AZojono
Journal of Nanotechnology Online

OARS
Open Access Rewards System

Nanotechnology and Developing Countries
Part 1: What Possibilities?

Donald C. Maclurcan

Submitted: June 28th, 2004
Posted: September 30th, 2005

DOI: 10.2240/azojono0104

Topics Covered

Abstract

In recent times, nanotechnology has been included in a number of the debates considering emerging technology and developing countries. However, the literature considering nanotechnology's application to the developing world has often varied in its interpretation of what nanotechnology really is. Furthermore, despite a wide range of perspectives as to the relevance, appropriateness and potential impact of nanotechnology for developing countries, the key debates have often remained disengaged. This paper attempts to clarify understandings of nanotechnology and synthesize discussions on issues of relevance, appropriateness and distribution with respect to developing countries. In support, recent developments in nanotechnology and healthcare are provided.

Background

In recent times, a number of research groups have stimulated debate on nanotechnology's possible applications and implications for developing countries [see, for example, 1, 2, 3]. However, many of the subsequent papers have failed to distinguish theoretical- from currently feasible-nanotechnology [see, for example, 3, 4, 5]. In international debates, distinction between the near-term, possible reality and theoretical science is crucial to the efficient exchange of information.

Furthermore, amongst those considering developing country engagement with nanotechnology, a range of perspectives are held concerning 'appropriateness' and nanotechnology's likely impact on the developing world. Some individuals challenge a pervasive acceptance of nanotechnology, expressing concern about developing country exploitation [Shiva cited in 6], insubstantial consideration for issues of risk and regulation [7], the loss of traditional markets [8] and an identification of nanotechnology applications that fails to consider historical trends and current barriers to technology distribution [9]. Others adopt a more utilitarian approach, linking nanotechnology applications in water, energy, health, food and agriculture to the fulfilment of the United Nation's (U.N.) Millennium Development Goals[a] [4, 10], despite earlier recognition of its potential to stimulate a greater divide between the 'haves' and 'have-nots' [1].

Despite surprising levels of nanotechnology research and development (R&D) in the developing world [1], arguments concerning nanotechnology's role as a protagonist or antagonist to sustainable development[b] remain disengaged.

In this paper we seek to clarify understandings of nanotechnology and synthesize discussions on issues of relevance, appropriateness and equity with respect to developing countries. With infectious and parasitic disease remaining the greatest cause of death in the developing world [12] and nanotechnology predicted to affect half of the world's drug production by 2011 [13], examples relevant to health are commonly cited.

What is Nanotechnology and How is it New?

For citizens in the developed world already exposed to the term 'nanotechnology', associated impressions may be that it deals with 'very small things', concerns 'submarine robots in the bloodstream' and brings with it the threat of 'grey goo'[c]. The latter, more popular ideations, essentially stem from K. Eric Drexler's proposal that atoms and molecules could act as self-assembling machinery, performing production tasks at the nanoscale[d] [15].

However, what is now universally accepted as 'nanotechnology', yet sometimes less noted, is an area evolving somewhat independently of Drexler's visions. Following challenges from the general scientific community, on the basis of technological feasibility, Drexler renamed his understanding and aspirations for nanotechnology: 'molecular manufacturing'. Thus, in the 21st Century, the term 'nanotechnology', whilst similar to molecular manufacturing in that it involves work on the level of atoms and molecules, refers to an applied science, focussed upon exploiting novelties arising from size-dependent phenomena exhibited in nanoscale matter. When dealing with matter below approximately 50 nanometres, the laws of quantum physics supersede those of traditional physics, resulting in "…changes to a substance's conductivity, elasticity, reactivity, strength, colour, and tolerance to temperature and pressure" [16]. Such changes are useful to all industrial sectors where nanotechnology will enable smaller, faster, 'smarter', cheaper, lighter, safer, cleaner and more precise solutions [17-19]. For example, in the field of drug delivery, Peppas notes that nanoscale pH-sensitive hydrogels for treating patients with multiple sclerosis, "release at varying rates depending on the pH of the surrounding environment", suggesting that "…these nanoparticle carriers may protect drugs from being broken down in the body until they reach the small intestine" [20]. Furthermore, progressing from the micro- to nano-scale involves inherent increases in a material's surface area and surface-to-volume ratio that can be used to manufacturing advantage.

---

[a] 8 goals set by all U.N. Member States pertaining to: eradication of extreme poverty and hunger; achievement of universal primary education; promotion of gender equity and empowerment of women; reduction in child mortality; improvement of maternal health; combating of HIV/AIDS, Malaria and other diseases; ensuring of environmental sustainability; and development of a global partnership for development, by 2015 (see http://www.un.org/millenniumgoals/ for greater detail).

[b] Most commonly defined as being, "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [11].

[c] The hypothetical, end-of-the-world scenario in which self-replicating, omnivorous nanoscale robots create global ecophagy.

