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The Project on Emerging Nanotechnologies

NANOFRONTIERS

Developing Story: Nanotechnology and Low-Income Nations

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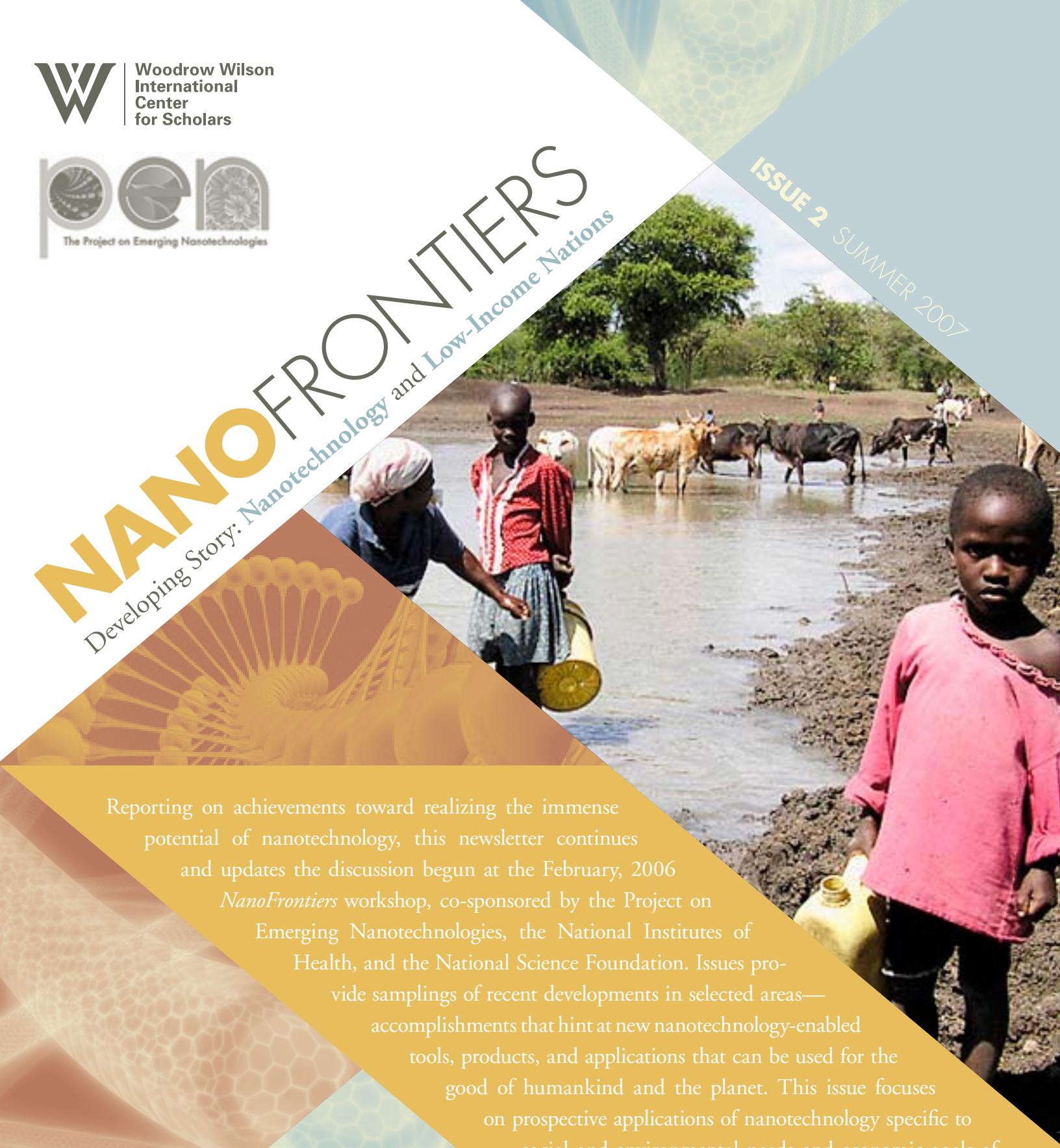

Reporting on achievements toward realizing the immense potential of nanotechnology, this newsletter continues and updates the discussion begun at the February, 2006 *NanoFrontiers* workshop, co-sponsored by the Project on Emerging Nanotechnologies, the National Institutes of Health, and the National Science Foundation. Issues provide samplings of recent developments in selected areas—accomplishments that hint at new nanotechnology-enabled tools, products, and applications that can be used for the good of humankind and the planet. This issue focuses on prospective applications of nanotechnology specific to social and environmental needs and economic goals of developing countries. Progress in this fast emerging field of science and engineering suggests that, although far from being a panacea, nanotechnology can provide important tools on the path toward solutions.

