, to different extents, focused on the role of nanotechnologies in enhancing human performance. Researchers in other developed and developing countries are also working on research related to human enhancement and performance using nanotechnology. Some people and organizations are now raising questions about this research, asking specifically about its ethical implications. Some groups, for example, have asked about the ethical implications of expensive nanotechnologies that would benefit disabled people in developed, but not developing countries.

Other questions are being raised about nanotechnology monitoring devices that, because of their small size, could be both ubiquitous and invisible. These devices, argue some, raise issues about surveillance and the right to privacy.

## Ownership and Access

Some groups are urging that the effects of patents, conditions in technology licenses, and impacts of government and corporate policies on people's ability to use nanotechnology for meeting human development be considered now, even though some of the potential benefits of nanotechnology may be years away. Without this discussion, they argue, the technology will be controlled by developed countries and multinational corporations, primarily benefit consumers in the North, and lead to a deepened divide between developed and developing countries.

## 6. Roles and Responsibilities of Sectors

The issues in the section above explain, in part, why the goal of “technology transfer” from wealthier to poorer countries has always been elusive and now tends to be left mainly to market forces. “Technology fixes” offered by outsiders have not proved efficient at fixing problems. Technology, to work, must be part of a demand-driven solution, not “the solution.” To work well, solutions must fit into the habits, norms, aspirations, laws, knowledge base, resource base, and regulatory systems of the societies into which they are inserted.

Perhaps, also, the notion of technology transfer is becoming less meaningful as more developing countries develop their own science and technology capacity, and, as described below, businesses develop ventures that are designed to benefit both companies and the poor.

### Government

Most industrial country governments and a few governments in the developing world are investing heavily in nanotechnology, but even in the countries where a large proportion of citizens are poor, little of this investment is going to benefits for the poor. Northern aid agencies tend not to be involved in the funding or guidance of nanotechnology.

A survey by Peter Singer and his group of nanotechnology work in developing countries found a surprising amount of research in some countries with large percentages of poor people.<sup>65</sup> China, South Korea, and India were identified as “front runners”; Thailand, the Philippines, South Africa, Brazil, and Chile were placed in the middle; while Argentina and Mexico are labelled as “up-and-comers.”

Singer’s group also found a few examples of North-South cooperation. The European Union has allocated €285 million (\$384 million) for scientific and technological cooperation with developing world countries, including Argentina, Chile, China, India, and South Africa. A priority research area is nanotechnology and nanosciences. The US is funding nanotechnology research in Vietnam and collaborating with research programs in Argentina and India.

Most government investments are aimed at improved national corporate competitiveness in nanotechnology. Few seem to focus directly or even indirectly on the needs of the poor. The South African Nanotechnology Initiative (SANI) is an exception. SANI aims to establish a critical mass in nanotechnology R&D in South Africa for the benefit of all its citizens.<sup>66</sup> Projects include the development of better and cheaper solar cells and nanomembrane technology for water. Another exception is an agreement among the governments of India, Brazil, and South Africa, who have identified potential areas of scientific cooperation, including nanotechnology research and efforts to prevent and treat HIV/AIDS.<sup>67</sup>

Generally, governments are investing in nanotechnology for national economic and commercial advantage. Discovery-oriented scientists in universities are encouraged to undertake research that can be commercially exploited. Thus while much nanotechnology research is publicly funded, the benefits may not equitably reach all sectors of the public.

In the United States, the National Nanotechnology Institute (NNI) has made over 2,500 awards to universities, grants that usually go to individual investigators, an approach that makes a strategic approach to the development of nanotechnology more difficult. Other grants go to the US government’s “mission agencies.” The NNI lists 17 agencies as participating in NNI, including NASA, the Environmental Protection Agency, and the Departments of Commerce, Energy, and Agriculture. The US Agency for International Development (USAID) is not among them.

Few governments have effectively connected their nanotechnology programs with their official development assistance (ODA) programs. Given the stated commitment by many aid-giving governments to helping achieve the Millennium Development Goals, a reasonable proportion of their ODA should surely go toward developing and transferring technologies that could be of help.

Governments may also have a useful role in assuring citizens’ participation in guiding the way public monies are spent in developing emerging technologies. They should assure transparency in explaining which research they are funding and why.

<sup>65</sup>P.A. Singer et al. 2004. op. cit.

<sup>66</sup>South African Nanotechnology Initiative (SANI). Information available at: <http://www.sani.org.za/>. Accessed 28 November 2004.

<sup>67</sup>SciDev.Net. 27 October 2004. *India, Brazil and South Africa Discuss Joint Research*. Available at: <http://www.scidev.net/News/index.cfm?fuseaction=readNews&itemid=1693&language=1>.

<sup>68</sup>R. Paull et al. 2004. *Investing in Nanotechnology*. Nature Biotechnology, Volume 21, Number 10, pp. 1144-1147.