[d] 1-100 nanometres [14], with 1 nanometre equal to 1 billionth of a metre.

Ancient Origins of Nanotechnology

Yet, utilising science at the nanoscale is not new. For example, in the 4th Century A.D., the Romans applied gold and silver nanoparticles to colour glass cups [21]. The resulting artefacts were red in transmitted light and green in reflected light – a sophistication not reproduced again until medieval times. There are many scientists today who would argue they have been conducting research in the realms of the nanoscale since well before 1990.

Reasons Why Nanotechnology has only Come to the Fore in Recent Times

So how come more and more people are talking about nanotechnology as the 'next big thing' if it has 'existed' for such a long time? There are three main reasons. Firstly, only in the past few decades have we really had the experimental means to conduct work focussed on activity at the nanoscale. Emerging tools, including scanning probe microscopy, quantum mechanical computer simulation and soft X-ray lithography, have combined with new synthesis methods, such as chemical vapour deposition, leading to a significantly greater, ever accelerating understanding of scientific endeavour at the nanoscale. These progressions have been paralleled by the discovery of materials such as fullerenes and nanotubes and, in more recent years, stimulated by a flood of government nanotechnology funding in countries such as the U.S., China and Japan.

Secondly, nanotechnology has, as its underlying aim, the desire to manufacture with ultimate precision on the atomic scale in a 'bottom-up' manner. This means that, rather than the traditional approach to manufacturing whereby bulk materials are whittled down, nanotechnology aims to produce devices commencing with the self-assembly of individual atoms into precise configurations, as has been the case with combinational chemistry for many years. Whilst a great deal of nanotechnology continues to utilise 'top-down' processes such as lithography, the gradual trend is towards 'bottom-up' approaches that hold numerous, long-term manufacturing, financial and environmental advantages.

Thirdly, and arguably most importantly, the recognition of nanotechnology as an emerging field demands and creates new levels of multi-disciplinary collaboration and cross-fertilisation amongst the sciences. Practically, this happens because of the integrated exploitation of biological principles, physical laws and chemical properties at the nanoscale [22]. The increasing desire and need to classify technology resulting from nanoscale manipulation and the progressive integration of scientific disciplines at a unifying length-scale, has led to the accepted term 'nanotechnology', under which new research is growing and existing research is often re-classified. Whilst nanotechnology is projected by the U.S. National Science Foundation (NSF) to have a global market value of $1 trillion[e] by 2011 [23], early signs in the information and communications technology (ICT) and textile industries are that nanotechnology is more complementary, than displacing.

According to a UNESCO-sponsored study in 1996, "nanotechnology will provide the foundation of all technologies in the new century" [24]. However, basket-casing nanotechnology as 'another biotechnology' runs the risk of disregarding novel implications (both advantageous and detrimental). For those involved in the development of nanotechnology policy, one of the greatest challenges will be the efficient use of time; distinguishing and dealing with novel ethical, legal and social implications whilst ensuring appropriate contextualisation.

Relevant, Appropriate Applications for Developing Country Healthcare?

Given the 'capital intensive, high-tech, science fiction' branding it has received from much of the developed world media, nanotechnology would appear highly incongruous with sustainable development practices. In response to a recent study that ranked nanotechnology applications, from social development cluster areas[f], according to their potential benefit for developing

---

[e] All monetary figures in this paper refer to U.S. dollars.

[f] According to the South African Nanotechnology Initiative, nanotechnology sectors can be classified into 'industrial' and 'social development', with the latter incorporating: energy; water; and health. 'The environment' crosses both sectors [25].

countries [10], Invernizzi and Foladori, cite the ability of China and Vietnam to significantly reduce malaria in the last century without the use of emerging technologies [9].

Furthermore, Brown notes that, “within development circles there is a suspicion of technology boosters as too often people promoting expensive, inappropriate fixes that take no account of development realities” [26]. Others believe the promotion and debate about nanotechnology in countries such as India, China and Brazil, threatens to divert and detract resources, political will and attention from the needs of the poor [27] and could inhibit research necessary to “address society’s problems in a systemic manner” [Mulvaney cited in 6]. In addition to nanotechnology possibly promoting a ‘technical fix’ approach [28], there is a concern that high entry prices for new procedures and skills are “very likely to exacerbate existing divisions between rich and poor” [Healy, cited in, 28].

Dispelling Misconceptions about Nanotechnology

Yet much of the early commentary from research groups and developing countries engaging in nanotechnology discussions has been united in the identification of relevant applications in areas such as solar cell technology, water purification; and health-related diagnostics and therapeutics [1, 4, 29-32]. At an international policy level there has been a push from individuals, such as the U.N. Under-Secretary for Economic Affairs, to include nanotechnology in discussions concerning emerging technology and sustainable development [33]. Representatives from the U.N. Conference on Trade and Development and Commission on Science and Technology for Development have suggested that nanotechnology can help “reduce the cost and increase the likelihood of attaining the Millennium Development Goals” [34]. Individuals with the National Science Foundation of Sri Lanka believe that, whilst nanotechnology research and development is ‘high-tech’, the products it enables, can be appropriate for use throughout the world [30]. Harper suggests it is this misconception, that nanotechnology is “all about high technology, semiconductors and science fiction”, that is creating a major barrier to nanotechnology being viewed as appropriate to the development setting [35].