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Developing Story: Nanotechnology and Low-Income Nations

From South Africa to Mexico to Malaysia and from Jordan to Uruguay to Uzbekistan, the quest to gain the many envisioned benefits of nanotechnology has grown to include scientists from more than 100 nations.[1] Of the 62 countries with nanotechnology efforts carried out on the national level, three in five are developing nations (19) or transitional economies (18).[2]

By one tally, nanotechnology pursuits now account for 2.5 percent of all scientific articles (see map) and almost 1 percent of all patents issued.[3] These efforts, in turn, have attracted the commercial attention of more than 3,000 businesses worldwide.

Such statistics attest to the ambitious high-technology hopes that nations across the globe have pinned on the tiniest of technologies.

Goals of research and commercialization efforts range widely. Clearly, profits and economic growth are major impetus for business and government investments.

At the same time, progress in nanotechnology presents exciting opportunities to steer the development of nanotechnology and its prospective solutions to crucial problems that confront developing nations – from combating tropical diseases to ensuring clean drinking water for the one in six people who now lack access to reliable supplies.

Considered a general-purpose – or platform – technology, nanotechnology can, according to a United Nations review,[4] "be particularly important in the developing world." The report notes that many nanotechnology products and applications have the potential to be "highly productive and inexpensive," while requiring "only modest amounts of materials and energy."

Yet, as this same assessment also observes, "Advances in nanotechnology tend to be geared toward the interests of industrial countries. Applications for cosmetics, sports apparel, and various digital gadgets do not address the pressing needs of the more than 5 billion people in developing countries."

Nanotechnology Applications Most Likely To Benefit Developing Nations

- Energy storage, production, and conversion
- Agricultural productivity enhancement
- Water treatment and remediation
- Disease diagnosis and screening
- Drug delivery systems
- Food processing and storage
- Air pollution control and remediation
- Construction
- Health monitoring
- Vector and pest detection and control

From: F Salamanca-Buentello, et al., "Nanotechnology and the Developing World," *PloS Medicine*, April 12, 2005 (http://medicine.plosjournals.org/)

1. R Kostoff, et al., "The Structure and Infrastructure of the Global Nanotechology Literature," Office of Naval Research, 2006 (www.onr.navy.mil/sci_tech/33/332/docs/nano_dtic_report_textmin.doc).

2. D Maclurcan, "Nanotechnology and Health Care in Developing Countries," University of Technololgy, Syndey (www.ics.trieste.it/Documents/Downloads/df2694.pdf).

"We owe it to the millions of poor people worldwide to ensure that every step we take gets us closer to a world without poverty and deprivation. . . . [N]anotechnology does have the potential to contribute towards our ability to achieve these goals in an unprecedented way. It is up to us to be bold and imaginative enough to achieve this opportunity."

—Derek Hanekom, South Africa's Deputy Minister of Science and Technology*

*Speech to the World Nano Economic Congress, Pretoria, South Africa, April 23, 2007.

It has been argued that nanotechnology can contribute significantly to attaining five of the eight Millennium Development Goals (MDGs) designed to promote human development and social and economic sustainability.[5] Indeed this fast-emerging field is seen as an engine of sustainable economic growth in all regions of the globe as well as a fertile source of solutions to challenges specific to the developing world. Compiled from an international survey of experts, the "top 10" list in the box on the previous page is illustrative.

Without deliberate steps and integrated strategies that promote access to its benefits, however, nanotechnology is not likely to live up to its potential as a tool that can

THREE-WAY NANO PARTNERSHIP TAKES OFF

Regarded as "innovative developing countries," India, Brazil, and South Africa recently agreed to formalize a collaboration initially begun to acquaint each with the others' nanotechnology endeavors and capabilities. Linking three continents, the partnership will emphasize moving nanotechnology out of the laboratory and into applications.

