Nanotechnology Policy: An Analysis of Transnational Governance Issues Facing the United States and China

Evan S. Michelson

Research Associate
Project on Emerging Nanotechnologies
Woodrow Wilson International Center for Scholars

National Science Foundation Young Scholar

October 2006

I. Introduction

Nanotechnology, the emerging field of manipulating matter at the nanoscale, is expected to become a key, transformative technology of the 21st century. Researchers are exploring ways to see and build at this small scale by re-engineering familiar substances like carbon, silver, and gold to create new materials with novel properties and functions. Not surprisingly, nanotechnology applications in areas as diverse as healthcare, energy storage, agriculture, water purification, and security are envisioned, and these anticipated developments have encouraged significant investments in nanotechnology research and development (R&D) worldwide, with the United States National Science Foundation (NSF) estimating that by 2015 nanotechnology will have a $1 trillion impact on the global economy.[1]

Nanotechnology has also emerged as a central science and technology policy topic in both the United States and China, and, accordingly, it is expected to pose a number of significant transnational governance challenges and opportunities for a wide range of stakeholders—including government, industry, and the public—in the near future. These broad ranging issues will have to be addressed in a collaborative and proactive manner in order to make certain that nanotechnology is developed in a safe, sustainable, and responsible manner. By analyzing a number of these transnational governance matters, this article will sketch out some of the multiple and complex factors and needs involved in establishing appropriate management strategies for nanotechnology in particular and for new and emerging technologies in general. In particular, five points will be addressed, including:

- Prioritization of nanotechnology research and development;
- Need for internationally coordinated risk research strategies;
- Need for effective oversight mechanisms;
- Rapid commercialization of consumer products; and
- Low levels of public awareness and trust in government.

Overall, this assessment will illuminate that a host of new occasions for collaboration and topics for deliberation will emerge as developments in nanotechnology move from the fringes to the center of society. Policymakers in both the United States and China must begin to focus on questions as diverse as how does nanotechnology factor into their nation's long-term future, who does the public trust to handle and manage the potential risks posed by nanotechnology, how should information related to nanotechnology be communicated and made available to the public, what mechanisms work best to regulate nanotechnology-based products, and how can potential chronic risks and consequences be systematically analyzed and addressed by government agencies. Clearly, in order to adequately tackle these interrelated subjects, an open dialogue is needed that can produce imaginative approaches to the governance of nanotechnology.

II. Prioritization of Nanotechnology Research and Development

As noted earlier, both the United States and China have been at the forefront of this trend in adopting nanotechnology as a main component of their strategic policy plans for future developments in science and technology. This was most recently enunciated in the February 2006 report from the United States Office of Science and Technology Policy, *American Competitiveness Initiative: Leading the World in Innovation*, which articulates that in order to succeed on the global stage, the United States must develop a necessary suite of technology platforms that includes "world-class capability and capacity in nanofabrication and nanomanufacturing that will help transform current laboratory science into a broad range of new industrial applications for virtually every sector of commerce."[2] China has taken a similar approach in its recently released *National Medium- and Long-term Science and Technology Development Plan (2006-2020)*, where nanotechnology is identified as a "priority mission area"[3] and as a key frontier technology over the next 15 years. For China, the overall aim is to use nanotechnology R&D as way toward reaching its eventual goal of setting "the proportion of research and development expenditures at 2.5 percent of the gross domestic product."[4]

More specifically, nanotechnology research priorities in both countries seem to be progressing along similar lines of inquiry, with two of their similar aims being (1) the societal benefit of nanotechnology and (2) better understanding the intersections and inter-relationships between nanotechnology and other strands of technology. With respect to these points, the *Guide to Programs* from the National Natural Science Foundation of China (NSFC) highlights "basic research on nano science and technology" as one of two new Major Research Plans for 2006, the broader aim of which is to "solve nano science issues that are of great importance in the progress of science and technology of China" and use nanotechnology commercialization toward "the development of the national economy."[5] NSFC also highlights a range of interdisciplinary scientific goals, from studying "nano materials design and preparation" to "new theory and new methods for nano system construction," with particular and preferential emphasis on funding areas in "nano electronics and nano electronics devices" and "nanobiology."[6]

In the United States, *The National Nanotechnology Initiative Strategic Plan* offers a vision in which nanotechnology becomes socially relevant by facilitating the "transfer of new technologies into products for economic growth, jobs, and other public benefit" and simultaneously developing "educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology."[7] Moreover, the National Nanotechnology Initiative's (NNI) *Supplement to the President's FY 2006 Budget* makes a point to emphasize "interdisciplinary research at the intersections of nanotechnology, biotechnology, and information technology," noting that a variety of federal agencies "will seek new opportunities for synergistic research" at the interfaces of these technologies.[8]

