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Health and Environmental Implications In Commercialization of Nanotechnology

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I. <u>Introduction</u>

Nanotechnology applications have positive as well as negative implications for health and the environment. This paper discusses both. Some of the societal benefits of nanotechnology were examined in my earlier presentation to this forum. Therefore the discussion of positive implications will be brief, allowing a closer focus upon societal concerns over possible health and environmental risks posed by present and potential commercial uses of this technology.

We will see that it is the special properties of nanoparticles that determine both benefits and risks.

We will distinguish between naturally occurring nanoparticles and engineered nanoparticles (ENP^s). Naturally occurring nanoscale materials and particles are ubiquitous, long found throughout the atmosphere, the oceans, and in groundwater. These particles (such as some volcanic dust, ocean spray, soot) have been present throughout history; human life evolved in their presence. (Wiesner et. al. 2009). The oceans hold the greatest reservoir. Nature has for eons used materials with nanoscale structures. To illustrate, a half billion years ago soft-bodied ocean organisms began to use minerals to grow shells that contain exquisite nanostructures such as abalone shells (Angela Belcher, January 2011). Health and environmental concerns center on engineered nanoparticles (ENP^s) rather than theses found in nature.

II**. Positive Implications**

We first consider the contributions that nanotechnology has made or promises to make to improve health and foster cleaner, healthier and more sustainable environment

In health, there are now abundant examples of biomedical advances flowing from innovations in nanotechnology that have had measurable impacts upon how well we live, and how long we live. These include various forms of inexpensive nanofilters to treat contaminated drinking water, devices that will help reduce child mortality rates in Africa, Asia and Latin America. Vertically aligned nanotubes may also be used in desalinization in regions lacking sufficient potable water. As noted in my earlier presentation, cancer diagnosis and treatment both have been enhanced by ingenious applications of nanotechnology. Tissue engineering, a result of the convergence of nanotech, biotech and infotech, is already improving and extending the lives of a growing number of patients with failing organs or damaged skin and bones.

The beneficial effects of nanotechnology on the environment and on energy availabilities and energy conservation are just beginning to become apparent. Nanowires are being developed that conduct electricity with minimal power loss due to resistance. This will not only conserve energy in itself, it will also allow stranded capacity in solar and wind energy to come onto the grid.

Scientists at UCLA expect that nano-methods may increase the efficiency of light bulbs to 55% of light generated from electrical energy versus only 20% from present-day light emitting photodiodes. In power generation, nanotechnology could one day make solar cells more efficient through use of nano-devices that mimic photosynthesis.

Nanotechnology is being deployed to deal with most some of the significant world concerns in energy and the environment. Specifically, an engineered nanoparticle may help enable environmentally sustainable extraction of the world's huge reservations of hydrocarbons previously locked up in inaccessible shale formations that are especially abundant in the U.S., China, Argentina, Boliva, Brazil, South Africa perhaps Siberia and others.

The successful development of horizontal drilling techniques, coupled with hydralic fracturing (fracking), has transformed previously uneconomic shale deposits into large hydrocarbon reserves. Wells are directionally drilled, and then fluids (water, sand and other proppants) are pressure pumped into tight shale formations fracturing them, thereby releasing the hydrocarbons, which then take them back to the surface.

However, significant environmental concerns have arisen over the implication of hydraulic fracturing for water availability and water purity.

In Pennsylvania, fracturing a horizontal well may require 4.5 million gallons of water, in Texas up to 6 million gallons. (By comparison, a typical golf course uses about 300,000 gallons of water per day). Oil wells in much of California are vertical and utilize far less water (less than 175,000 gallons, owing to special features of the state's geology and the presence of substantial water in California oil deposits. Generally, fracking wells costs about $6 million of which ¼ the cost is water.

In fracking, large amounts of the injected water is returned to the surface as produced water, which contains contaminants, and is therefore of environmental concern. This led France and some U.S. states such as Vermont and New Jersey to ban fracking. It has also caused the Federal Government to draft regulations that are expected next year to increase the cost of each oil well in the Eagleford shale (Texas) by about $240,000.