Each nation has pledged an initial investment of $1 million to launch the program and to fund specific projects. The countries have targeted research areas that are aligned with their own national nanotechnology strategies and also complement the goals of their partners:

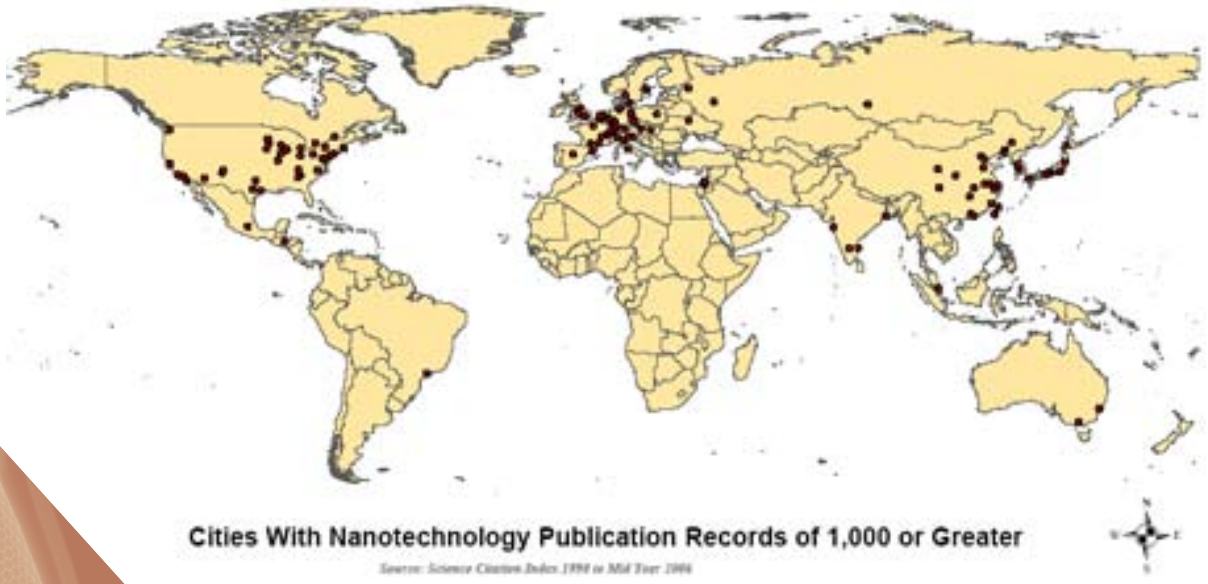
- India: advanced materials, health (TB, HIV, malaria) and drug-delivery systems, clean water, energy, and nanosensors for agriculture.
- Brazil: energy, including solar and bio-fuel applications.
- South Africa: nano-catalysis, gold nanomaterials, and drug delivery.

Education and training programs, along with exchanges of researchers, will be key elements. The trilateral collaboration will strengthen the nations' growing nanotechnology programs and enable the partners to assemble a critical mass of researchers when new nanotechnology opportunities arise.

3. L Zucker and M Darby, "Socio-economic Impact of Nanoscale Science: Initial Results and NanoBank," National Bureau of Economic Research Working Paper No. 11181, March 2005.

4. C Juma and L Yee-Cheong, "Platform Technologies with Wide Applicability" in *Innovation: Appying Knowledge in Development*, UN Millennium Project, 2005 (www.unmillenniumproject.org)

5. F Salamanca-Buentello, DL Prasad, DB Court, et al., "Nanotechnology and the Developing World," *PloS Medicine*, April 12, 2005 (medicine.plosjournals.org)



Credit: Program in Nanotechnology Research and Innovation Systems Assessment, Georgia Tech Technology Policy and Assessment Center, Center for Nanotechnology and Society, Arizona State University (CNS-ASU). Based on A. Porter, J. Youtie, P. Shapira, and D. Schoeneck, Refining Search Terms for Nanotechnology, Georgia Tech Technology Policy and Assessment Center, 2007.

help alleviate poverty and hunger and resolve other developing world challenges.[6] Many developing nations – acting on their own and in partnership – are taking steps to seize the benefits of nanotechnology. (For an example, see "Three-Way Nano Partnership Takes Off.")