Both countries are also ensuring that substantial funding and financial investments are directed toward nanotechnology.[9] In the United States, the 2007 budget request allocates over $1.2 billion under the NNI, bringing total federal government spending in nanotechnology to over $6.5 billion since the NNI's inception in 2001.[10] While it is difficult to accurately compare funding levels between the United States and China, Lux Research estimates that the Chinese government spent $250 million on nanotechnology in 2005—a figure that, when adjusted for purchasing-power parity, places China's nanotechnology investment second only to the United States.[11] Similarly, local, state, and regional governments in the United States and China are investing in nanotechnology, with United States hotspots including California,[12] Texas, Virginia, Massachusetts, and New York, and with Chinese hotspots including Beijing, Hong Kong, and Shanghai, the latter of which established the Shanghai Nanotechnology Promotion Center in 2001.[13]

Such investments by both the United States and China have begun to translate into world-class research results in terms of published papers, paper citations, and patents. In particular, while United States leadership in the field has been consistent throughout previous decades, China's transformation into an emerging nanotechnology power is more recent. In their article on the subject, Liu and Zhang[14] highlight various supporting points for this claim, noting that a 2001 Asia-Pacific Economic Cooperation (APEC) report indicated that China followed only the United States and Japan in terms of the number of nanotechnology papers published in that year. They also note that studies undertaken by the Scientific Citation Index indicate that during the 1992-2002 timeframe, the top four institutions with the most citations of published nanotechnology papers include the University of California-Berkeley, IBM, the Massachusetts Institute of Technology (MIT), all in the United States, and the Chinese Academy of Sciences. Finally, they cite an estimate that from 2000 to 2002, China ranked third behind only the United States and Japan in terms of the number of nanotechnology patents held. More recent studies analyzing publication outputs from 1999 to 2004 have shown similar results, with China maintaining its third place position with roughly 7,000 papers.[15] Taken together, these data points indicate, as Andrew Batson of *The Wall Street Journal* notes, that "China is rapidly catching up to the United States in nanotechnology" and that this "success could hold lessons for U.S. policy makers seeking to maintain a competitive edge in scientific research."[16]

III. Need for Internationally Coordinated Risk Research Strategies

However, even given the currently high level of funding and planning for nanotechnology, there are no currently internationally coordinated risk research strategies designed to investigate and manage the potential environmental, health, and safety (EH&S) risks posed by nanotechnology. In the absence of such risk management strategies, it will be difficult for the science community to determine the potential downsides of the technology and reach conclusions about where the greatest risks may lie. Over the past 15 years, scientific data on the EH&S impacts of nanostructured materials have been growing slowly. However, research results on the implications of engineered nanomaterials have been readily available only for the past five years.[17,18] Though much more work needs to be done in this area, a number of research studies have begun to raise more questions than answers about potential hazards—hazards that could impact populations in developed countries, like the United States, and in more developing countries, like China.

In short, published research has demonstrated that because of their unique size, shape, and chemistry, some engineered nanomaterials can behave differently in the body and in the environment than more conventional materials. Moreover, these nanomaterials may present health risks that are not captured within established risk assessment paradigms. For example, in testimony before the United States Senate Committee on Commerce, Science, and Transportation, J. Clarence Davies, Senior Advisor to the Project on Emerging Nanotechnologies, highlighted concerns raised by some of these early-stage risk research results, including:

- Nanometer-scale particles behave differently from larger sized particles in the lungs, possibly moving to other organs in the body;
- The surface of some nanostructured particles is associated with toxicity, rather than the more usually measured mass concentration; and
- Conventional toxicity tests do not seem to work well with some nanomaterials, such as carbon nanotubes.[19]

In order to learn more about the novel effects of nanomaterials on human health and the environment, it is clear that more research will be needed. To this end, both the U.S. and Chinese governments have begun to heed the call for more risk-related research. The United States government estimates that is spent $38.5 million on EH&S research in 2005, and there are signs that it is looking to increase this level of investment in the future. More specifically, the Environmental Protection Agency (EPA) plans to nearly double its implications research budget in fiscal year 2007 and has put together a *Nanotechnology White Paper* that identifies a set of key questions that the agency should address as nanotechnology R&D progresses.[20]

Though China has trailed the United States in terms of focusing its resources on investigating EH&S issues, it began to study the potential toxicological effects of nanotechnology by establishing a Nanosafety Lab under the auspices of the National Center for Nanosciences & Nanotechnology (NCNN), located in Beijing. It is estimated that the Chinese government will spend nearly $5 million on such EH&S research from 2004-2010, an amount of money that, once again, may rather substantial in terms of purchasing-parity power.[21] Moreover, as demonstrated by hosting the International Symposium on Nanotechnology in Environmental Protection and Pollution in Hong Kong in June 2006[22], it is becoming evident that China is looking to play an increasingly substantial role in advancing nanotechnology EH&S research in the future.