## Business

Though governments fund much start-up research, it is the private sector that determines which results of the research reach the marketplace.

In 2003, the more than 700 companies involved in nanotechnology were expected to spend close to \$3 billion worldwide on nanotechnology R&D. Venture capital spending has fallen generally since the late 1990s but has risen sharply in nanotechnology. Some \$900 million in venture capital funding has gone to nanotechnology start-ups since 1999, with \$386 million invested in 2002.<sup>68</sup>

Not surprisingly, little of this investment is aimed at products that could benefit the poor specifically. Science journalists wrote for years that the manipulation of plant genes held the promise of crops that would be more nutritious, drought-resistant, salt-resistant, and resistant to tropical diseases and pests – all for the benefit of poor country agriculture. In fact, the first products on the market were crop varieties resistant to proprietary weed killers used predominately by large-scale farmers in developed countries.

Similarly, nanotechnology promises new cancer treatments, cheaper energy, and purer water, but the first products offered to the public have been more airtight tennis balls, transparent sunblock, and stain-resistant trousers.

As in the biotech rush, companies are trying to lock up patents, a syndrome that will limit the number and types of products that may become public goods. The corraling of broadly defined patents could also slow innovation and drive up costs of products. There were 500 nanotechnology patent applications in 1998; 1,300 in 2000.<sup>69</sup>

According to some estimates, corporate investments in nanotechnology R&D worldwide are now in the hundreds of millions of dollars annually.<sup>70</sup> This trend is likely to accelerate the locking up of new knowledge, technologies, and techniques by patents and licensing practices. While patent protections provide an important benefit to the private company and investor, an unintended consequence can be increasingly restricted access to advances that can help reduce

human suffering or contribute to human development in the poorest regions.

However, a number of companies are beginning to turn their attention to the poor. Since about 2000, there has emerged an approach among companies labeled variously as “pro-poor business,” “business at the base of the pyramid,” and “sustainable livelihoods business.”

The idea, espoused by academics such as Prof. Stewart Hart, Cornell University; Prof. C. K. Prahalad,<sup>71</sup> University of Michigan Business School; the World Business Council for Sustainable Development (WBCSD); and the Washington-based World Resources Institute, states that the markets of developed countries are saturated, and companies are ignoring the potential market of the four billion or so poor people at the base of the global economic pyramid.

This approach involves doing business with the poor in ways that benefit the poor and benefit the corporate bottom line. It is not a new form of exploitation, it is argued, because (1) leading companies are now devoted to corporate social responsibility, and (2) the world is too transparent for companies to get away with exploiting the poor. Nor is it philanthropy; it is meant to be profitable. If pro-poor projects do become profitable, they can be grown to a huge scale that would have a much greater impact than any corporate philanthropy ever could.

Today there are scores of pro-poor demonstration projects afoot, run by dozens of major corporations.<sup>72</sup> There have as yet been no large-scale successes, and we know of no examples of pro-poor business projects that contain nanotechnology.

As an example of pro-poor business, DuPont sells agricultural products to poor corn farmers in Colombia. The farmers cannot afford improved seeds, fertilizers, and pesticides at planting time, because they have spent much of their income from the last harvest. The company, working with government agencies, has developed a program whereby farmers are paid ahead of time for a portion of expected future harvest. Their incomes improve with improved inputs, and they can afford the company's products.<sup>73</sup>

<sup>69</sup>Ibid.

<sup>70</sup>Ibid.

<sup>71</sup>Prahalad, C.K. 2004. *The Fortune at the Bottom of the Pyramid: Eradicating Poverty through Profits*. Wharton School of Publishing, Philadelphia, PA.

<sup>72</sup>World Business Council for Sustainable Development (WBCSD). 2004. *Doing Business with the Poor: a Field Guide*. Geneva, Switzerland. Available at: <http://www.wbcscd.org/web/publications/sl-field-guide.pdf>.

<sup>73</sup>Ibid.

Procter & Gamble has developed several products to improve the lives of the poor. One is a sachet of powder, which when added to water causes impurities, including microbes, to coagulate so that they can be strained out with a cloth. Hewlett Packard has pioneered a solar-powered digital camera and printer so that poor women in India can go into the business of providing ID photos for official documents.<sup>74</sup>

There are many developing country examples. The South African electricity utility Eskom provides poor customers, who lack postal addresses or checking accounts, with meters so they can pay for their electricity with prepaid tokens, buying only what they need.<sup>75</sup> The Latin American company GrupoNueva has developed about a dozen pro-poor business projects, including one to sell simple irrigation units to Guatemalan small landholders. The company helps farmers finance the purchase, with which they can double their harvests.<sup>76</sup>

Companies find other reasons besides stagnant northern markets for their new interest in doing business with the poor. Those listed in a WBCSD report include:<sup>77</sup>

- Framework conditions in developing countries are improving.<sup>78</sup>
- The world is smaller, and communications are faster and cheaper; lower communications and transportation costs allow more geographically dispersed production.
- Public expectations of corporations are changing, and the public is expecting companies to be a stronger force for sustainable development.
- The development NGOs are becoming more “businesslike” partners to companies, helping them to do business in poor communities.