In response to these concerns, several new techniques have been developed to purify produced water and conserve water resources generally. One of the methods now in use is nano-enabled. A Texas firm has developed a nanoparticle called Ceralumoxane™ an organophopic ceramic membrane. The process promises to be much less expensive and much more favorable to the environment then traditional methods now commonly used to dispose of or purify produced water. Mobile units utilize the nanoparticle to rid produced water of contaminants.*

Another Texas firm has developed a manufactured nanoparticle to treat produced water for radioactive contamination, using graphene oxide. Both firms utilize technology developed at Rice.

Mobilization of nanotechnology for meeting the global challenge of clean water

*Treatments would cost less than $3.00 per bbl of output. The firm is Lance Energy Services. Containments removed include bacteria, viruses, any hydrocarbons in the water (as much as 2%) as well as additives such as proppants and surfactants. The process removes 100% of bacteria, 99% of organic content and 75% of iron content of produced water.

has gone well beyond the energy sector. Research at Rice University indicate that one property of nanoparticles, superparamagnetism, will allow the particles to temporarily form large agglomerates with contaminants. Then, the particles can be easily separated from the contaminants in a low magnetic field. When the external magnetic field is removed, the agglomeration process is reversed. This results in desegregation of contaminants, and also allows the nanoparticles to be reused.**

Moreover, researchers are discovering that nanotechnology can be easily and cheaply used in water monitoring, treatment and reuse systems. Examples include membrane filtration systems using nanotechnology. This type of system has become a core method of water treatment (Brame, Li and Alvarez 2011, and Qu, Brame, Li and Alvarez 2012).

Titanium dioxide, when hit by UV light is a bactericide. Other filters utilizing nanotubes remove bacteria such as E. Coli and some Staphylococcus, and can remove poliovirus from contaminated water. Nanotechnology can be deployed to target inorganic contaminants as well as bacteria. Other nanoparticles, such as one with the commercial name, "Nanorust" have been found to be efficient in removal of arsenic and heavy metals.*

**Qilin Li, Margaret Diamond, Mason Thomson, Michael Wong and Pedro Alvarez, "Nanotechnology One Answer to the Global Challenge of Clean Water."

*All of the applications cited in this paragraph and many others, are presented and discussed in two recent publications. See Brome, Li and Alvarez, "Nanotechnology and Water Treatment and Use: Opportunities and Challenges for Developing Countries' in Trends and Food Science and Technology, 2011, and Qu, Brame, Li and Alvarez, "Nanotechnology for Safe and Sustainable Water Supply in Accounts of Chem Research, 2011.

The convergence of nanotech and infotech has given risen to another wholly unforeseen environmental benefit: the beginnings of "additive" manufacturing, wherein 3-D printers build up solid objects of material, one small layer at a time, producing items ranging from cupcakes to hammers to clothing to skin.

This innovation promises to sharply reduce the use of materials in manufacturing processes, reducing the costs of transport, thereby reducing depletion of scarce natural resources. There are those who believe that additive manufacturing will lead to a third industrial revolution, and could even mean the end of economies of scale in production (<u>Economist</u>, April 21, 2012).

Even now, one American firm (3D Systems) can print, cheaply, a customized hammer, complete with handle and a metalized head. Some firms are also using 3D printers to make plastics, ceramics and rubber-like substances. Some researchers are <u>already</u> using 3D printers to produce living tissues, such as skin and muscles.

Finally, nanomaterials for environmental remediation and waste cleanup have been deployed successfully to remediate sites contaminated with both organic and nonorganic pollutants (EPA <u>White Paper</u>, Feb. 2007).

With those perspectives in mind, we may turn now to consideration of possible dark sides of nanotechnology.

