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Modern approaches of nanotechnology and impact of engineered nano materials on environment : An overview

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Abstract- Nanotechnology is an emerging technology. Its significance lies in comprehension, use, and control of matter which lies at the level of almost atoms, with which to manufacture new substances, instruments and frameworks, It is also known as molecular manufacturing. It is an emergent diversity of technologies in which medicine and engineering come together with physical and chemical science and opening up many new possibilities. In a world increasingly concerned about climate change, resource depletion, pollution and water shortages, nanotechnology has been much heralded as a new environmental saviour. Its proponents have claimed that it will deliver different efficient, inexpensive and environmentally sound technologies. In short, nanotechnology will enable ongoing economic growth and the expansion of consumer culture at a vastly reduced environmental cost, since the use of smaller quantities of potent nanomaterials will break the tie between economic activity and resource use. However, the extent industrial and commercial use of nanomaterials affecting organisms and ecosystems is greatly debated. These include Potential risks such as environmental, health and safety issues; transitional effects such as displacement of traditional industries as the products of nanotechnology become dominant, military applications such as biological warfare and implants for soldiers and surveillance through nano-sensors. These may be particularly important if potential negative effects of engineered nanoparticles are overlooked before they are released.

Key words: Nanotechnology, Nanomaterials, Dose-response relationship, Antibacterial nano-silver, Nanotubes, Resource depletion, Environmental saviour, Domino effect

INTRODUCTION

Nanotechnology is revolutionizing the world by showing the way through which new materials and devices are being developed. As scientists work at nanoscale (think small, very small, like atoms and molecules) they are discovering new behaviours and properties for matter of this size. Some are better for conducting electricity or heat, some are stronger or have different magnetic properties. Despite these good things reports are that nanotechnology have occupational and environmental exposures.[1,2] Uncertainties in health and environmental effects associated with exposure to engineered nanomaterials raise questions about potential risks from such exposures.[3-6]

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A challenge in evaluating risks associated with the manufacture and use of nanomaterials is their diversity and complexity, as well as their limitless potential uses. A risk assessment is the evaluation of scientific information on the hazardous properties of environmental agents, the dose response relationship, and the extent of exposure of humans or environmental receptors to these agents. The risk assessment depends upon the probability that human population or other environmental receptors on exposure will be harmed to what degree.

Nanomaterials have large surface areas per unit/ volume, and novel electronic properties composed to conventional chemicals. Nanomaterials may be both useful hazarduous to man and the environment. Furthermore, many nanomaterial coatings are being developed to enhance performance as per desired applications, may have some behavioural effects on the materials and may or may not be retained in the environment.

Several authors have reviewed characterization, fate, and toxicological infornmation for nanomaterials and proposed their research strategies for safety evaluation of nanomaterials.[7-10] Tsuji *et al.* (2006)[8] proposed a general framework for risk assessment of nanomaterials. It identifies nanomaterial characteristics, such as particle size, structure/properties, coating, and particle behavior. There are also some efforts to identify research needs for nanomaterial risk assessment.[11]

The release of nanomaterials to the environment may also result in accelerated generation of potent greenhouse gas emissions. Antibacterial nano silver is used widely in clothing, textiles, cleaning products, personal care products and surface coatings. A preliminary study shows that when nano silver is exposed to sludge, there is four times increase in the level of the potent greenhouse gas nitrous oxide.

At present nanotechnology is not an unqualified environmental saviour and its widespread use in everything will not enable us to pursue "Business as usual" but substantively reduce our environmental footprint. At best, high claims about this technology may be regarded as wishful thinking of its proponents and may be a misleading green wash.

Present Environmental Condition

Wasteful and inequitable consumption and production has had a devastating environmental impact.[12] Desertification, salinity, polluted air and soils, lack of potable water, huge losses to biodiversity, plummeting fish stocks, and increasing competition for arable land between buildings, food crops and biofuels characterise the first decade of the 21st century.