There are a number of companies that are leaders in pro-poor business thinking and are also doing much R&D in nanotechnology. But there appears to be little or no connection within the individual companies between the practitioners in both efforts. This may be a missed opportunity in at least two ways. First, there may well be a mass market in the developing world for simple, nano-based water filters or photovoltaic devices. Second, public acceptance of nanotechnology could be greatly enhanced if business could demonstrate large-scale benefits early in the

rollout process. Nano-based applications for the poor could be a great boost to the technology overall, raising its stature in the public perception and its acceptability by society.

While not strictly part of the pro-poor business movement, there have been a number of efforts to make business-held IP available to poor people in poor countries. The African Agricultural Technology Foundation (AATF)<sup>79</sup> eases access to technology by integrating both upstream and downstream activities, from basic research on staple African crops to product development and end user. It is an African-led, African-based organization that facilitates public-private partnerships for the transfer and use of appropriate agricultural technologies. It has received commitments from a number of major technology owners (private companies, public-sector institutions, and NGOs) that allow it to acquire IP through royalty-free licenses and to sub-license the technologies to private, public, and NGO sectors for adaptation to smallholder farming conditions.

## Academia

It is impossible to discuss university involvement in nanotechnology separate from government and business involvement, as so much of the academic research funding comes from governments and so much of the fruits go to companies.

Many universities and research institutes around the world are working on nanotechnology,<sup>80</sup> and many are involved in collaborative projects that involve researchers in developed and developing countries.

Universities and research institutes receive much of their funding for nanotechnology research through government programs and, to a lesser extent, through partnerships with the private sector. As described in the preceding section, much of this nanotechnology funding is going to research that supports improved national corporate competitiveness and improved quality of life in developed countries and is generally not targeted to addressing the needs of poor people.

In general, communications are good between first-world universities and their governments and between these universities and companies. However, “signals from developing countries about their technology needs are not getting through to developed world universities,” according to David

<sup>74</sup>Ibid.

<sup>75</sup>Ibid.

<sup>76</sup>Julio Moura, CEO, GrupoNueva, Pers. Comm., 27 December 2004.

<sup>77</sup>WBCSD. 2004. op. cit.

<sup>78</sup>The country risk analysis group Political Risk Services has reported that over 1993-2003 their average political risk score in low- and middle-income countries improved from 59 to 64, and almost three times as many countries showed an improving political risk climate as a deteriorating one.

<sup>79</sup>Information about the AATF, which is partially funded by The Rockefeller Foundation, is available at: <http://www.aftechfound.org>.

<sup>80</sup>For example, see Cientifica, *The Nanotechnology Opportunity Report*, 2004.

Rejeski, director of the Foresight and Governance Project at the Washington-based Woodrow Wilson Center. “The lines are down. No signals get through. There is a major structural impediment to thinking about meeting the needs of poor nations through nanotechnology.”<sup>81</sup>

Another break in communications seems to be within universities, many of which have many researchers involved in development research and many involved in developing technologies for development. In Europe, 150 academic institutions have formed the European Association of Development Research and Training Institutes (EADI) to promote development research and training activities in economic, social, cultural, technological, institutional, and environmental areas. Some institutions, such as the International Association of Science and Technology for Development (IASTED), bring academic researchers and members of industry together to promote economic development through science and technology. Yet there seems to be little contact between these bodies and the experts within them and the academic researchers working on nanotechnology.

A recent report on technological innovation and the MDGs noted that in the developing world the old split between “pure” and applied research tends to hamper the harnessing of technology to development goals. It said that most developing country governments “still distinguish between science and technology policies designed to focus on the generation of new knowledge through support for research and development (R&D) and industrial policies that emphasize building manufacturing capabilities. A transition toward convergence in the two approaches would lead to increased attention to the use of existing technologies while building a foundation for long-term R&D activities.”<sup>82</sup>

While much public money goes into funding technology development at universities, only a small percentage of these technologies could be considered public or “humanitarian” goods. Universities in the developed world today are more and more expected to “pay their way” by patenting and licensing advances to the private sector. This is much more the case in the United States than in Europe and Japan, but the latter are more and more adopting the US approach.