China now ranks second in production of nanotechnology articles[7] and reportedly is home to more than 800 companies that are working in the field.[8] South Africa and India recently unveiled newly-minted national nanotechnology strategies, which include increased investment in research and development. India also has created incentives to attract private-sector investment in nanotechnology manufacturing plants.

Meanwhile, the United Nations is proceeding with plans to create an international center for South-South cooperation in science, technology and innovation, based in Malaysia. Nanotechnology will be a major thrust of the new center's research programs and its collaborations to foster technology transfer and the birth and growth of new industries.

To spotlight nanotechnology ambitions tied to developing-world needs, examples of progress in two areas – healthcare and drinking water – are featured below.

Improving Health and Access to Care

Many healthcare experts believe that progress in nanotechnology can yield powerful weapons to combat disease in the developing world. In particular, nanotechnology can play a key role in attaining the three health-specific MDGs: reducing child mortality, improving maternal health, and combating HIV/AIDS, malaria, and other diseases.[9]

As noted in the previous issue of the *NanoFrontiers* newsletter, healthcare applications account for a large share of today's nanotechnology research and subsequent patents. By 2015, according to one forecast, applications of nanotechnology in pharmaceuticals and healthcare may grow to be a trillion dollar industry, second only to semiconductors.[10]

Whether the spectrum of anticipated nanomedicine products will be responsive to the most pressing health needs of the developing world is a question that warrants attention. There is concern, for example, that progress in nanotechnology alone will not close the so-called 10/90 gap – that only about 10 percent of total health-research funding is directed towards illnesses affecting the poorest 90 percent of the world population. At the same time, there is

6. See, for example, N Invernizzi and G Foladori, "Nanotechnology and the Developing World: Will Nanotechnology Overcome Poverty or Widen Disparities?" *Nanotechnology Law & Business,* 2005.

7. China's rapid rise in nanotechnology was the focus of a Feb. 6, 2007, symposium sponsored by the Project on Emerging Technologies. See additional reading.

8. NanoChina, "Nanotechnology In China Is Focusing On Innovations and New Products," May 14, 2007, (www.nanochina.cn/english)

9. UNESCO, The Ethics and Politics of Nanotechnology, 2006, (unesdoc.unesco.org/images/0014/001459/145951e.pdf)

"Significant nanotechnology activity is already occurring in developing countries. This activity may be derailed by a debate that fails to take account of the perspective of developing countries. The evolution of nanotechnology can benefit from the lessons learned from previous technologies. The aim should be to encourage public discourse and consider potential benefits for the developing world."

—Innovation: Applying Knowledge in Development, UN Millennium Project, 2005

optimism that nanotechnology will open a wide path to practical, effective solutions to specific healthcare needs in developing regions.

Nanotechnology provides new strategies and tools to turn achievements in molecular biology and genetics – for example, sequencing the genomes of parasites that cause tropical diseases, such as leishmaniasis and sleeping sickness – into practical methods for treatment and, perhaps, prevention. As they increase their investments in nanotechnology, China, India, Brazil, and South Africa are targeting opportunities in healthcare. For example, Brazil's nanobiotechnology network includes about 30 companies and universities and is credited with more than 20 patents.[11]

India is already the world's fourth largest supplier (by volume) of pharmaceutical medicines, exporting to more than 150 nations. Many of its products are lower-cost generic alternatives. Up to an estimated 50 percent of drugs used today to treat HIV-AIDS patients come from India. Not surprisingly, healthcare applications are a major focus of the country's expanding nanotechnology efforts.

India's newly launched Mission on Nano Science and Technology will quintuple the public investment in nanotechnology research, to about $245 million over the next five years.[12] Ongoing efforts have yielded a rapid technique for detecting typhoid fever, which afflicts 16 million people worldwide. Still undergoing development, the tiny diagnostic kit would reduce the time for detecting typhoid from weeks to minutes. Innovations in nano-based drug delivery systems and a promising "dipstick" method for quickly detecting dengue fever, a mosquito-borne viral disease, are among India's other useful nanotechnology "works in progress."