Potential Benefits of Nanotechnology to Developing Countries

In a recent study that ranked nanotechnology applications according to their potential benefit for developing countries, water treatment, disease diagnosis/screening and drug delivery systems respectively rated 3rd, 4th and 5th, behind energy storage, production, and conversion (1st) and agricultural productivity enhancement (2nd) [10]. Salvarezza believes nanotechnology offers an area such as developing country healthcare, “safer drug delivery, new methods for prevention, diagnosis and treatment of diseases” [36]. In rural areas, Harper argues that pulmonary or epidermal drug delivery applications utilising nanotechnology, “have the potential to free up the large numbers of trained medical personnel who are currently engaged in administering drugs via hypodermic needles” [35]. Furthermore, Barker comments that slow-release drugs, important for those in remote areas, could be assisted by nano-porous membranes [4]. In a joint project between groups in the U.S., India and Mexico, inexpensive, maintenance free solar panels, aimed at powering rural clinics and refrigerating medicines, are currently being developed [37]. Could nanotechnology empower local healthcare auxiliaries, in rural settings worldwide, to address diagnostic and therapeutic concerns by reducing reliance on trained specialists or technical assistance? Or does such as suggestion sound similar to the many promises of past technological revolutions that were challenged by the realities of global development and domestic technology distribution?

Diagnosis and Treatment of Tuberculosis using Nanotechnology

Many believe nanotechnology offers new ways to address residual scientific concerns for *Mycobacterium tuberculosis* (TB). Declared a global emergency by the World Health Organisation (WHO) in 1993, the re-emerging threat of TB continues to be technically compounded by significant increases in the prevalence of multi-drug resistance (MDR), in a number of settings [38]. Treatments with improved sustained release profiles and bioavailability can increase compliance through reduced drug requirements and therein minimise MDR-TB [39]. Additionally, improved diagnostic tools are required to meet the needs of the WHO's expansion of the Directly Observed Treatment Short-course, MDR and co-infection with HIV [40].

In India, the country with the highest estimated number of TB cases [41], research is underway into the role nanotechnology can play in addressing such concerns. A nanotechnology-based TB diagnostic kit, designed by the Central Scientific Instruments Organisation of India and currently in the clinical trials phase, does not require skilled technicians for use [42] and offers efficiency, portability, user-friendliness and availability for as little as 30 rupees [43] (less than US$1). In the Medical Sciences division of the U.S. Department of Energy, researchers are investigating an optical biosensor for rapid TB detection [44]. Furthermore, a group at RMIT University, in Australia, is conducting research into the application of novel tethered nanoparticles as low-cost, colour based assays for TB diagnosis [45].

Polylactide co-glycolide nanoparticles are being investigated by groups at Harvard University (U.S.), the Postgraduate Institute of Medical Education and Research (India) and the Council for Scientific and Industrial Research (South Africa), as drug carriers for treating TB [46-48]. So far, all groups have registered high levels of drug encapsulation efficiency, whilst both the Indian and South African groups have demonstrated sustained release profiles. Furthermore, the Indian group have reported increased bioavailability and "undetectable bacterial counts in the lungs and spleens of *Mycobacterium tuberculosis*-infected mice" 21 days post-inoculation [49]. The South African group claim that a prototype of their work should be ready for commercialisation by 2007/8 [39]. Furthermore, a nanotechnology-based vaccine adjuvant for TB was developed by the U.S firm, Biosante, in 2002 [50].

Nanotechnology Research into Prevention of Other Infectious Diseases such as HIV/AIDS

TB is just one example of current nanotechnology research relevant to infectious diseases most prevalent in the developing world. Inter alia, science ministers from South Africa, Brazil and India have been working together on identifying ways in which nanotechnology can assist HIV/AIDS [3]. An Australian company, Starpharma™, is developing a preventative, clear, HIV microbicide gel, based on dendrimer nanotechnology, that would remain effective when applied by women up to four hours in advance of sexual intercourse [51]. Also in Australia, the Austin Research Institute has conducted successful trials into nano-vaccines for malaria [52]. Researchers at the State University of Campinas, Brazil, are investigating drug and vaccine delivery for leishmaniasis [53]. At the Chidicon Medical Center in Nigeria, researchers are studying nanoscale copolymer assemblies for diagnostic imaging and therapeutic management of infectious diseases [54]. Furthermore, in a joint project between the Rensselaer Polytechnic Institute (U.S.) and Banaras Hindu University (India), scientists are investigating easy-to-manufacture, carbon nanotube filters that remove nano-scale germs, such as the polio viruses, E. coli and Staphylococcus aureus bacteria, from water [55].