In the United States, the Bayh-Dole Act of 1980 encourages universities to patent publicly funded innovations

and to license them to private-sector companies in order to encourage their commercial use.<sup>83</sup> Since that time, formal mechanisms for transfer of public research results to the private sector for further development have accelerated, and there has been a marked increase in the number of public-sector patents and the licensing of technology to the private sector.<sup>84</sup> This dramatic increase in patenting and restrictive licensing by universities and companies locks up knowledge, tools, and products, thereby limiting access to developing country researchers or those who would like to conduct research to benefit the poor.

This was the case in biotechnology, where the scramble for IP made it difficult to access technologies that had been patented or had complex IP ownership situations.

The challenge to the academic community is to find ways to ensure the broadest public benefit of their inventions. The UK’s Commission on Intellectual Property Rights recommended that “commitments should be made to ensure that the benefits of publicly funded research are available to all, including developing countries.”<sup>85</sup> Universities could play an important role in managing innovation to ensure that developing countries can reap the benefits from publicly funded research.

One attempt to make IP generated at US universities available for development purposes is the Public Intellectual Property Resource for Agriculture (PIPRA),<sup>86</sup> which is committed to managing IP to enable the broadest humanitarian and commercial applications of existing and emerging agricultural technologies. It is the collaborative project of an expanding group of universities and not-for-profit agricultural research institutions.

PIPRA enables research on a wide array of agricultural applications and facilitates their transfer from the laboratory to the field by providing collaboratively developed research tools built primarily upon technologies owned by its members and designed for optimal Freedom to Operate (FTO).<sup>87</sup>

It promotes the use of common licensing languages with specific “fields of use” designations that encourage licensing of current and future technologies to the private sector while maintaining rights for the development of subsistence and specialty crops. The Centre for the Management of IP in Health R&D (MIHR) advocates similar patent management and licensing approaches regarding biomedical technology.<sup>88</sup>

<sup>81</sup> David Rejeski, Pers. Comm., 1 November 2004.

<sup>82</sup> Task Force on Science, Technology and Innovation, UN Millennium Project. 2004. *Forging Ahead: Technological Innovation and the Millennium Development Goals*.

<sup>83</sup> D.C. Mowery et al. 2001. *The Growth of Patenting and Licensing by U.S. Universities: An Assessment of the Effects of the Bayh-Dole Act of 1980*, Research Policy 30, pp. 99-119.

<sup>84</sup> R.C. Atkinson et al. 2003. *Public Sector Collaboration for Agricultural IP Management*, Science 301, pp. 174-175.

<sup>85</sup> Commission on Intellectual Property Rights. 2002. *Integrating Intellectual Property Rights and Development Policy*. London, UK.

<sup>86</sup> Information about PIPRA, which is partially funded by The Rockefeller Foundation, is available at: <http://www.pipra.org>.

<sup>87</sup> Freedom to Operate (FTO) can be described as ensuring that the use of a new innovation does not infringe other’s intellectual property.

<sup>88</sup> Information about MIHR is available at: <http://www.mih.org>.

Biological Innovation for Open Society (BIOS) seeks to apply and extend the models of open innovation, which have become successful in open source software, to problems of biology affecting the disenfranchised of the world. It intends to apply the open source model to “fields ranging from human nutrition, food security and agriculture, to environmental management and improvement, conservation and use of biodiversity, human and veterinary medicine, and public health.”<sup>89</sup>

Can similar approaches be used to ensure that public funding for research conducted by universities can be turned into public goods, especially for the benefit of the developing world?

## Nongovernmental Organizations

Very few NGOs are paying attention to nanotechnology – pro or con. Those that have issued reports or made statements have tended to be the environmental groups concerned with various risks, who have called for more societal and regulatory scrutiny. Development groups have tended to stay away from the emerging nanotechnology debate, perhaps seeing it as of little relevance to their constituency.

An exception to this disinterested or largely cautionary approach of the development NGOs is an India-based NGO, Nimbkar Agricultural Research Institute (NARI), which mentions nanotechnology in its research strategy and advocates for R&D to develop cheap and efficient solar energy devices that can power a small fan to improve the efficiency of cookstoves.<sup>90</sup> This was one of the few calls for nanotechnology to be developed to serve the poor that we found.

The ETC Group, a Canadian-based international NGO, has written a great deal about nanotechnology and called for an immediate moratorium on commercial production of new nanomaterials and for the launch of a transparent global process for evaluating the socioeconomic, health, and environmental implications of the technology. ETC argues that nanotechnology may bring benefits to society, but it advocates a precautionary approach that would entail more research into the potential risks.<sup>91</sup>

Greenpeace UK commissioned a study by Alexander Huw Arnall of Imperial College on existing nanotechnology applications, current research and development, the main players behind these developments, and the associated incentives and risks. The study finds potential societal benefits but is concerned about how to ensure that nanotechnology applications will be properly researched, developed, and deployed.<sup>92</sup>