Nevertheless, focusing solely on such investments does not address the issue of whether government agencies in the United States or China possess sufficient human and strategic resource capacities to adequately address EH&S concerns raised by academic researchers and various non-governmental organizations (NGOs). For instance, the Project on Emerging Nanotechnologies (at the Woodrow Wilson Center in Washington, DC) has assembled the only publicly available inventory of ongoing EH&S research projects, indicating that there may be significant gaps—such as a lack of research on the effects of nanomaterials in the gastrointestinal track and few resources devoted to life-cycle analysis and end-of-life issues—that have yet to be systematically addressed in the present risk research portfolio. Moreover, Andrew Maynard, in his report *Nanotechnology: A Research Strategy for Addressing Risk*, has argued that a new, internationally coordinated, comprehensive framework for methodically exploring nanotechnology's possible risks is needed both to address such research gaps and to ensure that the limited financial resources devoted to these issues are leveraged in a strategically planned portfolio of short, medium, and long-term projects.[23]

IV. Need for Effective Oversight Mechanisms

In the United States, there is currently a concern amongst a wide range of NGOs—including Environmental Defense, Natural Resources Defense Council, Friends of the Earth, International Center for Technology Assessment, and ETC Group—that, so far, the United States government's overall regulatory approach to nanotechnology been ad hoc and incremental, with little attention focused on how nanomaterials are *already* being used in consumer and industrial products. As will be discussed in greater depth in following sections, one difficulty is that there are many kinds of nanotechnology-based consumer products, such as cosmetics and dietary supplements, that are entering the market in areas where there is less government oversight. This point is emphasized in a recent Project on Emerging Nanotechnologies submission to the Food and Drug Administration (FDA), where it is argued that the government's approach to nanotechnology oversight has been limited by a number of factors, including:

- Insufficient consideration of how nanotechnology systematically impacts a range of agencies, including EPA, FDA, the United States Department of Agriculture (USDA), and the Consumer Product Safety Commission (CPSC);
- A focus on single statutes, such as EPA's Toxic Substances Control Act (TSCA), rather than on an integrated, multi-statute approach; and
- A focus on regulating products more than on the facilities where production occurs and processes are used.[24]

Concerns about regulatory jurisdiction and responsibility are particularly pressing because as new nanotechnology based products are commercialized, it is evident that similar kinds of nanomaterials will be employed in a variety of ways, requiring substantial coordination of oversight on the part of government agencies tasked with ensuring the health and safety of the public and the environment. Similar problems related to regulatory overlap and confusion could occur in China as well, especially if the government is focused primarily on funding and supporting R&D related to nanotechnology's applications and places less importance on managing the possible implications of nanotechnology. Only a concerted effort between different parts of the regulatory system—at local, state, national, and international levels—within both countries will be able to overcome these governance challenges and ensure that consistent regulatory regimes and safety standards are developed worldwide. One possible solution, as Davies argues in his report *Managing the Effects of Nanotechnology*, is that a new law or set of laws may be required to address the current oversight system's deficiencies.[25]

However, the difficulties associated with managing nanotechnology's potential risks are not restricted to a simple lack of regulation. For instance, many countries may be forced to rely on potentially outdated legislative and regulatory regimes that are not equipped to address nanotechnology's potentially revolutionary impacts. Additionally, in more developing countries like China, government agencies may still be grappling with the policy implications of past and on-going technological revolutions, particularly those associated in biotechnology, genomics, and information technology. In short, because the bureaucracies of these nations may already be stretched thin to deal with a range of science and technology challenges, they could be hard-pressed to oversee the responsible development of nanotechnologies in a proactive manner.

Recently, there have been attempts to address this lack of effective oversight mechanisms through advancing nationally and internationally coordinated efforts in this area. On a national level, a voluntary information reporting program for engineered nanomaterials has been developed by the Department for Environment, Food, and Rural Affairs (Defra) in the United Kingdom[26] and a voluntary stewardship program is being planned by the EPA in the United States for the middle of 2007.[27] Additionally, in China, Chunli Bai, Executive Vice President of the Chinese Academy of Sciences, notes that China has established a "national technical committee on nanotechnology standardization," charged with "strengthening the inspection of research facilities in public institutions and with meeting the needs of manufacturers in China."[28]

On an international level, the Organization for Economic Co-operation and Development (OECD) recently established a Working Party on Manufactured Nanomaterials to discuss issues surrounding the environmental, health, and safety implications of nanotechnology, particularly in the area of chemicals and toxic substances.[29] More specifically, both the Meridian Institute's Global Dialogue on Nanotechnology and the Poor (GDNP)[30] and the United Nations Industrial Development Organization (UNIDO) North-South Dialogue are explicit attempts to include developing countries in the global discussion of managing nanotechnology's risks and benefits.[31] The International Risk Government Council (IRGC) is also in the process of developing an oversight and risk management framework for nanotechnology through an elaborate consultation process that includes input from a range of stakeholders in multiple countries.[32] Finally, attempts to collect and detail "best practices" for worker protection and standardize nanotechnology nomenclature and definitions are occurring on an international basis, with efforts underway through the International Council on Nanotechnology (ICON)[33], the International Standards Organization (ISO)[34] and ASTM International.[35]

While representatives from the United States and China are actively participating in a number of these oversight endeavors, it is of great importance that the national governments of these countries remain committed to structuring their own, internal regulatory system in harmony with such international efforts. Doing so will allow for the establishment of a globally level playing field for private firms involved in commercializing nanotechnology research and products and, in turn, ensure that they do not encourage irresponsible corporate actors, thereby damaging the industry as a whole.