III. Rational and Irrational Concerns

Richard Feynman, Nobel Laureate in physics in 1965, first alerted the wider world to the brighter side of the possibilities of nanoscale science and nanotechnology in his famous 1959 lecture, "There's Plenty of Room at the Bottom." Twenty years later, the Buckyball, Carbon 60, a previously unknown form of carbon was discovered at Rice University. That was followed in short order by the identification of other fullerenes and carbon nanotubes, and then by a rapidly growing number of scholarly publications in nanoscale science

Until about the year 2002, the tone of these publications was decidedly upbeat, as nanotech innovations were just beginning to be utilized in biomedicine, material science and other fields. But at about that time there began to appear scholarly and popular publications dealing with a darker side of nanotechnology. These dealt mainly with health implications of the possible toxicity of nanoparticles. In particular, authors utilizing zebra fish and rats as experimental subjects exposed to nanoparticles came to differing, or inconclusive, results on toxicity. The popular press at the time also helped foster the irrational fear that swarms of self-assembling robots could one day destroy humanity. Fortunately this view, based on junk science, is today little evident.

Rational concerns, however, are nevertheless widespread. The body politic as well as the general public in the U.S., Europe and Japan appears especially fearful over the possibility that certain engineered nanoparticles may be carcinogenic. These fears were reinforced by the results of two recent studies. One study was undertaken by the National Institute of Health Sciences in Japan. In this study the lung disease mesothelioma was induced in mice injected with carbon nanotubes. However, the significance of this study for human health is in doubt, since human exposure would be through inhalation, not injection. (Citation coming).

Another study, (the Poland Study) indicated that mice exposed to carbon nanotubes through inhalation and injection developed something closely resembling the early stages of mesothelioma. While care should be taken not to merely extrapolate rat pathology to humans, this study did, in a figurative sense, touch some exposed nerves about nanotech risks. Rational concerns center upon some of the health implications of the size, shape and surface characteristics of engineered nanomaterials such as the Buckyball or various forms of carbon nanotubes.

We have long known that commonplace natural nanoparticles such as those in soot and some fibers such as asbestos present health dangers. Only recently has it been widely recognized that many familiar materials already in commerce and trade have different properties when the materials are engineered down to the nanoscale (100 nanometers, or one ten-millionth of a meter) and that not all these properties are benign. One extreme example is aluminum. When this ordinary metal is taken down to the nanometer scale, it explodes spontaneously.

Another example: Silver in bulk form is no threat to bacteria. Silver ions, flowing from silver nanoparticles are deadly to some harmful bacteria. However, these properties can be two edged swords. Silver nanoparticles in clothing may possibly enter waste water by the washing out of garments. And, at least at high doses, they have been shown to cause neurotoxicity in rats ("Engineered Nanoparticles in Consumer Products," in Environmental Health Perspective, March 2011). This is by way of saying that the size and shape of engineered nanoparticles are properties that provide large potential social and economic benefit from nanotechnology, but also account for many of the risks it presents.

The very small size of engineered (or naturally occurring) nanoparticles means that they possess a large surface area per unit of mass because of their small size. They are practically "all" surface with little mass (Mark Wiesner, et. al. 2009). These properties allow certain nanoparticles to skirt the body's natural defense mechanisms designed to prevent intrusion of harmful foreign substances. Routes of invasion that may be taken by nanoparticles include inhalation into the lungs, where small particles are otherwise filtered out of inhaled air by cilia and macrophages. Another route is the skin, ordinarily protected first by the dead cells of the epidermis and then by the underlying derma containing protective sweat and sebum secretions (Royal Academy of Engineering, 2005). A third route is the gut, where the epithelium prevents absorption of large molecules such as proteins, so that they can later be broken down into useful nutrients. Some potentially toxic nanoparticles may evade these defenses owing to their extremely small size.

There are other critical factors determining the toxicity of nanoparticles, including their shape and length. Nanofibers are nano materials with a length at least three times their diameter. In the lung nanofibers up to 3 nanometers in length are more readily exhaled, but nanofibers of length greater than 15 nm are too long to be easily removed by the previously mentioned macrophages. So they may lodge deeply in the lung, often leading to scarring and lung cancer (Royal Academy of Engineering, 2005).