The Center for Responsible Nanotechnology, an affiliate of the US-based nonprofit World Care, has stated that “effective use of nanotechnology can benefit everyone.” The NGO is dedicated to the principle of making these benefits available as widely as possible through effective administration of “molecular manufacturing.” It adds: “Unwise use of nanotechnology can be very dangerous. Some restrictions, implemented worldwide, will probably be necessary for sufficient control of the use of molecular manufacturing.”<sup>93</sup>

Eric Drexler, a prominent nanotechnology researcher and policy advocate, serves as the Chairman of The Foresight Institute’s Board of Advisors. Foresight aims to guide emerging technologies to improve the human condition. Foresight specifically focuses its educational and research efforts upon preparing society for nanotechnology and seeks to ensure that nanotechnology, when developed, will be used to improve conditions in the broadest sense rather than for destructive or narrow purposes.<sup>94</sup>

A NGO in the Netherlands, the Rathenau Institute, is conducting research and organizing events to start an open dialogue on nanotechnology between academia, government, industry, and society.<sup>95</sup>

Other NGOs submitted comments during the process to develop the Royal Society and the Royal Academy of Engineering report. One expressed concerns about how nanotechnology may intersect with biotechnology and the social, environmental, health, and other consequences of this. Another was concerned that an inadequate examination of the social, environmental, and ethical implications of nanotechnologies will result in unpredicted and potentially large adverse effects.

<sup>89</sup>Information about BIOS is available at: <http://www.bios.net>.

<sup>90</sup>A.K. Rajvanshi. 2003. *R & D Strategy for Lighting and Cooking Energy for Rural Households*. Current Science. Available at: <http://education.vsnl.com/nimbkar/houseenergy.html>.

<sup>91</sup>ETC Group. 2003. op. cit.

<sup>92</sup>A.H. Arnall. 2003. *Future Technologies, Today’s Choices*. Greenpeace Environmental Trust. London, UK.

<sup>93</sup>Information about the Center for Responsible Nanotechnology is available at: <http://www.crnano.org>. Accessed on 28 November 2004.

<sup>94</sup>Information about Foresight Institute is available at: <http://www.foresight.org>. Accessed 29 December 2004.

<sup>95</sup>Information about the Rathenau Institute is available at: <http://www.rathenau.nl>. Accessed 29 December 2004.

## 7. Going Upstream, Together?

Most people believe that new technology tends to help people meet their needs. In the developed world, this is more or less true. Recent developments of small computers, mobile phones, and wireless, handheld devices have been disseminated quickly by the market and help people meet their perceived needs for more information and easier communications.

However, the more sophisticated and costly the technology, the more slowly it tends to reach developing countries, and especially their poorer citizens. There are very few organizations or efforts in any sector of society to speed this transfer.

The development of a new technology tends to outpace the development of methods to ensure a more egalitarian sharing of its benefits or even the analysis of its associated risks. This was true in the growth of biotechnology and has led to a backlash against that technology that has slowed both its further development and the dissemination of its benefits.

One long-term answer to this challenge is for NGOs, civil society organizations, and funding bodies inside and outside of governments to get involved in what is coming to be called “upstream engagement.” This means that concerned groups engage early in the development of a technology with those doing the developing. Such engagement would include discussion both about the direction of the development and the types of research needed to evaluate risks and deliver benefits. For this to happen, universities, companies, and the government agencies that fund research would need to be amenable to working constructively with stakeholders and the public earlier rather than later.

Several groups have raised questions about the lack of involvement of society in deciding how research funding is applied.<sup>96</sup> These groups are calling for a more transparent process and public involvement in making decisions about how public research funds are being spent and what aspects of nanotechnology are being studied.

The British science journal *Nature* has called upon the science community to open itself to upstream engagement, which it defined as “the involvement of non-specialists in setting research priorities.”<sup>97</sup>

“On an ethical and political level, the research community has no right to reject public involvement outright,” it added. “Taxpayers fund research, buying themselves the right to help shape its course. Objecting to public involvement would simply undermine the current enthusiasm shown for science funding by some governments, such as those in the United States and Britain.” The journal suggested the use of such engagement practices as citizens’ juries, consensus conferences, and deliberative mapping processes.

*Nature* was directing its argument to governments. The argument to business would be a little different. More and more companies are publicly committing themselves to working with stakeholders and to transparency, while maintaining their focus on profitability. Upstream engagement seems to be a logical outcome of such a commitment.

Upstream engagement must begin early in the technology development process, it must involve all major stakeholders, it must be funded, and it must be long-term. Stakeholders must also agree to abide by the results of the process.