At the same time as ecological systems and services have been stretched to a breaking point, economic inequity between the global rich and global poor has widened. The years 2008 and 2009 saw the worst world food crisis ever Despite decades of medical breakthroughs, between 1.7 and 2 billion people worldwide have inadequate or no access to life-saving basic medicines.[13]

Climate change and global warming have been viewed as the meta problem, "the defining human development issue of our generation".[14] If left unchecked, climate change is predicted to promote greater ocean acidification, loss of species, loss of arable crop land, and diminished fresh water resources. At the same time, more extreme weather events, crop failures and rising ocean levels may create a new wave of environmental refugees and shifting patterns of disease. The world's poorest people will dísproportionately bear the negative impacts of these changes.[14]

According to NASA, "Glaciers have shrunk, ice on rivers and lakes is breaking up earlier, plant and animal ranges have shifted and trees are flowering earlier. Effects that scientists had predicted in the past would result from global climate change are now occurring: loss of sea ice accelerated sea leve rise and longer, more intense heat waves". The International Panel on Climate Change (IPCC) has advised that for a 46 % chance of stabilizing temperature rises below 2°C, the point at which major melting of sea ice and a 'domino effect of warming could occur, greenhouse gas (GHG) emissions from industrialised countries must fall by 25-40 % on 1990 levels by 2020, and must fall by 85-90 % by 2050 (Chapter 13, Box 13.7; IPCC AR4 WGIII 2007) Even using the IPCC's assumptions, which have been criticised by environmeitalists as unreasonably conservative, this dramatic reduction in greenhouse gas emissions delivers only roughly even odds that global temperatures will not rise above 2°C.[15,16]

Nanotechnology, Nanoparticles and Nanomaterials

A nanometer is one billionth of a meter (10-9 m) i.e. about one hundred thousand times smaller than the diameter of a human hair or a thousand times smaller than a red blood cell, or about half the size of the diameter of DNA. Nanotechnology is defined as the research and technology development at the atomic, molecular or macromolecular levels using a length scale of approximately one to one hundred nanometers in any dimension; the creation and use of structures, devices and systems that have novel properties and functions because of their small size; and the ability to control or manipulate matter on an atomic scale.[17-19] It is the manipulation of matter for use in particular applications through certain chemical and /or physical process to create materials with specific properties.

Properties of Nanotechnology

Nanotechnology is already enhancing everyday products Such as sunscreens, golf clubs, clothing and cell phones. Within the next decade, it will be common part in drug therapies, water filters, fuel cells, power lines, computers, and a wide range of other applications (Table 1 & 2) Widespread commercial application of nano technology is growing rapidly. Examples of areas in which nanotechnology is expected to have a high commercial impact are as such,

Table 1 & 2- Examples of products containing nanomaterial developed through nanotechnology.

Short-term (1-5 years)	Mid-term (5-10 years)	Long-term (20+ years)
• Long-lasting rechargeable batteries • Improved chemical & biological sensors • Point-of-care medical diagnostic devices	• New targeted drug therapies • Enhanced medical imaging • High-efficiency, cost-effective solar cells	• New molecular electronics • New all-optical information processing • New neural prosthetics for health care

Health & fitness	Electronics & Computer	Home & Garden	Food & Beverage	Other
Wound dressing: Pregnancy test; Tooth paste; Golf Club; Tennis Racket; Skis; Antibacterial Socks; Water and stain resistant; Cosmetics; Air filter; sunscreen	Computer displays; Games; Computer Hardware	Paint; Antimicro bial Pillows; Stain resistant cushions	Non- stick coating; for pans; Antimicrobial refrigerator; Canella oil	Coatings,; lubricants

Source: Woodrow Wilson center consumer products Inventory (2006).

Risk Assessment of Nanomaterials

The presence of nonmaterial is not in itself threat. It is only certain aspects that can make them risky, in particular their mobility and their increased reactivity. Only if certain properties of certain nanoparticles are harmful to living beings or the environment causing genuine hazard it will be called nanopollution.

For considering the health and environmental impact of nanomaterials we need to differentiate between two types of nanostructures: (1) "Fixed" nanoparticles, where nanoscale particles are incorporated into a substance, material or device and (2) "Free" nanoparticles, where at some stages in production or use individual nanoparticles of a substance are present.

The free nanoparticles could be nanoscale species of elements and is coated with another substance. Concern has been expressed about their safety because materials become extremely reactive at nano size (10^{-9} m to 10^{-7} m) and behave unpredictably i.e. different from their everyday counterparts. It has been hypothesized that nanomaterials might become toxic and adversely impact the environment.