Often-underappreciated challenges abound in efforts to develop effective diagnostic, therapeutic, and preventive technologies that respond safely and effectively to the health problems of the developing world. Clinics and other elements of a public health infrastructure – including trained personnel – are often rare. Reliable tests and medicines that can be administered cheaply and effectively in the field – in the community or in the home – are among the top practical requirements. Lack of refrigeration, necessary for vaccines and many other medicines, and unsanitary field conditions at immunization sites, which contribute to the spread of blood-borne diseases, are but a few examples of the many other obstacles that must be factored into the search for nanomedicines for the developing world.

A few examples of recent progress in applying nanotechnology to developing-world healthcare needs are reported below.

10. Cientifica Ltd., "Half Way to a Trillion Dollar Market? A Critical Review of the Diffusion of Nanotechnologies," April 2007 (www.cientifica.eu).

11. M Knobel, "Nanoscience and Nanotechnology in Brazil." Presentation at North South Dialogue on Nanotechnology: Challenges and Opportunities, Feb. 2005 (www.ics.trieste.it/Documents/Downloads/df2600.pdf)

12. DailyIndia.Com, "Government approves launch of Nano Mission," May 3, 2007 (www.dailyindia.com)

"Nanotechnology is about people, it is about making sure we educate, integrate ideas, technology, and knowledge to produce better products with novel properties at the nanoscale, which enhances our environment and standard of living..."

—Datuk Seri Najib Tun Razak, Deputy Prime Minister of Malaysia*

* Malaysia Nanotechnology Forum 2005

HIV/AIDS: Most of the 40 million people with HIV/AIDS live in the developing world,[13] where it is the second leading cause of death. Reducing the incidence and prevalence of HIV/AIDS in developing nations is a high priority, the specific aim of one of the MDGs.

- A credit card-sized HIV diagnostic and monitoring system allows tests to be conducted with only a finger-prick quantity of blood. This analyzer uses a microchip to count certain types of cells (CD4) to indicate the presence of HIV in a patient. The test is easy to administer, as it does not require sample preparation, and provides results within eight minutes.[14]

- A topical microbicide made with dendrimers, a type of nanoparticle, shows great potential as a practical means to prevent HIV and other sexually-transmitted infections.[15] VivaGel has been given "fast track" status, a priority designation that expedites clinical testing and subsequent reviews for approval. The need for preventive approaches is great. People under age 25 account for half of all new HIV infections worldwide; about 6,000 become infected with HIV every day.

Tuberculosis (TB): Affecting one-third of the world population, TB kills about 2 million people annually, mostly in developing countries.[16] Moreover, many strains of TB are becoming drug resistant and increasingly harder to cure. In fact, lack of prompt diagnosis and immediate follow-up treatment has contributed significantly to drug resistance.

- The India-based Central Scientific Instruments Organization has developed a tuberculosis diagnosis kit that only requires a microliter blood sample and is smaller than a stack of postage stamps (only 1 cubic centimeter). This test is expected to cost about 30 rupees (the equivalent of about $0.70 U.S.).[17] The kit is a huge step up from currently used TB tests that can only be administered by technicians, usually in well-equipped hospitals.

- South African researchers and their Swiss collaborators have begun animal tests of a slow-release nanocapsulized drug for TB treatment. The formulation has the potential to significantly reduce the amount and frequency of drugs administered for treating people with the disease — from daily to once a week. Current treatment regimens, which can span up to six months, are blamed for

13. UNAIDS, AIDS Epidemic Update, 2006 (data.unaids.org/pub/EpiReport/2006/02-Global_Summary_2006_EpiUpdate_eng.pdf)

14. McDevitt Research Laboratory (www.tastechip.com)

15.Starpharma, (www.starpharma.com/vivagel.asp)

16. World Health Organization, Top Ten Causes of Death, 2007 (http://www.who.int/mediacentre/factsheets/fs310/en/index.html).

17. *Times of India*, "CSIO develops nanotechnology for TB diagnosis kit," Jan. 3, 2004

"Nanotechnology is knocking at our doors. It is the field of the future that will replace microelectronics and many fields with tremendous application potential in the areas of medicine, electronics and material science."