Solubility is another factor affecting potential toxicity of inhalation of nanofibers. Those that dissolve easily into shorter particles are readily removed by macrophages and are therefore not accumulated in the body (Royal Academy of Engineering, 2004).

A final critical factor in nanoparticle toxicity is of course the size of the dose, or extent of exposure. While toxicity of nanoparticles stems largely from small size, their shape and (for fibers) solubility, the degree of toxicity is generally dependent upon inhalation, ingestion or absorption of a very large number of nanoparticles over time.

IV. <u>**Public and Private Sector Responses to Societal Concerns over Nanotechnology**</u>

Early into the twentieth century, concerns over health and environmental implications of nanoparticles in commercial and medical applications was widespread enough in Britain to cause the government to commission a blue-ribbon study on aspects of applications of the technology that could positively or negatively impact society, especially health and the environment. The Royal Academy of Engineering study, published in 2005 remains, in my view, the single best place to begin any serious consideration of the risks posed by nanotechnological applications. The study, is entitled *Nanoscience and Nanotechnologies: Opportunities and Uncertainties*. Chapter 5 focuses on possible adverse health, environmental and safety impacts. At least one issue seems to have been settled by that report. Nanoparticles incorporated in fixed form into products such as coatings and films, building materials, or aircraft are not a source of primary concern. Rather, the principal worries about health and environmental issues involved in uses of nanotechnology are focused upon non-fixed, inhalable and ingestible nanoparticles not incorporated into products, such as those in that can be easily inhaled or ingested.

While the British Royal Academy report stands out among the early responses to health and environmental risks posed by nanotechnology, over the past decade pre-existing as well as new public and private entities have devised new standards and regulations to cope with these risks. Pre-existing entities such as the U.S. EPA and FDA, and in Europe the E.U. and OECD have fashioned new policies and programs designed to promote and assure safe and sustainable utilization of nanotechnology and other new entities have arisen for this purpose. What follows is a sampling from a growing universe of entities and agencies in the U.S., Europe, Japan and China. We first consider responses from the private sector.

A) Private Sector

Early on in the 21st Century, the private sector began to adapt mechanisms developed in other fields to help assure safety of use of nanomaterials in commercial applications. One example: a new U.K. exchange for trade in nanomaterials. The exchange is intended to do for ENPs what London Metal Exchange has done for Industrial Metals: to help coordinate the on-going exploitation of these metals (European Business Review, July 21,2011).The exchange, called INSCX, is a self-regulating organization that provides an electronic trading platform for accredited, inspected and validated engineered nanomaterials, for physical delivery. In turn INSCX relies on other new enterprises such as Assured Nano to certify the handling and transportation of traded ENPs, in order that purchasers may be assured of safety, and so that appropriate insurances can be secured. With these features, the exchange has become the worldwide focal point for growing commercialization of engineered nanomaterials.

A second example of innovative responses to emerging issues in commercialization of nanotechnology is NanoBank.org, created in 2005. This is a public digital library that matches and links individuals and organization within and across subfields in nanotechnology across the world.

Another private entity, nanoTox, has evolved in the U.S. to assist business and government entities in assessing and reducing the risks in synthesis, handling, recycling and disposal of emerging nanomaterials. The firm offers nanoparticle characterization and toxicology testing. It also identifies hazards, advises on exposure containment and control, occupational hygiene, and related services. It also offers toxicology services needed for product development, and ongoing monitoring to confirm exposure conditions.

The U.S. private sector has mounted a number of other nanotechnology entities concerned both with pursuit of profit as well as nanosafety. By 2006 several trade associations, including the NanoBusiness Alliance had emerged. The American Chemistry Council is fostering research in the environmental health and safety of nanomaterials. Finally, industry has formed the Nanoparticle Occupational Safety and Health Consortium to help assure on-the-job safety in using aerosol nanoparticles, and to develop workplace exposure monitoring. A complete listing of these private sector organizations may be found at www.nanovip.com.