V. Rapid Commercialization of Consumer Products

Concerns about the shortage of toxicity data and lack of effective oversight mechanisms are all the more pressing given the rapid commercialization of nanotechnology in consumer and industrial products. In March 2006, the Project on Emerging Nanotechnologies released an online inventory that now contains over 300 manufacturer-identified, nanotechnology-based consumer products that are available on the market from over 15 countries, including the United States, China, and many European and Asian nations.[36] This number far exceeds the previous United States government accepted estimate of approximately 80 consumer products on the market, and, according to EmTech Research, there are an additional 600 nano-based electronics components, raw materials, drug delivery technologies, and research, process, and software tools, the latter of which is used to manipulate nanomaterials and fabricate at the nanoscale.[37] However, since the searches conducted by the Project on Emerging Nanotechnologies were largely limited to English-language sources, it is expected that there may be many more nanotechnology consumer products on the market throughout Asia—particularly in China—that have yet to be accounted for, thereby further amplifying the extent of nanotechnology's commercialization.

The fact that this first wave of consumer products is already available on store shelves may be surprising, especially since only a few years ago, there were a mere handful of nanotechnology companies and virtually no nanotechnology-based products being made and marketed to consumers. However, it has been estimated that over the past few years, 1,200 nanotechnology-related start-up companies have emerged, many of which are based in the United States.[38] In China, Liu and Zhang have estimated that "the number of registered companies with a nanotechnology focus reached 800 by [the] end of 2003, resulting in a total of 10 billion RMB ($1.2 billion) in registered capital."[39] Along these lines, Lux Research has estimated that more than $32 billion in products incorporating nanotechnology were sold worldwide in 2005, a number that is only expected to grow as more research is funded, more patent applications are filed, and more companies are formed.[40]

A search of the Nanotechnology Consumer Products Inventory can provide numerous examples of products already on the market, ranging from cosmetics and personal care items to dietary supplements and cooking supplies and from automotive and home improvement products to advanced coatings for glass surfaces and stain-resistant clothing. In many cases, these products are available for purchase in local stores or over the Internet. However, in the event of a mishap or accident, it is not clear whether product safety laws in the United States, China, or elsewhere are sufficiently robust to protect the public's health or safety. While such a situation may sound far-fetched, there has already been the case of Magic Nano, a bath and tile treatment product sold in Germany that was recalled after causing significant health problems, with over 100 people affected with respiratory problems and six hospitalized with pulmonary edema.[41] Although the Federal Institute for Risk Assessment (BfR) in Berlin concluded that the product did not actually contain nanomaterials and that nanotechnology was not the cause of the reported health problems,[42] the Magic Nano incident illuminated other concerns—such as a lack of transparency in terms of timely disclosure of information and misuse of a third-party verification seal purporting to ensure that the product was independently tested—that could affect regulatory agencies in the United States or China if a similar situation were to occur in either country.

It is also anticipated that there are many more nanotechnology consumer products on the market that are either not labeled or described as containing nanomaterials or that make claims about nanotechnology that may not be accurate. While there are currently no stipulated requirements to either label a product that contains nanomaterials or independently verify claims associated with nanotechnology, such products are beginning to garner increased attention and scrutiny from consumer and environmental groups around the world, including:

- In the United States and Australia, environmental groups have called for an interim recall of sunscreens that contain nanosize zinc oxide and titanium dioxide until more adequate safety tests are undertaken;[43]
- In Korea, a consumer group has tested a washing machine claiming to use silver nanomaterials as anti-bacterial agents and has concluded that there was little to no improvement in performance over similar products that did not contain nanotechnology;[44] and
- In Germany, a media outlet has investigated claims made by a dietary supplement manufacturer that purports to use nanotechnology to make vitamins more easily available to the body.[45]

Such instances illustrate a growing policy challenge: the mislabeling or over-promising associated with nanotechnology consumer products may have the potential to negatively impact the public's perception of the field in general, well before potentially more significant and transformative applications, in applications such as healthcare and energy, can be developed. Bai indicates that this tension between nanotechnology hype and reality is beginning to emerge in China. He notes that while there are rising numbers of legitimate and beneficial applications of nanotechnology being made available through commercialization—such as the use of photocatalytic nanoparticles in a self-cleaning glass coating on the new National Opera House in Beijing—some firms are taking advantage of nanotechnology's growing popularity as a buzzword and are "finding that they can raise their profits simply by adding the label 'nano' to their products."[46] It is imperative that such misunderstandings are avoided in the United States and China so that a consumer backlash does not occur and that the nascent nanotechnology industry has an opportunity to develop more fully over the long term.