Long Term Effects of Nanoparticles

Whilst Barker comments that "any helpful technologies should be brought into service…" for developing countries [4], others caution about the unknown risks associated with nanoparticle accumulation, toxicology and permeation [2]. As a report to the European parliament noted, "the state of research concerning [sic]… The behaviour of nano-particles is actually rather limited, preliminary as well as contradictory" [56]. Whilst the comprehensive 2004 report by the Royal Society and Royal Academy of Engineering (U.K.) recommends that "factories and research laboratories treat manufactured nanoparticles and nanotubes as if they were hazardous waste streams" [28], many traditional Chinese medicines are now known to have contained metal nanoparticles [57]. Hoet et al. argue that "…producers of nanomaterials have a duty to provide relevant toxicity test results for any new material, according to prevailing international guidelines on risk assessment" [58], leaving others disturbed that the cosmetic industry has refused to release test data into the public domain[g], despite claiming that products such as sunscreen lotions are safe [59].

Furthermore, early suggestions from the U.S. and U.K., that nanotechnology is inherently regulated [56], have encountered stiff opposition from the action group on erosion, technology and concentration (ETC group), and others, who believe nanotechnology enters a 'regulatory vacuum' and that some new properties of nanoparticles are not covered by existing chemical regulations [2, 60].

Risk versus Benefits of Nanotechnology and its Effect on Applications

However, in light of the debate surrounding Genetically Modified foods, Court et al. argue that an exclusive focus from the developed world upon issues of risk threatens to divert attention from identifying and applying nanotechnology to the developing world [1]. An engagement with 'risk' and the consideration of nanotechnology's application to the developing world need not be mutually exclusive. In fact, although technological 'risk' affects countries in different ways depending on the nature of their engagement with change, it remains a universal consideration and a crucial factor in ensuring the appropriateness of new technology, to any setting.

Although in-depth discussions about health risks and the contribution of developing country perspectives are beyond the scope of this paper, it is clear that a number of issues remain unresolved and require greater consideration that incorporates truly global perspectives.

The Potential Nature of Developing Country Engagement with Nanotechnology

The nature of nanotechnology's global impact will largely depend on the answers to five, key questions surrounding nanotechnology innovation: who? what? when? where? and why? Developing countries will experience differing forms of engagement with nanotechnology but can we comment on any overall impacts? Will nanotechnology, as Daar suggests, be "a profitable industry for countries in the South[h]" [61]? Or will it "exploit the South" [Shiva cited in 6] and threaten developing country markets in primary production areas such as cotton, rubber and minerals [8]?

Will developing countries play the role of the 'manufacturing-base' for nanotechnology innovation, as suggested by Whittingham and Bateman's 2003 'cost-benefit analysis of moving nanotechnology R&D and manufacturing to Eastern European and developing countries' [62]? Already, Malaysia and South Africa have been highlighted as countries with comparative advantage in manufacturing for nanotechnology [32, 63].

Which Countries will Manufacture and which Will become Nanotechnology Importers

Perhaps the nature of developing country engagement with nanotechnology is believed as largely given? Salvarezza argues that an identification of Northern-based nanotechnology applications for the developing world predisposes participants to a scenario where "developing countries appear as passive actors… turning them into NT [nanotechnology] importers", widening economic and technological dependence [36].

Yet others point to the effective development of biotechnology R&D in China, India, Brazil and Cuba, suggesting an early developing country engagement with nanotechnology innovation could reduce the possibility of these countries being net importers of the technology [25, 64]. Given that domestic innovation and technological advance have been identified as the most important mechanism for the ability of countries to improve economically and ultimately close the rich-poor divide [65], nanotechnology has been promoted by a recent UNESCO report as important to developing country innovation [3].

[g] Considering their well-known toxicological studies on nanoparticles within fish, Dupont is a notable exception.

[h] In this paper, the term: 'South' or 'Southern' is used to refer to developing countries, whilst the term: 'North' or 'Northern' is used to refer to developed countries.

Developing Countries Active in Nanotechnology Development

With this in mind, a 2003 report by the University of Toronto Joint Centre for Bioethics claimed a number of developing countries are exhibiting a "surprising amount of nanotechnology activity" [1]. The study noted that China, India and South Korea had established national activities in nanotechnology; Thailand, The Philippines, South Africa, Brazil and Chile had some form of government support and national funding programs were being developed; whilst Mexico and Argentina had some form of organised nanotechnology activity but no specific government funding [1]. Some see nanotechnology enabling developing countries "to 'leap frog' their way to leadership" [66], with the Indian government looking to use nanotechnology to 'catch up' in global economic terms [67, 68].