Characterization of Nanomaterials and Chemical Identification

Understanding the physical and chemical properties of nanomaterials in particular is necessary in the evaluation of hazard and exposure. Their diversity and complexity makes chemical identification and characterization not only more important but also more difficult. A detailed studies of properties will be needed to characterize a given nanomaterial for the purposes of evaluating hazard and assessing risk. Chemical properties may be important for some nanomaterials, but other properties such as particle size and size distribution, surface/volume ratio, shape, electronic properties, surface characteristics, state of dispersion agglomeration and conductivity are also expected to be important for the majority of nanoparticles.

Fate of Nanomaterials in the Environment

As more products containing nanomaterials are developed, there is greater potential for environmental exposure through direct and/or indirect release sources. Directly these may be released from the use and disposal of consumer products containing these materials. The fundamental properties concerning the environmental fate of nanomaterials are not well understood.[4] The fate of nanomaterials in the atmosphere, in soils and in water can be discussed.

Behaviour and Effect of Nanomaterials in Air

A number of factors influence the fate of airborne particles in addition to their initial dimensional and chemical characteristics. These are length of time the particles remain airborne, the nature of their interaction with other airborne particles or molecules, and the distance that they may travel prior to deposition. Diffusion, agglomeration, wet and dry. deposition, and gravitational settling are the important processes to understand the potential atmospheric transport of particles, ultrafine particles and nanomaterials as well.[20] However, nanoparticles may behave quite differently from incidental ultrafine particles, for example, nanoparticles that are surface coated to prevent agglomeration. In addition, there may be differences between freshly generated and aged nanomaterials.

Particles with aerodynamic diameters in the nanoscale range (<100 nm) may follow the laws of gaseous diffusion when released to air. The rate of diffusion is inversely proportional to particle diameter, while the rate of gravitational settling is proportional to particle diameter.[21]

Early research shows that some forms of nanotubes can cause mesothelmia, the deadly cancer associated with asbestos exposure. Antibacterial nanosilver is used widely in clothing, textiles, cleaning products personnel care products and surface coatings. Preliminary study shows that when nanosilver is exposed to sludge, similar to that found in typical waste water treatment plants, four times the typical level of green house gas nitrous oxide is released.[22] It has been observed that during production of Single Walled Carbon Nanotubs (SWCNT) 40.62g of methane gas was generated for every one gram of SWCNT produced.

Many nanomaterials manufacturing process use large quantities of toxic, basic or acidic chemicals and solvents. Out of which some chemicals do not readily breakdown in our bodies or in the environment and get accumulated in the body and are Toxic.Emissions of 15 different hydrocarbons have been identified.[23]

Many nanoparticles are reported to be photoactive,[24] but their susceptibility to photodegradation in the atmosphere has not been studied. Some nanomaterials are known as absorbent of a variety of materials,[20] and also act as a catalysts. Reijnders (2009)[25] concluded that manufactured nanoparticles used in cosmatics, coatings may be hazarduous. Up to 95 % of these and 50 % of nanoparticles used in paints may end up in sewage treatment plants and finally to land as sludge.[26]

Behaviour and effects of Nanomaterials in Soil

The fate of nanomaterials released to soil is likely to vary depending upon the physical and chemical characteristics of the nanomaterial. Nanomaterials released to soil can be strongly absorbed to soil due to their high surface areas and therefore be immobile. On the other hand, nanomaterials are small enough to fit into smaller spaces between soil particles, and might therefore travel farther than larger particles before becoming trapped in the soil matrix. The strength of the absorption of any intentionally produced nanoparticle to soil will be dependent on its size, chemistry, applied particle surface treatment, and the conditions under which it is applied. Studies have demonstrated differences in mobility of a variety of insoluble nanosized materials in a porous medium.[27]

Additionally, the types and properties of the soil and environment can affect nanomaterial mobility. For example, the mobility of mineral colloids in soils and sediments is strongly affected by charge.[20] Surface photoreactions provide a pathway for nanomaterial transformation on soil surfaces. Humic substances, common constituents of natural particles, are known to photosensitize a variety of organic photoreactions on soil and other natural surfaces that are exposed to sunlight. Studies of nanomaterial transformations in field situations are further complicated by the presence of naturally occurring nanomaterials of similar molecular structures and size ranges like Iron Oxides.