Within the past decade a number of academic institutions in the U.S. and Europe have also developed new centers, institutes and programs to evaluate both benefits and risks in utilization of nanotechnology and to promote nanosafety. Among those are:

1. The Houston-based alliance for nanohealth was established in 2004. This organization utilizes expertise on nanotechnology and biotechnology developed in the Texas Medical Center. This center is comprised of eight institutions, incorporating two medical schools (Baylor Medicine and UT Health Science), two universities (Rice and Houston), and several major hospitals (Methodist, Texas Children's).

   The Alliance was the first collaborative research undertaking to deploy nanotechnology to bridge gaps between medicine, biology materials, science, computer science and public policy. The Alliance draws on multi- and interdisciplinary strengths of its eight members. The purpose of the Alliance is to develop nanotechnology based solutions to unresolved problems in medicine, through new clinical approaches (http://www.nanohealthalliance.org).

2. The International Alliance on Nano EHS Harmonization is a global collaborative of scientists from the U.S., Europe and Japan. This partnership focuses upon environmental and health safety in applications of nanotechnology.

3. The European Centre for Environment and Human Health, universities in Cornwall in 2011 was established to conduct research on the interactions between

health and the environment generally, and on the effects of nanotechnology in particular.

4. The Center for BIONANO Interactions, University College Dublin was created in 2009 to allow better understanding of the interaction of nanoparticles with living systems.

B) Public Sector

Public sector agencies were not long in responding to emerging health and safety issues in nanotechnology. Prominent among these in the U.S. include the EPA (Environmental Protection Agency) and FDA (Food and Drug Administration) and most recently OSHA (Occupational Health and Safety Administration).

The Environmental Protection Agency (EPA) derives it regulatory authority on nanomaterials from the U.S. Clean Water Act, the Clean Air Act and other legislation. The EPA has taken up to now, a cautious, measured approach toward evaluation of potential health and environmental risks in adoption of nanotechnology. The EPA has stressed research, particularly on nanosafety, and is a very active participant in the National Nanotechnology Initiative, discussed below. The EPA approach is exemplified in the EPA's 2007 *Nanotechnology White Paper*.

By 2007, the EPA had identified over 300 consumer products and 600 raw materials and intermediate components and capital equipment items in the U.S. market, including not only carbon-based materials (fullerenes and nanotubes) but metal-based substances, such as quantum dots, nanosilver and metal oxides such as that for titanium (see Table 1 for examples).

The FDA has focused primarily not upon the adoption of a regulatory definition of nanotechnology, but rather has taken what it calls a "broadly inclusive approach" to considering whether FDA- regulated products (especially drugs) contain nanomaterials or involve nanotechnology, and especially how those materials are absorbed through inhalation, ingestion or other routes of exposure.

The FDA has thus far been reluctant to require that products containing nanomaterials be reported or labeled. Manufacturers are not required to report the use of engineered nanomaterials, except for single and multi-walled carbon nanotubes. Manufacturers are also not required to label products that contain engineered nanoparticles (ENP^s^). Therefore, at least in the U.S., consumers are largely unaware about their intake of these particles (Environmental Health Perspectives, March 2011).

Table 1 presents examples of products that utilize nanotechnology and nanomaterials.

Table 1
Illustrative Examples of Products that Use Nanotechnology and Nanomaterials (Especially carbon, copper, silver, titanium, zinc nanoparticles).

Health and Fitness	Electronics and Computers	Home and Garden	Food and Beverage	Other
Wound dressing	Computer displays	Paint	Non-stick coatings for pans	Anti-corrosive Coatings
Baseball Bats	Games	Antimicrobial refrigerators	Antimicrobials	Anti-barnacle
Pregnancy tests				Lubricants
Golf clubs	Computer hardware	Stain-resistant cushions		Anti-oxidants
Tennis rackets	Touch screens			Odor-resistant garments
Dietary supplements	Ultrafast transistors			Composites for auto bodies
Skis				De-icing (Aircraft wings etc.)
Bowling balls				Strain paint
Antibacterial socks				Self cleaning glass in buildings
Diagnostic chip				
Waste and stain resistant pants				
Shampoos and cosmetics				
Engineered human tissue				
Air filters				
Extreme wear makeup				
Sunscreens				

Sources: EPA Technology White Paper 2007, and "Engineered Nanoparticles in Consumer Products" Environmental Health Perspectives, March 2011, and Hobson, 20XX).