Patent Applications as an Indicator of Nanotechnology Activity

However, with patents known to be a useful indicator of "technology development" [69], an assessment of 2003 figures from the U.S. Patent and Trademark Office (USPTO) highlighted the commanding lead held by the U.S. in nanoscale science and engineering patenting, with 42% of the overall share. Germany followed with 15.3%, and Japan was placed 3rd, with 12.6% [69]. Fast growth was said to be occurring in South Korea, the Netherlands, Ireland and China. A report later that year claimed China was ranked 3rd in general nanotechnology patents behind the U.S. and Japan [70].

Furthermore, of all the U.S. patent applications in nanotechnology, 90% are held by the private sector, with the remainder split amongst the public sector (roughly 7% from universities and 3% from government agencies and collaborative research centres) [71]. In recent times, companies such as '3M', 'IBM' and 'Hewlett Packard' are allocating approximately one-third of their respective R&D budgets to nanotechnology [72]. Canadian-based nanotechnology start-up, 'C Sixty Inc', has, as its core assets, numerous patents concerning fullerenes and drug delivery. As their CEO stated, "if people want to get in this game they have to deal with us" [Sagman, cited in 73]. These figures and comments raise the concern that innovation will be tied up by the private sector of the North, with broad-sweeping patents limiting the development of new technologies and increasing global science's ties to market demands [24].

A further example of market pressures was witnessed with the 2004 'Nanowater' conference, held in North America. Following the claim by researchers at Oklahoma State University in the U.S. that they could utilise the ability of zinc oxide nanoparticles to remove arsenic from water [74], preliminary conference material presented Bangladesh as an example in which nanotechnology could address the very serious problem of arsenic levels and potable water. Furthermore, the conference aimed "to focus the attention of the nanotechnology community on the potential of technology to change the world for good" [75]. However, the conference did not involve any developing country in its proceedings, and developing country issues were not directly addressed[i].

Already, civil society organisations from South Africa, Ghana, Kenya, Zimbabwe, Mali, Tanzania, Ethiopia and Benin have signed the 'Cape Town Declaration', calling for global participation in decisions about nanotechnology [76], highlighting fear that certain groups will be poorly represented in relevant discussions. The issue of participation is not limited to country participation. For nanotechnology to make a significant contribution to sustainable development within developing countries, a much greater interplay amongst business, academic, donor, non-governmental and governmental sectors is required [4].

Conclusions

Scientific developments and increasing international attention have promoted our ability to work with and understand the nanoscale. Nanotechnology provides a new focus for research through its aim to manufacture from the 'bottom-up' rather than from the 'top down'. It also demands an unprecedented collaborative and integrated approach to science and technology.

---

[i] See www.nanowater.com for a full list of speakers and conference agenda.

In the interest of dialogue, it is important that papers concerning nanotechnology and developing countries distinguish the kind of nanotechnology being discussed.

Like many past technologies, nanotechnology could be both relevant and appropriate to sustainable development practices in developing countries. In an area such as tuberculosis and rural health, nanotechnology has the potential to empower a local response to challenges such as the diagnosis and treatment of infectious disease. However, there is also a danger in viewing nanotechnology as a 'solution' to developing country challenges. In some cases its application may undermine alternative, more appropriate approaches to dealing with the problems at hand. Throughout nanotechnology's ongoing evaluation process, both risk assessment and the global contextualisation of nanotechnology's promises must be recognised as universal requirements in order for debates to progress on mutual ground.

However, with relatively little research commenting on global nanotechnology developments, the true picture, with respect to developing country engagement, remains unclear. A subsequent paper, published in this journal, will seek to clarify: which countries are engaging with nanotechnology R&D; the general focus of such research; who controls research in an area such as healthcare; the orientation of health-related research; and the levels of participation in international nanotechnology policy dialogue.