A team of researchers from University of Texas in EL paso showed that metal nanoparticles present in soil are easily absorbed by soya bean plants and stand a fair chance of entering the food chain, and finally enter the blood stream. It is important to study that what are the bio-transformation or modifications into other organic forms are taking place in plants (Down to Earth, March 16-31, 2013, page 483).

Behaviour and effects of Nanomaterials in Water

Behaviour of nanomaterials in aqueous environments is controlled by aqueous solubility or dispersability. interactions between the nanomaterial and natural and anthropogenic chemicals in the system and biological and abiotic processes. Waterborne nanoparticles generally settle more slowly than larger particles of the same material. However, due to their high surface-area-to mass ratios, nanosized particles have the potential to get seperated from the soil and sediment particles.[28] Some nanoparticles will be subject to biotic and abiotic degradation (hydrolysis and photolysis) resulting in removal from the water column. Particles in the upper layers of aquatic environments, on soil surfaces, and in water droplets in the atmosphere are exposed to sunlight. Light induced photoreactions plays an important role in determining environmental fate of chemical substances.

These reactions may alter the physical and chemical properties of nanomaterials and so alter their behavior in aquatic environments. Certain organic and metallic nanomaterials may possibly be transformed under anaerobic conditions, such as in aquatic (benthic) sediments. From past studies, it is known that several types of organic compounds are generally susceptible to reduction under such conditions. There is a serious paucity of nano-ecotoxicological data However early studies have revealed that nanoparticles of zinc oxide are very toxic to the development of sea urchin embryos.[29] There is also preliminary evidence that some nanoparticles could have negative impact on algae and plants, and impair the function or reproductive cycle of bacteria and fungi which play an important role in primary productivity, nutrient cycling and waste decomposition that support ecosystem function.[30] It was further observed that the addition of nano silver to activated sludge has not only slowed down the decomposition reactions but also enhanced the emission of green house gases (nitrous oxide) by four times.[22]

Bioavailability and Bioaccumulation of Nanomaterials

Bacteria and living cells can take up nanosized particles, providing the basis for potential bioaccumulation in the food chain.[31] Aquatic and marine filter feeders near the base of the food chain feed on small particles, including nanometer size particles. The bioavailability of specific nanomaterials in the environment will depend in part on the particle. Environmental fate processes may be too slow for effective removal of persistent nanomaterials before they can be taken up by an organism. It was noted that some physical removal processes, such as gravitational settling, are slower for nanosized particles than for microparticles. This would lead to an increased potential for inhalation exposure to terrestrial organisms and for increased exposure of aquatic organisms to aqueous colloids. There is not much information on the rates of deposition of nanomaterials from the atmosphere and surface water, or of absorption to suspended soils and sediments in the water column, to determine whether these processes could effectively isolate specific nanoparticles before they are taken up by organisms.

Complexation of metallic nanomaterials may have important interactive effects on biological availability and photochemical reactivity. For example, the biological availability of iron depends on its free ion concentrations in water and the free ion concentrations are affected by combination. Combination reduces biological availability by reducing free metal ion concentrations and dissolved iron is quantitatively complexed by organic ligands. Solar UV radiation can interact with these processes through photoreactions of the complexes. Further, iron and iron oxides can participate in enzymatic redox reactions that change the oxidation state, physical chemical properties and bioavailability of the metal.[32]

Potential for Toxic Transformation Products from Nanomaterials

Certain nanomaterials are being designed for release as reactants in the environment, and therefore are expected to undergo chemical transformation. One example of this is iron (FeO) nanoparticles employed as reactants for the dechlorination of organic pollutants. As the reaction progresses, the iron is oxidized to iron oxide. Other metal particles are also converted to oxides in the presence of air and water. Whether the oxides are more or less toxic than the free metals depends on the metal. Under the right conditions, certain metal compounds could be converted to more mobile compounds. In these cases, small particle size would most likely enhance this inherent reactivity. Some types of quantum dots have been shown to degrade under photolytic and oxidative conditions, and furthermore, compromise of quantum dot coatings can reveal the metalloid core, which may be toxic.[33] Degradation products from carbbn nanomaterials (fullerenes and nanotubes) have not yet been reported.