*Table 2 shows a partial list of FDA approved nano pharmaceuticals***.**

TABLE 2

Table 2.

EXAMPLES OF FDA APPROVED
NANO PHARMACEUTICALS

- **Liposomals**
  - Liposomal Amphoterecin B – Mycotic infection – 1990
  - Liposomal Daunorubicin (DaunoXome) – Kaposi's Sarcoma – 1995
  - Cytarabine liposome injection (Depocyt) – Lymphomatous meningitis – 2007
  - Collagran MMP inhibiting – wound dressings – 2006
  - Stealth liposome doxorubicin – Kaposi's Sarcoma – 1995
  - Doxil/Caelyx – Ovarian/Breast cancer – 1999
  - Verteporfin liposomal (Visudyne) – Wet macular degeneration – 2000
- **Solid Polymeric**
  - Carmustine (Gliadel) – Glioblastoma multiform – 1996
  - Abraxane (nanoparticles of paclitaxel-taxol) – Mammary cancer (metastitic) – 2005
  - TrivCor (nanoparticulate form) – high cholesterol treatment – 2004
- **PEGylated**
  - PEG-succinimidyl-L-asparaginase – Lymphloblastic leukemia – 1994
  - PEG-adenosine deaminase – Serius immunodeficiency – 1990
  - PEG-interferon -2a (Pegasyls) – Hepatitis C – 2002
- **Nanocrystal**
  - Emend nanocrystals – Nausea prevention in chemotherapy – 2003
  - Rapamune nanocrystal – Rejection prevention – 2000

Source: Hobson, 2012

National Nanotechnology Initiative (NNI)

The undertaking that perhaps best depicts the breadth of U.S. public sector responses to potentials and perils of nanotechnology has been the National Nanotechnology Initiative (NNI). Building upon the 1999 groundwork provided by the NSF, the NNI was established in 2001 to coordinate nanotechnology research and development across all federal agencies including the aforementioned EPA and FDA, as well as 23 other federal agencies. Other than the EPA and FDA, the agencies most relevant for the health and environmental implications of nanotechnology are OSHA, the NSF, the NIH, and the National Institute for Occupational Health and Safety. Of particular relevance is the NNI's working group focused upon Nanotechnology Environmental Health Implications (NEHI).

The NNI is an ideal umbrella entity for mounting further ambitious new initiatives to improve both understanding of, and remediation of, toxicological risks of nanotechnology. One example: an untold wealth of valuable information is contained in eight separate data bases on toxicity. Integration of these databases utilizing informatics, among other tools, is needed to make the data more accessible and more visible. This will enable agencies and enterprises to build predictive algorithms on toxic effects including those from nanomaterials, on a real-time basis.

OHSHA

The Federal Office of Occupational Health, Safety and Health Administration (OSHA) has developed major regulatory criteria relevant to nanosafety. The first is the “Employees General Duty Clause.” This obliges employers to protect workers for serious recognized workplace hazards (such as indoor air quality, occupational exposures, etc.). The employer must also take whatever hazard abatement actions feasible.

The second criteria is called “Right to Know.” This requires employers to transmit to all employees information on all hazards, to label containers, compile material safety data sheets and train employees on protective methods.

The final OSHA criteria is labeled “Global Harmonization.” This regulation establishes a four year transition and compliance schedule, to begin November 30, 2013 and end June 1, 2016. This regulation applies first, on November 30, 2013, to all firms using, handling or storing chemicals. All employees must be trained in safe handling. Then, on June 2015, the training requirements extend to chemical manufacturers and importers. By 2016 all firms will be required to update employees on any newly identified health hazards.