References

1. Court E., Daar A. S., Martin E., Acharya T. and Singer P. A., 2004, "Will Prince Charles Et Al Diminish the Opportunities of Developing Countries in Nanotechnology?" Accessed on: February 2004, 2004. Available: http://www.nanotechweb.org/articles/society/3/1/1/1.
2. ETC Group, "The Big Down: From Genomes To Atoms", ETC Group, Winnipeg, 2003.
3. Juma C. and Yee-Chong L., 2005, "Innovation: Applying Knowledge in Development". Accessed on: January 27, 2005. Available: http://bcsia.ksg.harvard.edu/BCSIA_content_stage/documents/TF-Advance2.pdf.
4. Barker T. *et al.*, 2005, "Nanotechnology and the Poor: Opportunities and Risks". Accessed on: January 26, 2005. Available: http://nanotech.dialoguebydesign.net/rp/NanoandPoor2.pdf.
5. Choi K., "Ethical Issues Of Nanotechnology Development in the Asia-Pacific Region", Regional Meeting on Ethics of Science and Technology, UNESCO Regional Unit for Social and Human Sciences in Asia and Pacific, Bangkok, pp. 327-76, 2003.
6. The Ecologist, "Promising the World, or Costing the Earth?" The Ecologist, vol. 33, no. 4, pp. 28-39, 2003.
7. ETC Group, 2004, "26 Governments Tiptoe toward Global Nano Governance: Grey Governance". Accessed on: September 27, 2004. Available: http://www.etcgroup.org/article.asp?newsid=466.
8. Shanahan M., 2004, "Nanotech 'threatens markets for poor nations' goods'". Accessed on: February 2, 2005. Available: http://www.scidev.net/News/index.cfm?fuseaction=readNews&item...
9. Invernizzi N. and Foladori G., 2005, "Nanotechnology as a solution to the problems of developing countries?" Accessed on: June 17, 2005. Available: http://cspo.org/ourlibrary/documents/NanoSolut.pdf.
10. Salamanca-Buentello F. *et al.*, "Nanotechnology and the Developing World", PLoS Medicine, 2 (4), pp. 300-03, 2005.
11. Bruntland G. (Ed.), *Our common future: The World Commission on Environment and Development*, Oxford, Oxford University Press, Oxford, 1987.
12. World Health Organisation, "The World Health Report, 1997: Conquering suffering, enriching humanity", World Health Organisation, Geneva, 1997.
13. LaVan D. A. and Langer R., Implications of Nanotechnology in the Pharmaceutics and Medical Fields in *Societal Implications of Nanoscience and Nanotechnology: NSET Workshop Report, edited workshop report,*, Roco, M. C. and Bainbridge, W. S. (Eds), National Science Foundation, Arlington, Virginia. pp. 79-83, 2001.
14. Nanoscale Science and Engineering Subcommittee, 2000, "Nanotechnology Definition". Accessed on: September 5, 2003. Available: http://www.nano.gov/omb_nifty50.htm.
15. Drexler K. E., *Engines of Creation: The Coming Era of Nanotechnology*, Doubleday, New York 1986.
16. ETC Group, "Nanotech Un-gooed! Is the Grey/Green Goo Brouhaha the Industry's Second Blunder?" Communiqué, (80) 2003.
17. Morrison S., (date unknown), "The Emerging Nanotech Industry; Lessons from Biotech Experience". Accessed on: December 9, 2003. Available: http://www.nanobioconvergence.org/files/sMorrison.pdf.
18. Harper T., "What is Nanotechnology?" Nanotechnology, 14 (1), p. introduction, 2003.
19. Merkle R., "It's a small, small, small, small world", MIT Technology Review, 100 (Feb/March), pp. 25-32, 1997.
20. Railey C. J., 2004, "Fourth Asan-HMI symposium highlights nanotechnology". Accessed on: September 9, 2004. Available: http://hmiworld.org/hmi/past_issues/Sept_Oct_2004/feature_nano.html.
21. Munroe P., 2003, "Nano, Nanotechnology (Or Nanoscience, or Nanomaterials) at UNSW". Accessed on: November 11, 2004. Available: http://www.science.unsw.edu.au/research/nanotalk_science2.pdf.
22. Bachmann G., "IPTS-ESTO Techno-Economic Analysis Report 1999-2000", Joint Research Centre, European Commission, Spain, 2000.
23. Roco M. C., "International Strategy for Nanotechnology Research and Development", Journal of Nanoparticle Research, 3 (5-6), pp. 353-60, 2001.
24. Mooney P., "The ETC Century Erosion, Technological Transformation and Corporate Concentration in the 21st Century", Development Dialogue, 1999 (1-2), pp. 1-128, 1999.