Health and Environmental Risks

Many nanomaterials used in the nano solar sector incorporate heavy metals and pose inherent toxicity. First Solar, which dominates the thin film PV market, uses cadmium telluride. Other applications in development use quantum dots that have cadmium cores. Early studies suggest that quantum dots could be transferred along food chains, could bioaccumulate or even biomagnify, and that in time coatings could degrade, exposing their toxic cores. The health risks associated with carbon nanotubes, in particular their potential to cause mesothelioma and similar disease, have also attracted international concern. Titanium dioxide nanotubes have a similar shape to carbon nanotubes. A test tube study on lung epithelial cells found that they had a strong dose-dependent effect on cell proliferation and cell death.[34] Early studies also show that nano forms of titanium dioxide, silver and carbon fullerenes, all touted for use in nano solar, can be toxic to people and the environment. The Silicon Valley Toxics Coalition provides an excellent detailed report on other toxic aspects of the solar energy industry.[35]

CONCLUSION

Nanopollution is the generie name for all waste generated by nanodevices or during the manufacturing process of nanomaterials. These nanoparticles may be dangerous because of its size and unknown effects on health. Most of the man-made nanoparticles do not appear in nature, so living organisms may not have appropriate means to deal with nanowaste. To properly assess their health hazards the whole life-cycle of these nanoparticles needs to be evaluated properly, including their fabrication, storage and distribution application and potential abuse, and disposal. The impact on humans or the environment may vary at different stages of their life-cycle as nanoparticles present new environmental impacts. It is not currently possible to "precisely predict or control the ecological impacts of the release of nanoproducts into the environment, since the research is in with a nascent stage and more studies are needed to ascertain how exactly they can be harmful to human health.

REFERENCES

1. **Baron P. A., Maynard A.D., Foley M. 2003.** Evaluation of Aerosol Release During the Handling of Unrefined Single Walled Carbon Nanotube Material. NIOSH-DART-02-191 Rev. 1.1, April 2003.
2. **Maynard A. D., Baron P. A., Foley M., Shvedova, A. A., Kisin E. R. and Castranova V. 2004.** Exposure to Carbon Nanotube Material: Aerosol Release During the Handling of Unrefined Single-Walled Carbon Nanotube Material. *J. Toxicol. Environ. Health A.* **67:** 87-107.
3. **UK Royal Society. 2004.** The Royal Society and the Royal Academy of Engineering. Nanoscience Nanotechnologies: Opportunities and Uncertainties.
4. **European Commission. 2004.** European Commission, Community Nanotechnologies: A Preliminary Risk Analysis on the Basis of a Workshop Organized in Brussels on 1-2 March 2004 by the Health and Consumer Protection Directorate General of Health and Consumer Protection. The European Commission.
5. **European Nano Safe Report. 2004.** Technical Analysis Industrial Application of Nanomaterials Chances and Risks.
6. **UK Health and Safety Executive. 2004.** Nanoparticles: An Occupational Hygiene Review. Research Report 274
7. **Morgan K. 2005.** Development of a Preliminary Framework for Informing the Risk Analysis and Risk Management of Nanoparticles. *Risk Anal.* **25:**1-15.
8. **Tsuji J. S., Maynard A. D., Howard P. C., James J. T., Lam C-W., Warheit D. B., Santamaria A. B. 2006.** Rescarch Strategies for Safety Evaluation of Nanomaterials, Part IV Risk Assessment of Nanoparticles. *Toxicol. Sci.* **88(1):**12-17.
9. **Borm P., Klaessig F. C., Landry T. D., Moudgil B., Pauluhn J., Thomas K., Trottier R., Wood S. 2006.** Research Strategies for Safety Evaluation of Nanomaterials, Part V: Role of Dissolution in Biological Fate and Effects of Nanoscale Particles. *Toxicol. Sciences.* **90(1):** 2332.
10. **Powers K. W., Brown S. C., Krishna V. B., Wasdo S. C., Moudgil B. M., Robert S. M. 2006.** Research Strategies for Safety Characterization of Nanoscale Particles for Toxicological Evaluation. Evaluation of Nanomaterials, Part VI: *Toxicol. Sci.* **90(2):** 296-303.
11. **UK Department for Environment, Food and Rural Affairs. 2005.** Characterising the Potential Risks Posed by Engineered Nanoparticles: A First UK Government Research Report.
12. **UNEP. 2010.** Assessing the environmental impacts of and consumption: Priority Materials production Products and Materials, A Report of the Working

Group on the Environmental Impacts of Products and Materials to the International Panel for Sustainable Resource Manage. International Panel for Sustainable Resource Management, Working Group on the Environmental Impacts of Products and Materials: Prioritisation and Improvement Options, United Nations Environment Programme.