### Connecting the Actors

A report by the UK-based thinktank Demos on the need to move upstream states: “Broader societal acceptance of new technologies, especially where they are novel and raise concerns, requires open dialogue throughout the development process. If opportunities are to be realized, then engagement and dialogue must take place at the right time and involve the right people.”<sup>98</sup>

It can be argued that the development of nanotechnology is not yet involving the right people, or at least is not bringing all of the right people into the process. In our look at the various sectors – business, government, academia, and NGOs – we have found in every sector a concern with helping to meet the needs of the poor and helping to realize the Millennium Development Goals:

- Some companies are getting involved in pro-poor business projects to help meet the needs of the poor for such things as food, safe water and sanitation, education, health care, housing, jobs, and opportunities while doing real business.

<sup>96</sup>For example, J. Wilsdon and R. Willis. 2004. *See-Through Science: Why Public Engagement Needs to Move Upstream*. Demos.

<sup>97</sup>Nature editorial. 2004. Volume 431, Number 21.

<sup>98</sup>J. Wilsdon and R. Willis. 2004. op. cit.

- Many government ODA agencies have been focusing on the needs of the poorest for decades.
- Most northern universities have development experts, many even focusing on technologies that can be of use in the developing world.
- Development NGOs have long championed the needs of the poor, and some have provided access to water, housing, health care, appropriate technology, etc.

Yet within each of these sectors there are disconnects, and certainly there are poor connections between sectors:

- The nanotechnology people and the pro-poor business people within companies tend not to communicate with each other.
- The ODA agencies of government tend to have little to do with the government agencies involved in the funding of nanotechnology R&D.
- University departments and scholars working on nanotechnology tend to have few, if any, incentives that focus on development needs, while the development academics know little of nanotechnology.
- NGOs that have pioneered ways of getting appropriate technology to the developing world have not yet tended to focus on nanotechnology, while the NGOs focusing on nanotechnology tend to focus on its risks rather than its opportunities.

The Global Dialogue on Nanotechnology and the Poor: Opportunities and Risks, for which this paper was produced, is one of several efforts needed to close such gaps and to find ways forward. Indeed, it is just one of many meetings that are already being held for this purpose. Some of the other efforts being planned are a Nanotechnology Conference organized by the South African Nanotechnology Initiative (SANI) and UNESCO in spring 2005 and the North-South Dialogue on Nanotechnology: Challenges and Opportunities, organized by the International Centre for Science and High Technology of UNIDO in February 2005 in Trieste, Italy.

While specific ways to responsibly bring the benefits of nanotechnology to the poor remain unclear, they will doubtless involve innovative partnerships within and between sectors. This paper is an attempt to challenge those sectors and to encourage cooperation within and among them. It is also an attempt to encourage positive answers to the following questions.

First, in regard to opportunities.

- Can governments spend a larger proportion of public money on benefits for the poor in the developing world, bringing their official development assistance agencies into their nanotechnology development efforts?
- Can companies combine their pro-poor business approaches with their development of nanotechnology?
- Can universities and research centers combine their efforts on technology for development with their efforts to create nanotechnology benefits?
- Can the development NGOs begin to focus on the potential development benefits of nanotechnology, always keeping in mind the concerns raised by NGOs that have focused on the risks of nanotechnology?

Questions regarding risks raise issues similar in spirit but different in detail.

- Can governments be more open and efficient in engaging civil society in prioritizing the risks of nanotechnology that need investigating, in explaining to the public (in all its many forms) why they are funding certain types of risk research, and in assuring that all this is done in the most transparent manner possible?
- Can business be more open about the risks inherent in nanotechnology and their efforts to responsibly manage these risks, having learned from previous experience in rolling out new technology that downplaying risk is always counterproductive?
- Can academia be more transparent about its relations with business and government and about the motivation, data, and results of its risk research?
- Can NGOs work more closely with business, government, and academia to help see to it that the risks are openly discussed, investigated, and managed?

The pieces for the responsible use of nanotechnology for development are on the table. There is an urgent need to begin putting them together.

## 8. Additional Reading

The following selection of reading materials provides readers of this paper and participants in the GDNP a starting point for further investigation of issues raised herein. There are many other relevant publications. Inclusion of these publications does not imply an endorsement of their contents by Meridian Institute.

### About Nanotechnology

R.P. Feynman. 1959. "There's plenty of room at the bottom." <http://www.zyvex.com/nanotech/feynman.html>.

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### About Risks and Benefits of Nanotechnology

The Royal Society and the Royal Academy of Engineering. 2004. *Nanoscience and Nanotechnologies: Opportunities and Uncertainties*. <http://www.nanotec.org.uk/finalReport.htm>.

The Health and Consumer Protection Directorate General of the European Commission. 2004. *Nanotechnologies: A Preliminary Risk Analysis on the Basis of a Workshop Organized in Brussels on 1–2 March 2004*. [http://europa.eu.int/comm/health/ph\\_risk/documents/ev\\_2004\\_0301\\_en.pdf](http://europa.eu.int/comm/health/ph_risk/documents/ev_2004_0301_en.pdf).