NIOSH

The National Institute for Occupational Safety and Health is a department of Health and Human Services agency that provides occupational limits to exposure to carbon nanotubes and nanofibers. NIOSH also issue periodic reports on health and environmental research on toxic reactions of animal subjects exposed to nanomaterials (http://www.cdc.gov/niosh).

EUROPEAN AND CHINESE GOVERNMENTAL AND MULTI-LATERAL ENTITIES: AGENCIES CONCERNED WITH NANOSAFETY.

Amidst rapidly growing activity in nanotechnology in Germany, U.K., France, Switzerland and China, governmental entities have established a range of new policies and programs to regulate use of engineered nanomaterials. For example, the French government recently issued, unilaterally, a new set of regulations and fines governing the import of nanomaterials in amounts of 100 grams or more. These regulations will apply in 2013, along with a system of fines.

The EU established in 2009 new regulations pertaining to nanomaterials, called Registration, Evaluation, Authorization and Restrictions of Chemicals (REACH). Importers and manufacturers subject to REACH are required to register nanomaterials.

They are also required to provide information on toxicity and potential hazards, for all imports or production of one metric ton per year (in contrast to the more severe limit of 100 grams established in France).

The OECD has also been active in alerting its 20-odd member nations to the implications of manufactured nanomaterials. In 2006 it established a subsidiary body to work on the environmental health and safety implications of nanomaterials.

Chinese investment in nanotechnology has increased sharply in recent years, to the point that total patent applications in the field now surpass the U.S. and Europe. (Nature News and Comments Online, September 19, 2012). Up until now only 3% of this investment has been in safety studies, relative to about 6% of nanotech funding in the U.S.. While 80% of the Chinese public (in a sample of 6,000 respondents) professed no concern over health and environmental concerns in nanotech, researchers have begun to take notice of safety issues, The first step in coping with the issue has been the formation of a multilateral project called “Nanosolutions.” This U.S. $17 million undertaking will involve researchers from China, Europe, the U.S. and Brazil. The aim, is to develop a nano-safety classification system based on toxicity studies and bioinformatics data.

V. **<u>Conclusion</u>**

Thus far we have the benefit of barely one decade of appreciable commercialization of nanotechnology. Research on the potential effects of nanoparticles on health and the environment also began only a few years ago. Hundreds of research projects sponsored or mounted by the aforementioned private and public entities in the U.S., Europe, Japan and China are still in progress. Doubtless the yield from this work will vastly shrink the zones of ignorance still surrounding much of the toxic health effects and any noxious environmental effects of using nanoparticles.

There are engineered nanoparticles that display little or no toxic properties, and there are nanoparticles that may prove quite harmful, certainly to laboratory animals if not humans. NIOSH notes that one of its key toxicological findings of pulmonary exposure to carbon nanotubes is as follows.

"Rapid and persistent fibrosis in mice, some cardiovascular dysfunction, and (for multi-walled carbon nanotubes) inflammation of the brain" (Laura Hodson, NIOSH, "Engineering Case Studies," <u>Nanomaterials</u>, 2010).

Nevertheless, according to one leader in the field of nanohealth, "insufficient toxicological evidence exists at this time to recommend the specific medical screening of workers potentially exposed to engineered nanoparticles" (Hobson, Pharmaceutical Formulation and Quality, Feb./March 2010).

Still, all agencies involved in research and regulation of nanotech application stress that care must be taken to avoid inhalation, ingestion and absorption of nanoparticles.

In the meantime conclusive, undisputed evidence of toxicity of nanoparticles has been scant, and the relative paucity of studies on environmental or ecological impacts has shed little light on this set of issues.

Nevertheless, notable concerns over these issues has already entered the marketplace, as evidenced by the reluctance of some insurers to cover nanotech risks. For example, the insurance company Continental Western recently announced that its future policies will include a nanotechnology exclusion (Kavanough, 2011). Other insurance companies are considering limiting their underwriting exposure in a variety of other ways. Clearly new perhaps complex insurance instruments will need to be developed if commercialization of nanotechnology is to proceed on a timely pace.