25. South African Nanotechnology Initiative, “South African Nanotechnology Strategy Volume 1 Draft 1.4”, South African Nanotechnology Initiative, Pretoria, 2003.
26. Brown M. M., Foreword in *Human Development Report: Making new technologies work for human development*, United Nations Development Programme (Ed.), Oxford University Press, New York 2001.
27. Scott A., 2003, "Nanotechnology and Nanoscience". Accessed on: February 17, 2004. Available: http://www.nanotec.org.uk/evidence/77aAndrewScott.htm.
28. The Royal Society and Royal Academy of Engineering, “Nanoscience and Nanotechnologies: Opportunities and Uncertainties”, The Royal Society and Royal Academy of Engineering, London, 2004.
29. Dayrit F. M. and Enriquez E. P., Nanotechnology Issues for Developing Economies (revised) (essay), Philippines, 2001.
30. National Science Foundation, Sri Lanka, "Cutting-edge technology and developing countries", Techwatch Lanka, vol. 2, no. 2, p. 1, 2002.
31. Tegart G., “Nanotechnology The Technology for the 21st Century”, APEC Center for Technology Foresight, Bangkok, 2001.
32. South African Nanotechnology Initiative, “National Nanotechnology Strategy: Nanowonders - Endless Possibilities, Volume 1, Draft 1.5”, South African Nanotechnology Initiative and the Department of Science and Technology, Pretoria, 2003.
33. Scott J., 2002, "New Technologies 'Central to Sustainable Development'". Accessed on: September 1, 2004. Available: http://www.scidev.net/News/index.cfm?fuseaction=readnews&itemid=163&language=1.
34. UNCTAD, 2004, "Interactive Dialogue on Harnessing Emerging Technologies to Meet the Millennium Development Goals". Accessed on: September 3, 2004. Available: http://stdev.unctad.org/unsystem/emerging.htm.
35. Harper T., 2003, "Nanotechnology in Kabul? Taking the First Steps". Accessed on: October 10, 2003. Available: http://www.nanotechweb.org/articles/column/2/8/2/1.
36. Salvarezza R. C., "Why Is Nanotechnology Important For Developing Countries?" Third Session of the World Commission on the Ethics of Scientific Knowledge and Technology, UNESCO, Rio De Janeiro, pp. 133-36, 2003.
37. Mahajan R., 2005, "North South Dialogue on Nanotechnology: Challenges and Opportunities". Accessed on: April 1, 2005. Available: http://www.ics.trieste.it/Documents/Downloads/df2682.pdf.
38. WHO Global Tuberculosis Program, “Anti-tuberculosis drug resistance in the world: third global report”, World Health Organisation, Geneva, 2004.
39. Council for Scientific and Industrial Research South Africa, 2005, "New nanodrug carriers to target TB sufferers". Accessed on. Available: http://www.csir.co.za/plsql/ptl0002/PTL0002_PGE128_NEWSLETTER?PUBLICATION_NO=1910024.
40. The Special Programme for Research and Training in Tropical Diseases, “Executive Summary of Meeting Report "Diagnosis of Tuberculosis: Countdown to New Tools" Geneva, Switzerland, 29-30 June 2000”, UNDP/WORLD BANK/WHO, Geneva, 2000.
41. World Health Organisation, 2005, "Global tuberculosis control: surveillance, planning, financing". Accessed on: May 20, 2005. Available: http://www.who.int/tb/publications/global_report/2005/pdf/India.pdf.
42. The Press Trust of India, 2003, "In The News - TB News". Accessed on: March 10, 2004. Available: http://www.stoptb.org/material/news/press/pti_030416.htm.
43. The Times of India, 2004, "CSIO Develops Nanotechnology for TB Diagnostic Kit". Accessed on: February 21, 2004. Available: http://www1.timesofindia.indiatimes.com/articleshow/401636.cms.
44. U.S. Department of Energy, Office of Science, 2003, "Faster Test for Tuberculosis". Accessed on: December 20, 2003. Available: http://www.doemedicalsciences.org/abt/projects/tbtest.shtml.
45. Walsh M., 2004, "Nanoscale Particle Systems Suitable for New Microdevices and Bio-Diagnostics". Accessed on: November 16, 2004. Available: http://www.rmit.edu.au/browse/Our%20Organisation%2FResearch%2FVRII%2FInformation%20and%20Communication%20Technology%20(ICT)%20VRII/#5.
46. Khuller G. K. and Pandey R., "Sustained Release Drug Delivery Systems in Management of Tuberculosis", Indian J Chest Dis Allied Sci, 45, pp. 229-30, 2003.
47. Liu Y., Tsapis N. and Edwards D. A., “Investigating Sustained-release Nanoparticles for Pulmonary Drug Delivery”, Harvard University, Cambridge, Massachusetts, 2003.
48. Maruping P., 2005, "South African Nanotechnology Strategy". Accessed on: March 12, 2005. Available: http://www.ics.trieste.it/Documents/Downloads/df2680.pdf.
49. Khuller G. K., "Subcutaneous nanoparticle-based antitubercular chemotherapy in experimental model", Journal of Antimicrobial Chemotherapy, 54 (1), pp. 266-68, 2004.
50. Biosante Pharmaceuticals, 2002, "Biosante Pharmaceuticals Announces Positive Trial Results for Tuberculosis Vaccine". Accessed on: April 7, 2004. Available: http://www.biosantepharma.com/newshtml/020515pr.html.
51. Starpharma Ltd, 2004, "Product Focus: Vivagel... Applying Dendrimer Nanotechnology to Prevent HIV and Other STDs". Accessed on: September 20, 2004. Available: http://www.starpharma.com/PDFs/Product%20Focus%20-%20VivaGel.pdf.
52. Fifis T. *et al.*, "Size-Dependent Immunogenicity: Therapeutic and Protective Properties of Nano-Vaccines Against Tumors", The Journal of Immunology, 173 (5), pp. 3148-54, 2004.
53. de Almeida A. O., 2003, "Responses to questionnaire on nanotechnology; Brazil". Accessed on: September 22, 2004. Available: http://www.nanotec.org.uk/evidence/brazil.htm.
54. Njemanze P. C., *Receptor mediated nanoscale copolymer assemblies for diagnostic imaging and therapeutic management of hyperlipidemia and infectious diseases* In esp@cenet, European Patent Office, 2005.
55. 55. Rensselaer Polytechnic Institute, 2004, "Efficient Filters Produced from Carbon Nanotubes". Accessed on: April 10, 2005. Available: http://www.physorg.com/news803.html.
56. Haum R., Petschow U. and Steinfeldt M., “Nanotechnology and Regulation within the framework of the Precautionary Principle. Final Report for ITRE Committeee of the European Parliament”, Institut für ökologische Wirtschaftsforschung (IÖW) gGmbH, Berlin, 2004.