VI. Low Levels of Public Awareness and Trust in Government

Given the increasing availability of nanotechnology consumer products worldwide, it might be expected that the public would be rather familiar with the term nanotechnology and understand what it means. However, in the midst of this accelerating commercialization, publics throughout the world remain largely in the dark about nanotechnology. A major study, funded by the NSF and conducted in 2004 by Michael Cobb and Jane Macoubrie at North Carolina State University (NCSU), found that 80 percent to 85 percent of the American public has heard "little" or "nothing" about nanotechnology.[47] Similarly, a nationally representative, August 2006 poll of over 1,000 adults, commissioned by the Project on Emerging Nanotechnologies and conducted by Peter D. Hart Research Associates, found similar results, with about 70 percent of the public reporting that they have heard little to nothing at all about nanotechnology.[48] These findings are consistent with similar polls that have been commissioned in Europe and Canada, and it is possible that these trends associated with low levels of public of understanding of nanotechnology would also occur in China as well.[49,50] Bai alludes to this potential lack of awareness about nanotechnology by the Chinese public by noting that, "the scientific community need[s] to better inform and educate the public about the transformations this new era is likely to bring."[51] Without such public engagement efforts, citizens and consumers may form negative public perceptions that could hinder nanotechnology's development far into the future.

What is even more striking about the public perception studies mentioned above is that, in addition to a lack of basic awareness about nanotechnology, publics in many countries have little to no trust in their government's ability to manage the potential risks posed by nanotechnology. Such findings were illustrated in Jane Macourbrie's 2005 study, *Informed Public Perceptions of Nanotechnology and Trust in Government*, which found that even when participants were provided with information about the roles and responsibilities of government regulatory agencies, such as EPA, FDA, USDA, and CPSC, no more than 50 percent of respondents believed that they could trust these agencies to regulate nanotechnology-based products accurately and successfully.[52] Along these lines, the Hart Research data also indicates that while public approval ratings for various agencies has declined in recent years, there tends to be more confidence in these bodies than in business or industry to management technological risk. It is evident that if concerns about government's and industry's ability to manage nanotechnology's risks are *not* addressed, these negative public perceptions may continue to grow and, once again, potentially hamper nanotechnology's development due to consumer backlash or over-regulation.

To address this current situation—in which a largely uninformed or under-informed public has little to no trust in the government's ability to manage nanotechnology's risks—Macoubrie has found that respondents have centered on a desire for "increased safety tests *before* products go to market" and "supplying more information to support informed consumer choices."[53] Additionally, by focusing on the issue of monitoring the safety and effectiveness of cosmetics and over-the-counter drugs—two product categories that have seen relatively high amounts of nanotechnology commercialization in recent years—Hart Research found that the public feels that federal government agencies, along with universities and independent researchers, should work together and be involved in such oversight. Such proactive and integrated policy steps would not only help build awareness, trust, and citizen engagement around nanotechnology, but they would signal to citizens and consumers that their concerns are being heard and addressed. As of now, there is still time to inform public perceptions about nanotechnology and to make clear that nanotechnology is being developed in a way that citizens—as well as the insurance industry, corporate investors, NGOs, and regulatory officials—can trust. However, with the production of nanomaterials ramping up in the United States and China, and with more and more nanotechnology-based products pouring into the marketplace, this window is closing fast. Without such assurances, publics around the world will increasingly have to make sense of competing claims, complex science, and emerging risk research with little or no preparation or support.

Conversely, worries are already being voiced that public input will be used simply as a "tokenistic add-on" rather than as a valuable policy-making tool.[54] To avoid this undesired outcome in both the United States and China, coordinated nanotechnology education and engagement programs will be needed, supported by both government and industry. These efforts will have to be structured to reach a wide range of consumers, many of which may have little to no scientific or technical training. Establishing such a widespread public engagement campaign will require the use of both traditional media outlets—such as print, radio, television, and film—alongside more non-traditional media outlets—such as the Internet, weblogs, games, and podcasts—to capture the attention of a diverse range of individuals in various age, gender, and socioeconomic categories. As researchers from the United Kingdom argue, a new approach to public engagement is required, one that can "build in more rich, more complex and nuanced, and more mature models of publics into 'upstream' modes of practice."[55]

VII. Conclusion

It would be unfortunate if government agencies, in the United States, China, and elsewhere, squandered this unique opportunity to help direct nanotechnology along a responsible path, improve public confidence in the private and public sectors, and increase the capacity of public institutions to deal with the risks and challenges posed by cutting-edge innovation. The thrust of the arguments presented above is clear: nanotechnology is here and that we, as a global society, are not yet fully prepared to deal with it. The encouraging point is that a collective response—with the United States and China as central players—to the aforementioned challenges can still be formulated.

Much remains to be done, however, and it cannot be assumed that addressing such transnational nanotechnology governance questions will be easy. In fact, the opposite is true, since nanotechnology's development is expected to test the notion that innovation progresses in a linear and continuous fashion. Due to the rapid pace of R&D, discoveries in nanotechnology could come in great, discontinuous leaps and, in turn, revolutionize society's knowledge and understanding of the physical world in rather short amounts of time. In turn, these technological leaps could come to strain the ability of public institutions and public infrastructure—especially in China, which will likely face an additional host of resource, population, and energy challenges in the coming decades—to respond in an effective and timely manner.