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### About Nanotechnology in Developing Countries

P.A. Singer et al. 2004. "Will Prince Charles et al. Diminish the Opportunities of Developing Countries in Nanotechnology?" <http://www.nanotechweb.org/articles/society/3/1/1/1>.

### About Doing Business with the Poor

World Business Council for Sustainable Development (WBCSD). 2004. *Doing Business with the Poor: A Field Guide*. Geneva, Switzerland. <http://www.wbcd.org/web/publications/sl-field-guide.pdf>.

# Appendix

<p><b>Goal 1</b></p>	<p><b>Eradicate extreme poverty and hunger</b>            Target 1: Halve, between 1990 and 2015, the proportion of people whose income is less than \$1 a day</p> <p>Target 2: Halve, between 1990 and 2015, the proportion of people who suffer from hunger</p>	<ul style="list-style-type: none"> <li>• 1. Proportion of population below \$1 (PPP) a day a</li> <li>• 1a. Poverty head count ratio (percentage of population below national poverty line) *</li> <li>• 2. Poverty gap ratio (incidence x depth of poverty)</li> <li>• 3. Share of poorest quintile in national consumption</li> <li>• 4. Prevalence of underweight in children (under five years of age)</li> <li>• 5. Proportion of population below minimum level of dietary energy consumption</li> </ul>
<p><b>Goal 2</b></p>	<p><b>Achieve universal primary education</b>            Target 3: Ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling</p>	<ul style="list-style-type: none"> <li>• 6. Net enrollment ratio in primary education</li> <li>• 7a. Proportion of pupils starting grade 1 who reach grade 5 b</li> <li>• 7b. Primary completion rate*</li> <li>• 8. Literacy rate of 15- to 24-year-olds</li> </ul>
<p><b>Goal 3</b></p>	<p><b>Promote gender equality and empower women</b>            Target 4: Eliminate gender disparity in primary and secondary education preferably by 2005 and in all levels of education no later than 2015</p>	<ul style="list-style-type: none"> <li>• 9. Ratio of girls to boys in primary, secondary, and tertiary education</li> <li>• 10. Ratio of literate women to men ages 15 to 24</li> <li>• 11. Share of women in wage employment in the nonagricultural sector</li> <li>• 12. Proportion of seats held by women in national parliament</li> </ul>
<p><b>Goal 4</b></p>	<p><b>Reduce child mortality</b>            Target 5: Reduce by two-thirds, between 1990 and 2015, the under-five mortality rate</p>	<ul style="list-style-type: none"> <li>• 13. Under-five mortality rate</li> <li>• 14. Infant mortality rate</li> <li>• 15. Proportion of one-year-old children immunized against measles</li> </ul>
<p><b>Goal 5</b></p>	<p><b>Improve maternal health</b>            Target 6: Reduce by three-quarters, between 1990 and 2015, the maternal mortality ratio</p>	<ul style="list-style-type: none"> <li>• 16. Maternal mortality ratio</li> <li>• 17. Proportion of births attended by skilled health personnel</li> </ul>
<p><b>Goal 6</b></p>	<p><b>Combat HIV/AIDS, malaria, and other diseases</b>            Target 7: Have halted by 2015 and begun to reverse the spread of HIV/AIDS</p>	<ul style="list-style-type: none"> <li>• 18. HIV prevalence among pregnant women ages 15 to 24</li> <li>• 19. Condom use rate of the contraceptive prevalence rate c*</li> <li>• 19a. Condom use at last high-risk sex*</li> <li>• 19b. Percentage of 15- to 24-year-olds with comprehensive correct knowledge of HIV/AIDS d*</li> </ul>