57. Huaizhi Z. and Yuantao N., "China's ancient gold drugs", Gold Bulletin, 34 (1), pp. 24-29, 2001.
58. Hoet P. H. M., Nemmar A. and Nemery B., "Health Impact of Nanomaterials?" Nature Biotechnology, 22 (1), p. 19, 2004.
59. Wilsdon J. and Willis R., 2004, "Will nanotechnology go the GM way?" Accessed on: September 15, 2004. Available: http://www.thehindu.com/thehindu/seta/2004/09/09/stories/2004090900031400.htm.
60. Moore R., 2004, "Medical nanotechnology: a new challenge for standardization?" Accessed on: March 23, 2005. Available: http://www.iso.org/iso/en/domains/WSC-MedTech/pdf/presentations/18%20Richard%20Moore.pdf.
61. Leahy S., 2004, "'Nano Divide' No Small Matter". Accessed on: February 27, 2004. Available: http://www.ipsnews.net/interna.asp?idnews=22193.
62. Whittingham J. and Bateman A., 2003 "???" Accessed on: May 25, 2004. Available: www.world-nano.com/WNEC_London.pdf.
63. Hamdan H., 2003, "Nanotech Initiative in Malaysia (Part 1)". Accessed on: May 30, 2004. Available: http://www.nanoworld.jp/apnw/articles/library/pdf/17.pdf.
64. Mnyusiwalla A., Daar A. S. and Singer P. A., "'Mind the gap': science and ethics in nanotechnology", Nanotechnology, 14, pp. R9-R13, 2003.
65. McArthur J. W. and Sachs J. D., "The Growth Competitiveness Index: Measuring Technological Advancement and the Stages of Development", 2001.
66. Henderson R., 2002, "The Next Technological Revolution: Predicting the Technical Future and its Impacts on Firms, Organisations and Ourselves". Accessed on. Available: mitsloan.mit.edu/50th/tech.pdf.
67. Patil R., 2005, "If Tomorrow Comes". Accessed on: February 3, 2005. Available: http://www.indianexpress.com/full_story.php?content_id=62323.
68. Kalam A. A. P. J., 2004, "Our Future Lies in Nanotechnology". Accessed on: September 1, 2004. Available: Our Future Lies in Nanotechnology.
69. Huang Z., Chen H., Chen Z.-K. and Roco M. C., "International nanotechnology development in 2003: Country, institution, and technology field analysis based on USPTO patent database", Journal of Nanoparticle Research, 6, pp. 325-54, 2004.
70. Xinhua News Agency, 2003, "China's nanotechnology patent applications rank third in the world". Accessed on: January 27, 2004. Available: http://www.chinadaily.com.cn/en/doc/2003-10/03/content_269182.htm.
71. Heines H., 2003, "Patent Trends in Nanotechnology". Accessed on: December 3, 2003. Available: http://library.lp.findlaw.com/articles/file/00315/009269/title/Subject/topic/Intellectual%20Property_Actions%20and%20Proceedings/filename/intellectualproperty_2_4490.
72. Nordan M. M. *et al.*, "The Nanotech Report 2004™", Lux Research Inc., New York, 2004.
73. 73. ETC Group, 2002, "Patenting Elements of Nature". Accessed on: August 1, 2004. Available: http://www.etcgroup.org/documents/nanopatentsgeno.rtf.pdf.
74. Kalaugher L., 2004, "Nanoparticles Clean Up Arsenic". Accessed on: December 23, 2004. Available: http://www.nanotechweb.org/articles/news/3/5/15/1.
75. Cientifica Ltd, 2004, "Nanowater: Technology Helping the Environment". Accessed on: September 1, 2004. Available: http://www.nanowater.org.
76. Biowatch South Africa, 2002, "The Cape Town Declaration". Accessed on: September 29, 2004. Available: http://www.biowatch.org.za/ctdecform.htm.

Contact Details

Donald C. Maclurcan

Institute for Nanoscale Technology, University of Technology, Sydney
PO Box 123, Broadway
Sydney, 2006
Australia

E-mail: Donald.C.Maclurcan@uts.edu.au