13. **UN Millennium Project. 2005.** Prescription for healthy development: increasing access to medicines. London: Earthscan.

14. **UNDP. 2008.** Fighting climate change: human solidarity in a changing world. Human development report 2007/2008. New York: United Nations Development Programme Human Development Report Office.

15. **Spratt David. 2020.** What's up with emissions reductions of 25-40% by 2020 Climate Code Red. 7 March 2009.

16. **Zhou Maggie. 2010.** IPCC targets lead to (at least) 54% odds of catastrophic climate change. *Secure Green Future*.

17. **National Nanotechnology Initiative. 2006a.** What is Nanotechnology?

18. **National Nanotechnology Initiative. 2006b.** About the NNI

19. **National Nanotechnology Initiative. 2006c.** Environmental, Health and Safety Research Needs for Engineered Nanoscale Materials.

20. **Wiesner M. R., Lowry G. V., Alvarez P., Dionysiou D., Bisawas P. 2006.** Assessing the Risks of Manufactured Nanomaterials. *Environ. Sei. Tech.* **40(14):** 4336-4345.

21. **Aitken R. J., Creely K. S., Tran C. L. 2004.** Nanoparticles: An Occupational Hygiene Review. Research Report 274. Prepared by the Institute of Occupational Medicine for the Health and Safety Executive, North Riccarton, Edinburgh, England

22. **Knight Helen. 2010.** Antibacterial socks may boost greenhouse emissíons. *New Scientist*.

23. **Sengul Hatice, Thomas L. Theis and Siddartha Ghosh. 2008.** Towards sustainable nanoproducts: An overview of nanomanufacturing. *Journal of Industrial Ecology.* **12(3):** 329-359.

24. **Colvin V. 2003.** The Potential Environmental Impact of Engineered Nanoparticles. *Nature Biotechnol.* **21(10):** 1166-1170

25. **Reijnders Lucas. 2009.** The release of Ti02 and Si02 nanoparticles from nanocomposites. *Polymer Degradation and Stability.* **94:** 873-876.

26. **Mueller Nicole and Bernd Nowack. 2009.** Modelling of engineered nanoparticles in the environment. *Environmental Science & Technology.* **42:** 4447-4453.

27. **Lecoanet H. F., Bottero J. Y., Wiesner M. R. 2004.** Laboratory Assessment of the Mobility of Nanomaterials in Porous Media. *Environ. Sci. Technol.* **38:**5164-5169.

28. **Oberdörster G., Oberdörster E., Oberdörster J. 2005a.** Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles. *Environ. Health Perspect.* **113(7):** 823839.

29. **UC CEIN. 2010.** University of California Center for Environmental Implications of Nanotechnology, Annual Report Year 2, April 1, 2009 -March 31, 2010 Annual Report, Los Angeles: UC CEIN, 2010.

30. **Navarro E., Baun A., Behra R., Hartmann N. B., Filser J., Miao A. J., Quigg A., Santschi P. H. and Sigg L. 2008.** Environmental behavior and ecotoxicity of engineered nanoparticles to algae, plants, and fungi. *Ecotoxicology.* **17(5):**372-386.

31. **Biswas P, Wu, C-Y. 2005.** Nanoparticles and the Environment. *Journal of the Air & Waste Management Azssociation.* **55:**708-746.

32. **Reguera, G., McCarthy, K.D., Mehta, T., Nicoll, J.S., Tuominen, M.T, Lovley, D.R. 2005.** Extracellular Electron Transfer Via Microbial Nanowires. Nature **453(23):**1098-1101.

33. **Hardman, R. 2006.** A Toxicological Review of Quantum Dots: Toxicity Depends on Physicochernical and Environmental Factors. *Envíron, Health Perspect.* **114(2):**165-172.

34. **Magrez A., Horváth L., Smajda R., Salicio V., Pasquier N., Forró L. and Schwaller B. 2009.** Cellular toxicity of TiO2-based nanofilaments. *ACS Nano*. **3:** 2274-2280.

35. **Silicon Valley Toxics Coalition. 2009.** Toward a Just and Sustainable Solar Energy Industry, San Jose: Silicon Valley Toxics Coalition, 2009.

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