<p><b>Goal 7</b></p>	<p>Target 8: Have halted by 2015 and begun to reverse the incidence of malaria and other major diseases</p> <p><b>Ensure environmental sustainability</b></p> <p>Target 9: Integrate the principles of sustainable development into country policies and program and reverse the loss of environmental resources</p> <p>Target 10: Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation</p> <p>Target 11: Have achieved, by 2020, a significant improvement in the lives of at least 100 million slum dwellers</p>	<ul style="list-style-type: none"> <li>• 19c. Contraceptive prevalence rate</li> <li>• 20. Ratio of school attendance of orphans to school attendance on nonorphans ages 10-14</li> <li>• 21. Prevalence and death rates associated with malaria</li> <li>• 22. Proportion of population in malaria- risk areas using effective malaria prevention and treatment measures e</li> <li>• 23. Prevalence and death rates associated with tuberculosis</li> <li>• 24. Proportion of tuberculosis cases detected and cured under directly observed treatment short course (DOTS)</li> <li>• 25. Proportion of land area covered by forest</li> <li>• 26. Ratio of area protected to maintain biological diversity to surface area</li> <li>• 27. Energy use (kilograms of oil equivalent) per \$1 GDP (PPP)</li> <li>• 28. Carbon dioxide emissions (per capita) and consumption of ozone-depleting chlorofluorocarbons (ODP tons)</li> <li>• 29. Proportion of population using solid fuels*</li> <li>• 30. Proportion of population with sustainable access to an improved water source, urban and rural</li> <li>• 31. Proportion of population with access to improved sanitation, urban and rural</li> <li>• 32. Proportion of households with access to secure tenure</li> </ul> <p>Some of the indicators listed below will be monitored separately for the least developed countries, Africa, landlocked countries, and small island developing states.</p> <p><b>Official development assistance</b></p> <ul style="list-style-type: none"> <li>• 33. Net ODA total and to the least developed countries, as a percentage of OECD/DAC donors' gross national income</li> <li>• 34. Proportion of bilateral, sector-allocable ODA of OECD/DAC donors for basic social services (basic education, primary health care, nutrition, safe water, and sanitation)</li> </ul>
<p><b>Goal 8</b></p>	<p><b>Develop a global partnership for development</b></p> <p>Target 12: Develop further an open, rule-based, predictable, nondiscriminatory trading and financial system (includes a commitment to good governance, development, and poverty reduction—both nationally and internationally)</p> <p>Target 13: Address the special needs of the least developed countries (includes tariff and quota-free access for exports enhanced program of debt relief for HIPC and cancellation of official bilateral debt and more generous ODA for countries committed to poverty reduction)</p>	

Target 14: Address the special needs of landlocked countries and small island developing states (through the Program of Action for the Sustainable Development of Small Island Developing States and 22nd General Assembly provisions)

Target 15: Deal comprehensively with the debt problems of developing countries through national and international measures in order to make debt sustainable in the long term

Target 16: In cooperation with developing countries, develop and implement strategies for decent and productive work for youth

Target 17: In cooperation with pharmaceutical companies, provide access to affordable, essential drugs in developing countries

Target 18: In cooperation with the private sector, make available the benefits of new technologies, especially information and communications

- 35. Proportion of bilateral official development assistance ODA of OECD/DAC donors that is untied
- 36. ODA received in landlocked countries as proportion of their gross national incomes
- 37. ODA received in small island developing states as proportion of their gross national incomes

**Market access**

- 38. Proportion of total developed country imports (by value and excluding arms) from developing countries and from least developed countries, admitted free of duty
- 39. Average tariffs imposed by developed countries on agricultural products and textiles and clothing from developing countries
- 40. Agricultural support estimate for OECD countries as a percentage of their gross domestic product
- 41. Proportion of ODA provided to help build trade capacity

**Debt sustainability**

- 42. Total number of countries that have reached their HIPC decision points and number that have reached their HIPC completion points (cumulative)
- 43. Debt relief committed under HIPC initiative
- 44. Debt service as a percentage of exports of goods and services

**Other**

- 45. Unemployment rate of 15- to 24-year-olds, male and female and total
- 46. Proportion of population with access to affordable, essential drugs on a sustainable basis
- 47. Telephone lines and cellular subscribers per 100 population
- 48a. Personal computers in use per 100 population
- 48b. Internet users per 100 population

\*These indicators are proposed as additional MDG indicators but have not yet been adopted.

- (a) For monitoring country poverty trends, indicators based on national poverty lines should be used, where available.
- (b) An alternative indicator under development is “primary completion rate.”
- (c) Among contraceptive methods, only condoms are effective in preventing HIV transmission. Since the condom use rate is only measured among women in union, it is supplemented by an indicator on condom use in high-risk situations (indicator 19a) and an indicator on HIV/AIDS knowledge (indicator 19b). Indicator 19c (contraceptive prevalence rate) is also useful in tracking progress in other health, gender, and poverty goals.
- (d) This indicator is defined as the percentage of 15- to 24-year-olds who correctly identify the two major ways of preventing the sexual transmission of HIV (using condoms and limiting sex to one faithful, uninfected partner), who reject the two most common local

misconceptions about HIV transmission, and who know that a healthy-looking person can transmit HIV.

However, since there are currently not a sufficient number of surveys to be able to calculate the indicator as defined above, UNICEF, in collaboration with UNAIDS and WHO, produced two proxy indicators that represent two components of the actual indicator. They are the percentage of women and men ages 15-24 who know that a person can protect herself from HIV infection by “consistent use of condom” and the percentage of women and men ages 15-24 who know a healthy-looking person can transmit HIV.

- (e) Prevention to be measured by the percentage of children under age five sleeping under insecticide-treated bed nets; treatment to be measured by percentage of children under age five who are appropriately treated.
- (f) An improved measure of the target for future years is under development by the International Labour Organization.