For this reason, authors such as Michael R. Taylor, in his report *Regulating the Products of Nanotechnology: Does FDA Have the Tools It Needs?*, argue that the eventual success or failure at overseeing nanotechnology will be based on the devotion of various kinds of resources—human, strategic, regulatory, and financial—to the issue. While Taylor makes this argument in the context of one agency (the FDA) in one country (the United States), the point and ensuing recommendations are applicable both for other agencies and for other countries. Such resources will become even more crucial and important as broader, cross-cutting policy issues—such as trade, intellectual property protection, and the open sharing of scientific and technical information—begin to emerge with respect to nanotechnology. While specific analyses of nanotechnology's interface with these larger areas of concern is beginning to occur,[56] it is clear that the expected innovative jumps increasingly associated with nanotechnology's future could make today's issues related to product risk management and internationally coordinated oversight strategies appear trivial by comparison. Such would be the case in the wake of a high-profile mishap or perceived accident, as occurred with respect to other areas of technological development, such as chemicals (Bhopal) and nuclear power (Three Mile Island).

In the meantime, in order to make certain that nanotechnology does not "fall through the cracks" of the oversight system, a dual risk management approach must be adopted, one that supports research into nanotechnology's greatest near-term risks and benefits while, simultaneously, looks prospectively to any transformations or shifts in the technology's development that that may occur in the future. Though nanotechnology R&D is currently an effort based largely upon chemistry and materials science, the high priority placed on it in both the United States and China will quickly lead nanotechnology to interact with other fields of study—such as biotechnology, information technology, and cognitive science—that could further quicken the pace of both basic research and product development. This convergence of technologies could cause an even greater set of governance challenges than nanotechnology alone, further impacting institutions tasked with the responsibility of managing new technological advances. Since developments in nanotechnology are at the forefront of these potentially radical innovations, the United States and China have the chance to think and operate proactively, and work collectively, toward getting the governance system "right" from the start.

Acknowledgements

Portions of this paper are based upon: Evan Michelson and David Rejeski, "Falling Through the Cracks: Public Perception, Risk, and the Oversight of Emerging Nanotechnologies," *IEEE International Symposium on Technology and Society Conference Proceedings*, New York, NY: IEEE, June 2006; "Nanotechnology & Developing Countries: Issues for Global Governance," Washington, DC: Project on Emerging Nanotechnologies, April 2006; "FDA-Regulated Products Containing Nanotechnology Materials [Docket No. 2006N-0107]," Washington, DC: Project on Emerging Nanotechnologies, July 2006. The author would also like to thank Kent York for his research assistance.

Endnotes

[1] Roco, M.C., R.S. Williams, and P. Alivisatos. *Nanotechnology Research Directions: IWGN Workshop Report*. Berlin, Germany: Springer, 2000.

[2] *American Competitiveness Initiative: Leading the World in Innovation*. Washington, DC: Domestic Policy Council, Office of Science and Technology Policy, February 2006, ACI report, p. 12. Available at http://www.whitehouse.gov/stateoftheunion/2006/aci/aci06-booklet.pdf, accessed November 9, 2006.

[3] Suttmeier, Richard P., Cong Cao, and Denis Fred Simon. "'Knowledge Innovation' and the Chinese Academy of Sciences," *Science*, 7 April 2006, 312(5770): 58-59. Available at http://www.sciencemag.org/cgi/content/full/312/5770/58, Accessed November 9, 2006.

[4] Feng, Chen. "China Issues Guidelines on Sci-Tech Development Program," Beijing, China: Xinhua, February 9, 2006. Available at http://www.gov.cn/english/2006-02/09/content_184426.htm, accessed November 9, 2006.

[5] *Guide to Programs: Fiscal Year 2006*. Beijing, China: National Natural Science Foundation of China, 2006, p. 127.

[6] *Guide to Programs: Fiscal Year 2006*, p. 127-128.

[7] *The National Nanotechnology Initiative Strategic Plan*. Washington, DC: Office of Science and Technology Policy, December 2004, p. 21. Available at www.nano.gov/NNI_Strategic_Plan_2004.pdf, accessed November 9, 2006.

[8] *The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry, Supplement to President's FY 2006 Budget*. Washington, DC: Office of Science and Technology Policy, March 2005, p. 40. Available at http://www.nano.gov/NNI_06Budget.pdf, accessed November 9, 2006.

[9] Schulte, Jurgen, ed. *Nanotechnology: Global Strategies, Industry Trends, and Applications*. West Sussex, England: John Wiley & Sons, Ltd., 2005.

[10] "Funding." Washington, DC: National Nanotechnology Initiative. Available at http://www.nano.gov/html/about/funding.html, accessed August 11, 2006.