—Dr. A. P. J. Abdul Kalam, former President of India*

*Address at the Birla Institute of Technology and Science, Pilani, Rajasthan, March 30, 2007 (www.presidentofindia.nic.in).

high rates of noncompliance, a major contributor to increasing drug resistance.[18]

Disease Diagnosis: The most widely used methods for disease detection are time consuming and usually require specialized technicians, who can be scarce in developing countries. Nanotechnology can help to simplify and speed up diagnostic testing and, at the same time, greatly expand disease surveillance. Researchers from four U.S. universities are teaming up to develop microarrays that can use a drop of saliva, rather than a syringeful of blood, to screen for a range of diseases. Lined with arrays of tiny biosensors, the envisioned chip-sized labs will enable tests for multiple indicators, making it possible to screen for as many as 75 pathogens at once. So far, saliva diagnoses have been used to detect diseases such as atherosclerosis, a precursor to heart disease,[19] which is a major killer in low- and high-income countries alike.

18. N Moodley, "Nanotech Capsules May Aid TB Treatment," *Engineering News On Line*, April 23, 2007 (www.engineeringnews.co.za/)

19. The collaborating universities are: University of Texas, Austin; University of Texas Health Science Center, San Antonio; University of Kentucky; and University of Louisville.

Precious Water

For those who live in industrialized nations, the developing world's litany of water-related woes is nearly beyond comprehension. Yet, collectively, illnesses and other problems related to shortages of water and contaminated supplies constitute the largest health problem in the world. More than 1 billion people lack access to reliable supplies of water, and more than 40 nations face water scarcity. About 4,500 children die each day from lack of water or poor sanitation. Nearly 65 million people – mostly in Bangladesh, India, and several other developing nations – are at risk of health problems due to arsenic-contaminated wells.

Meeting the food needs of a growing population will add new strains on supplies of water. Irrigation now accounts for two-thirds of all freshwater used by humans, and the share could grow significantly if, as projected, world food needs increase more than 50 percent over the next 25 years.

Nanotechnology coule help to increase international access to water and reverse the misery that these statistics only begin to tell. From more effective harvesting of rainwater to more practical means of desalination, nanotechnology-enabled approaches can advance efforts to achieve, by 2015, the MDG to reduce by half the number of people without reliable drinking water and basic sanitation.

"On the basis of research studies launched recently, why not believe that many micro- and nano pollutants can be removed even to extremely low levels, energy requirements can be reduced by nano-engineered membranes and high science can result in water technologies for regions in the developing world where power is not available?...Future water technologies will, in all likelihood, rely heavily on nanoreactor processes."

—Laszlo Somlyody, 2006 President of the International Water Association*

**Water21*, "Water science and practice: next generation problems – seven questions ," Oct. 2006 (http://www.iwapublishing.com/template.cfm?name=w21oct06_iwanews)

Prospects for progress toward this objective were surveyed in a report written by South African and Sri Lankan researchers and commissioned by the Meridian Institute. (See Additional Resources.) Although hardly an assured outcome, better, cheaper ways to clean water are on the horizon. Consider these examples of recent progress:

• An Indian-developed nanotechnology product that removes dissolved pesticide residues will soon make its market debut. Dispersed in a cartridge that is 21 centimeters (about 8 inches) long, particles of silver measuring 60 to 80 nanometers in diameter destroy three pesticides found at elevated levels in Indian water supplies. One such filter, according to the manufacturer, will last the typical Indian family for one year. The company will recycle the filters to recover the silver nanoparticles.[20]

• Yields achieved with rainwater harvesting, an important means of increasing portable water supplies in Thailand, Nepal, China, and other nations, may get a boost from nanotechnology. Following nature's lead, Massachusetts Institute of Technology scientists have designed a nano-sponge material that excels in snatching water droplets from the air. Compared with the polypropylene nets now used to "harvest" fog in some parched regions, the new material can increase water capture by tenfold. Inspired by the wax-like exterior of a beetle that lives in Africa's Namib Desert, the MIT-developed material features enhancements, including a decontaminating agent that eliminates harmful bacteria that might otherwise develop in rainwater as it collects.[21]