[11] "The United States, Japan, South Korea, and Germany Dominate in Nanotechnology Today—But Taiwan and China Are Rising," New York, NY: Lux Research, Inc., November 3, 2005. Available at www.luxresearchinc.com/press/RELEASE_Nation2.pdf, accessed August 11, 2006.

[12] *Thinking Big About Thinking Small: An Action Agenda for California*. Sacramento, CA: Blue Ribbon Task Force on Nanotechnology, December 19, 2005. Available at http://blueribbonnano.org/, accessed August 11, 2006.

[13] Blanpied, William A. "Research and Development in China: An Overview." Arlington, VA: National Center for Technology and Law, George Mason University, January 31, 2006.

[14] Liu, Lerwen, and Zhang, Li-De. "Nanotechnology in China—Now and in the Future," *Nanotechnology Law & Business*, November/December 2005, 2(4): 397-403.

[15] Hullmann, Angela. "Who Is Winning the Global Nanorace?" *Nature Nanotechnology*, November 2006, 1: 81-83.

[16] Batson, Andrew. "China's Nanotechnology Gains Have U.S. Looking Over Its Shoulder," *The Wall Street Journal*, September 27, 2006.

[17] Oberdörster, Günter, Eva Oberdörster, and Jan Oberdörster. "Nanotoxicology: An Emerging Discipline Evolving for Studies of Ultrafine Particles," *Environmental Health Perspectives*, July 2005, 113(7): 823-839.

[18] Maynard, Andrew, and Eileen Kuempel. "Airborne Nanostructured Particles and Occupational Health," *Journal of Nanoparticle Research*, 2005, 7: 587-614.

[19] Davies, J. Clarence. Testimony at "Developments in Nanotechnlogy" hearing. Washington, DC: United States Senate Committee on Commerce, Science & Transportation, February 15, 2006. Available at http://commerce.senate.gov/public/index.cfm?FuseAction=Hearings.Testimony&Hearing_ID=1713&Witness_ID=6264, accessed August 11, 2006.

[20] *External Review Draft Nanotechnology White Paper*. Washington, DC: United States Environmental Protection Agency, December 2, 2005. Available at http://www.epa.gov/osa/nanotech.htm, accessed August 11, 2006.

[21] Zhao, Yuliang. "Safety Assessment of Nanomaterials in China." Presented at International Dialogue on Responsible Research and Development of Nanotechnology, Tokyo, Japan, June 26-30, 2006.

[22] "International Symposium on Nanotechnology in Environmental Protection and Pollution 2006."Hong Kong, China: The Hong Kong University of Science & Technology. Available at http://www.apnf.org/ocs/themes/ISNEPP06/front1.htm, accessed November 9, 2006.

[23] Maynard, Andrew. *Nanotechnology: A Strategy for Addressing Risk*. Washington, DC: Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars, July 2006.

[24] "FDA-Regulated Products Containing Nanotechnology Materials [Docket No. 2006N-0107]." Comments submitted to the FDA Nanotechnology Public Meeting, Washington, DC: Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars, July 19, 2006.

[25] Davies, J. Clarence. *Managing the Risks of Nanotechnology*. Washington, DC: Project on Emerging Nanotechnologies, Woodrow International Center for Scholars, January 2006.

[26] *UK Voluntary Reporting Scheme for Engineered Nanoscale Materials*. London, United Kingdom: Department for Environment, Food, and Rural Affairs, September 2006. Available at www.defra.gov.uk/ENVIRONMENT/nanotech/policy/pdf/vrs-nanoscale.pdf, accessed November 9, 2006.

[27] Rizzuto, Pat. "EPA Plans to Launch Stewardship Program For Nanomaterials by Middle of Next Year," *Chemical Regulation Reporter*, 23 October 2006, 30(24): 1089.

[28] Bai, Chunli. "Ascent of Nanoscience in China," *Science*, 1 July 2005, 309: 61-63, p. 63.

[29] "Safety of Manufactured Nanomaterials." Paris, France: Organization for Economic Co-operation and Development, September 20, 2006. Available at http://www.oecd.org/department/0,2688,en_2649_37015404_1_1_1_1_1,00.html, accessed November 9, 2006.

[30] *Nanotechnology and the Poor: Closing the Gaps Within and Between Sectors of Society*. Washington, DC: Meridian Institute, January 2005. Available at http://www.meridian-nano.org/gdnp/NanoandPoor.pdf, accessed November 9, 2006.

[31] Shand, Hope and Wetter, Kathy Jo. "Shrinking Science: An Introduction to Nanotechnology," *State of the World 2006: Special Focus: China and India*. Washington, DC: The WorldWatch Institute, January 2006.

[32] *White Paper on Nanotechnology Risk Governance*. Geneva, Switzerland: International Risk Governance Council, June 2006. Available at http://www.irgc.org/irgc/_b/contentFiles/IRGC_white_paper_2_PDF_final_version.pdf, accessed November 9, 2006.