• Ranked among the top 10 nanotechnology developments of 2006, Rice University researchers have devised the nanotechnology equivalent of arsenic magnets – nano-sized rust particles that bind to the lethal contaminant. In an unexpectedly simple process, a magnet can remove the combinations of arsenic and rust, leaving behind water clean enough to meet Environmental Protection Agency standards.[22] Various types of nanoparticles, nanocatalysts, and other nano-based approaches to filtering, disinfecting, and otherwise purifying water are being pursued around the world.[23]

• Nanotechnology already is demonstrating its practical value in many of the some 10,000 desalination plants around the globe. Primarily in the form of advanced filters and membranes,

20. K Jayaraman, "Pesticide filter debuts in India," *Chemistry World*, April 20, 2007.

21. S Brown, "Water, Water Everywhere," *ScienceNOW Daily News*, May 25, 2006 (http://sciencenow.sciencemag.org/cgi/content/full/2006/525/1)

22. CT Yavuz, et al., "Low-Field Magnetic Separation of Monodisperse Fe_3O_4 Nanocrystals," *Science*, Nov. 10, 2006.

23. For a sampling, see, for example, "U.S. – Israeli Workshop on Nanotechnology for Water Purification," March 13-15- 2006 (http://www.nanoisrael.org/download/nanowater1/US-IL%20NanoWater%20Workshop%20Program%20Final%2009-MAR.pdf)

nanotechnology is helping to drive down costs and to improve the efficiency and reliability of steps to produce drinking or irrigation water from the sea. For example, desalination applications of nanotechnology earned the top two spots in the 2007 competition for innovation of the year in the global water industry. The winner was a new nanofiltration technology that was demonstrated at two plants in Saudi Arabia. The demonstration showed that the retrofitted pretreatment filtration method can increase production capacity at standard thermal desalination plants – an unanticipated boost in a maturing technology, according to the reviewers.

The runner-up innovation – a nanocomposite developed at the University of California at Los Angeles – is now in the transition from research to commercialization. The novel nanocomposite matrix technology may lead to a new class of low-energy, fouling-resistant membranes for desalination and water reuse. Initial tests suggest the new membranes have up to twice the productivity — or consume 50 percent less energy — potentially reducing the total expense of desalinated water by as much as 25 percent. The new reverse osmosis membrane has the potential to enable similar improvements in wastewater reclamation.[24]

ADDITIONAL RESOURCES

Project on Emerging Nanotechnologies, Nanotechnology in China: Ambitions and Realities (webcast and materials for program held Feb. 6, 2007):
www.nanotechproject.org/104/

Project on Emerging Nanotechnologies, Using Nanotechnology to Improve Health in Developing Countries (webcast and materials for program held Feb. 27, 2007):
www.nanotechproject.org/106

Meridian Institute Projects on Nanotechnology (including Global Dialogue on Nanotechnology and the Poor; Nanotechnology, Water, and Development; and *Nanotechnology and Development News*):
www.merid.org/nano/

Millennium Project, Task Force on Science, Technology, and Innovation (The Task Force's report contains a detailed overview of nanotechnology and relevant applications in Chapter 4, "Platform technologies with wide applicability.")
www.unmillenniumproject.org/reports/tf_science.htm

United Nations Environment Program (For an overview of prospective benefits and a discussion of potential environmental impacts, see "Emerging Challenges, Nanotechnology and the Environment," in the *Geo Year Book 2007*):
www.unep.org/geo/yearbook/yb2007/

24. Global Water Intelligence, "The Global Water 2007 – Innovation of the Year," (http://www.globalwaterawards.com/)

THE PROJECT ON EMERGING NANOTECHNOLOGIES was launched in 2005 by the Wilson Center and The Pew Charitable Trusts. It is dedicated to helping business, governments, and the public anticipate and manage the possible human and environmental implications of nanotechnology.

THE PEW CHARITABLE TRUSTS serves the public interest by providing information, advancing policy solutions and supporting civic life. Based in Philadelphia, with an office in Washington, D.C., the Trusts will invest $248 million in fiscal year 2007 to provide organizations and citizens with fact-based research and practical solutions for challenging issues. www.pewtrusts.org

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