[33] *Current Knowledge and Practices regarding Environmental Health and Safety in the Nanotechnology Workplace*. Houston, TX: International Council on Nanotechnology, Rice University, October 2006. Available at http://cohesion.rice.edu/CentersAndInst/ICON/emplibrary/Phase%20I%20Report_UCSB_ICON%20Final.pdf, accessed November 9, 2006.

[34] "ISO Launches Work on Nanotechnology Standards." Geneva, Switzerland: International Organization for Standards, November 16, 2005. Available at ISO http://www.iso.ch/iso/en/commcentre/pressreleases/archives/2005/Ref980.html, accessed November 9, 2006.

[35] "Committee E56 on Nanotechnology." West Conshohocken, PA: ASTM International. Available at http://www.astm.org/cgi-bin/SoftCart.exe/COMMIT/COMMITTEE/E56.htm?E+mystore, accessed November 9, 2006.
[36] "Nanotechnology Consumer Products Inventory." Washington, DC: Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars. Available at www.nanotechproject.org/consumerproducts, accessed August 11, 2006.
[37] *External Review Draft Nanotechnology White Paper.*
[38] Lane, Neil and Kalil, Thomas. "The National Nanotechnology Initiative: Present at the Creation," *Issues in Science and Technology*, Summer 2005, 21(4). Available at http://www.issues.org/21.4/lane.html, accessed August 11, 2006.
[39] Liu and Zhang, p. 399.
[40] "Nanotechnology in $32 Billion Worth of Products: Global Funding for Nanotech R&D Reaches $9.6 Billion." New York, NY: Lux Research, Inc., May 8, 2006. Available at www.luxresearchinc.com/press/RELEASE_TNR4.pdf, accessed August 11, 2006.
[41] Graber, David, and Pat Phibbs. "German Institute Working to Understand Why 'Magic Nano' Cleaner Caused Ailments," *Daily Environmental Report*, April 12, 2006.
[42] "Nano Particles Were Not the Cause of Health Problems Triggered by Sealing Sprays!" Berlin, Germany: Federal Institute for Risk Assessment, May 25, 2006. Available at http://www.bfr.bund.de/cms5w/sixcms/detail.php/7842, accessed June 20, 2006.
[43] "Legal Petition on FDA's Failure to Regulate Health Threats from Nanomaterials." Washington, DC: International Center for Technology Assessment, May 16, 2006. Available at http://www.icta.org/global/actions.cfm?page_id=15&section_title=Nanotechnology, accessed August 11, 2006.
[44] "Comparative Test of Drum-Type Washing Machines." Seoul, Korea: Korea Consumer Protection Board, November 18, 2005. Available at http://english.cpb.or.kr/user/bbs/code02_detail.php?av_jbno=2005111800005&av_pg=0&gubun=8101, accessed August 11, 2006.
[45] "Another Nano Consumer Product Gets Negative Attention in Germany." Nanowerk, August 8, 2006. Available at http://www.nanowerk.com/spotlight/spotid=726.php, accessed August 11, 2006.
[46] Bai, p. 63.
[47] Cobb, Michael D., and Jane Macoubrie. "Public Perceptions about Nanotechnology: Risk, Benefits and Trust," *Journal of Nanoparticle Research*, August 2004 6(4): 395-405.
[48] *Attitudes Toward Nanotechnology and Federal Regulatory Agencies: Report Findings*. Washington, DC: Peter D. Hart Research Associates, Inc., September 2006.
[49] *Nanotechnology: Views of the General Public*. London, United Kingdom: BMRB Social Research, January 2004, BMRB/45/1001-666. Available at http://www.nanotec.org.uk/Market%20Research.pdf, accessed June 21, 2006.
[50] Einsiedel, Edna. "In the Public Eye: The Early Landscape of Nanotechnology among Canadian and US Publics," *First Impressions: Understanding Public Views on Emerging Technologies.* Ottawa, Canada: Government of Canada, 2005: 99-117. Available at http://www.biostrategy.gc.ca/CMFiles/CBS_Report_FINAL_ENGLISH249SFD-9222005-5696.pdf, accessed June 21, 2006.
[51] Bai, p. 61.
[52] Macoubrie, Jane. *Informed Public Perceptions of Nanotechnology and Trust in Government*. Washington, DC: Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars, September 2005.
[53] Macoubrie, p. 15.
[54] Saleh, Anna. "Critics Say Nanotech Plan Sidelines Public," *ABC Science Online,* April 28, 2006. Available at http://www.abc.net.au/science/news/health/HealthRepublish_1625988.htm, accessed June 21, 2006.
[55] Grove-White, R., M.B. Kearnes, P. Macnaghten, P. Miller, J. Wilsdon, and B. Wynne. *Bio-to-Nano? Learning the Lessons, Interrogating the Comparison*. Lancaster, United Kingdom: Lancaster University and Demos, June 2004.

[56] Hermann, Kirk, Sean O'Neill, Blaine R. Turnacliff, Mark B. Wilbert, Ying Zhang, and Mark J. Graffagnini. "Protecting Nanotechnology Intellectual Property ('Nano-IP') in China," *Nanotechnology Law & Business* 2(1): 96-109.