Environmental Impacts of Nanotechnology and Its Products

B. Zhang[1], H.Misak[1], P.S. Dhanasekaran[1], D. Kalla[2] and R. Asmatulu[1]

[1]Department of Mechanical Engineering
Wichita State University
1845 Fairmount, Wichita, KS 67260-0133
[2]Department of Engineering Technology
Metropolitan State College of Denver
Denver, CO, 80014, USA

Abstract

Nanotechnology increases the strengths of many materials and devices, as well as enhances efficiencies of monitoring devices, remediation of environmental pollution, and renewable energy production. While these are considered to be the positive effect of nanotechnology, there are certain negative impacts of nanotechnology on environment in many ways, such as increased toxicological pollution on the environment due to the uncertain shape, size, and chemical compositions of some of the nanotechnology products (or nanomaterials). It can be vital to understand the risks of using nanomaterials, and cost of the resulting damage. It is required to conduct a risk assessment and full life-cycle analysis for nanotechnology products at all stages of products to understand the hazards of nanoproducts and the resultant knowledge that can then be used to predict the possible positive and negative impacts of the nanoscale products. Choosing right, less toxic materials (e.g., graphene) will make huge impacts on the environment. This can be very useful for the training and protection of students, as well as scientists, engineers, policymakers, and regulators working in the field.

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Email: ramazan.asmatulu@wichita.edu

1. Introduction

Nanotechnology utilizes the unique properties of nanomaterials which has at least one dimensional size of a material between 1 nm to 100 nm to produce nanoscale devices, components, and systems[1]. Applications utilizing nanotechnology includes manufacturing various products, measuring, imaging and manipulating matter on the nanoscale. Nanotechnology is of considerable interest by scientists in the fields of nanocomposites, biocomposites, optical, biomedical, and electronic manufacturing[2-4]. Nanoparticles are currently being developed fervently, and one novel application includes polymer based composite materials used in the aircraft and wind industries[5,6] . Nanoscale materials can be different in properties compared to bulk materials for two reasons:

- Nanoscaled particles have relatively larger surface area per unit mass which is the critical factor to increase mechanical modulus and other physical and chemical properties.

- Basic material properties are changed at nanoscale due to the dominance of quantum effects and lesser imperfections[7].

In general, nanotechnology devices consume less energy, reduce material wastes, and help in monitoring. Nanotechnology can also be used to reduce and prevent the toxicity of nanoparticles in environment more efficiently[8] . There are certain areas of manufacturing currently benefiting from the development of nanotechnology:

- Energy consumption: The use of graphene into a coating material resulting in the need for only one layer, which does not require a multifunctional film coating. Two applications for a graphene based coating are to apply it to a blade used in wind turbines or on the body of an airplane. It saves the weight increasing efficiency.
- Cost saving on materials: An alternative energy method such as hybrid automobiles will decrease the price by novel developments in nanotechnology.
- Less waste on raw materials: Large sample testing will be done on a smaller scale and simultaneously use of raw materials will become more efficiency. Nanoscale chemical reagents (or catalysts) increase the reaction rate and other efficiency of chemical reactions.
- Environmental monitoring and protection: Utilizing advanced nanotechnology, a detector was made to detect a nuclear leak faster and more accurate at the Fukushima Daiichi Nuclear Power Plant. Which is one of the best radiation detector in Washington and can sense the faintest amount of radiation[9] .
- Biological applications: Developing ultra-small probes on planetary surfaces for agricultural applications and control of soil, air, and water contamination.
- Biomedical applications: This includes the medical diagnostic and treatments.

Polymer composite materials when compared to traditional structural materials made out of metals have a reduced weight, high specific modulus and high resistance to environmental effects; however, polymer composites with nanoparticle reinforcement to composite materials offer engineers and scientists more options to tailor the material properties to meet design specifications. Common nanoparticles include nanofibers, buckyballs, carbon nanotubes, and graphene, etc. Nanodevices can also be made by using nanotechnology[10] and are used in many applications, such as sun glasses, sun screen, semiconductor, and sports equipment, etc. Nanotechnology can provide future solutions for certain environmental problems; however, it also creates negative impacts on the environment. Therefore, evaluation of the positive and negative impacts of nanotechnology is essential for the safety of society.

2. Potential Environmental Effects

Nanoparticles have higher surface areas than the bulk materials which can cause more damage to the human body and environment compared to the bulk particles. Therefore, concern for the potential risk to the society due to nanoparticles has attracted national and international attentions.

Nanoparticles are not only beneficial to tailor the properties of polymeric composite materials and environment in air pollution monitoring, but also to help reduce material consumption and remediation (Figure 1). For example, carbon nanotube and graphene based coatings have been developed to reduce the weathering effects on composites used for wind turbines and aircraft. Graphene has been chosen to be a better nanoscale inclusion to reduce the degradation of UV exposure and salt. By using nanotechnology to apply a nanoscale coating on existing materials, the material will last longer and retain the initial strength longer in the presence of salt and UV exposure. Carbon nanotubes have been used to increase the performance of data information system. However, there are few considerations of potential risks need to be considered using nanoparticles:

- The major problem of nanomaterials is the nanoparticle analysis method. As nanotechnology improves, new and novel nanomaterials are gradually developed. However, the materials vary by shape and size which are important factors in determining the toxicity. Lack of information and methods of characterizing nanomaterials make existing technology extremely difficult to detect the nanoparticles in air for environmental protection.
- Also, information of the chemical structure is a critical factor to determine how toxic a nanomaterial is, and minor changes of chemical function group could drastically change its properties.
- Full risk assessment of the safety on human health and environmental impact need to be evaluated at all stages of nanotechnology. The risk assessment should include the exposure risk and its probability of exposure, toxicological analysis, transport risk, persistence risk, transformation risk and ability to recycle.
- Life cycle risk assessment is another factor that can be used to predict the environmental impacts.
- Good experimental design in advance of manufacturing a nanotechnology based product can reduce the material waste.

Carbon nanotubes have applications in many materials for memory storage, electronic, batteries, etc. However, some scientists have concerns about carbon nanotubes because of unknown harmful impacts to the human body by inhalation into lungs, and initial data suggests that carbon nanotubes have similar toxicity to asbestos fiber[11]. Lam et al. and Warheit et al. studied on pulmonary toxicological evaluation of single-wall carbon nanotubes[12]. From Lam's research, carbon nanotube showed to be more toxic than carbon black and quartz once it reaches lung[13], and Warheit found multifocal granulomas were produced when rats were exposure to single-wall carbon nanotubes[14]. Also, previous disasters need to be re-analyzed to compare with current knowledge as well. In the 1980s, a semiconductor plant contaminated the ground-water in Silicon Valley, California. This is a classic example of how nanotechnology can harm the environment even though there are several positive benefits.

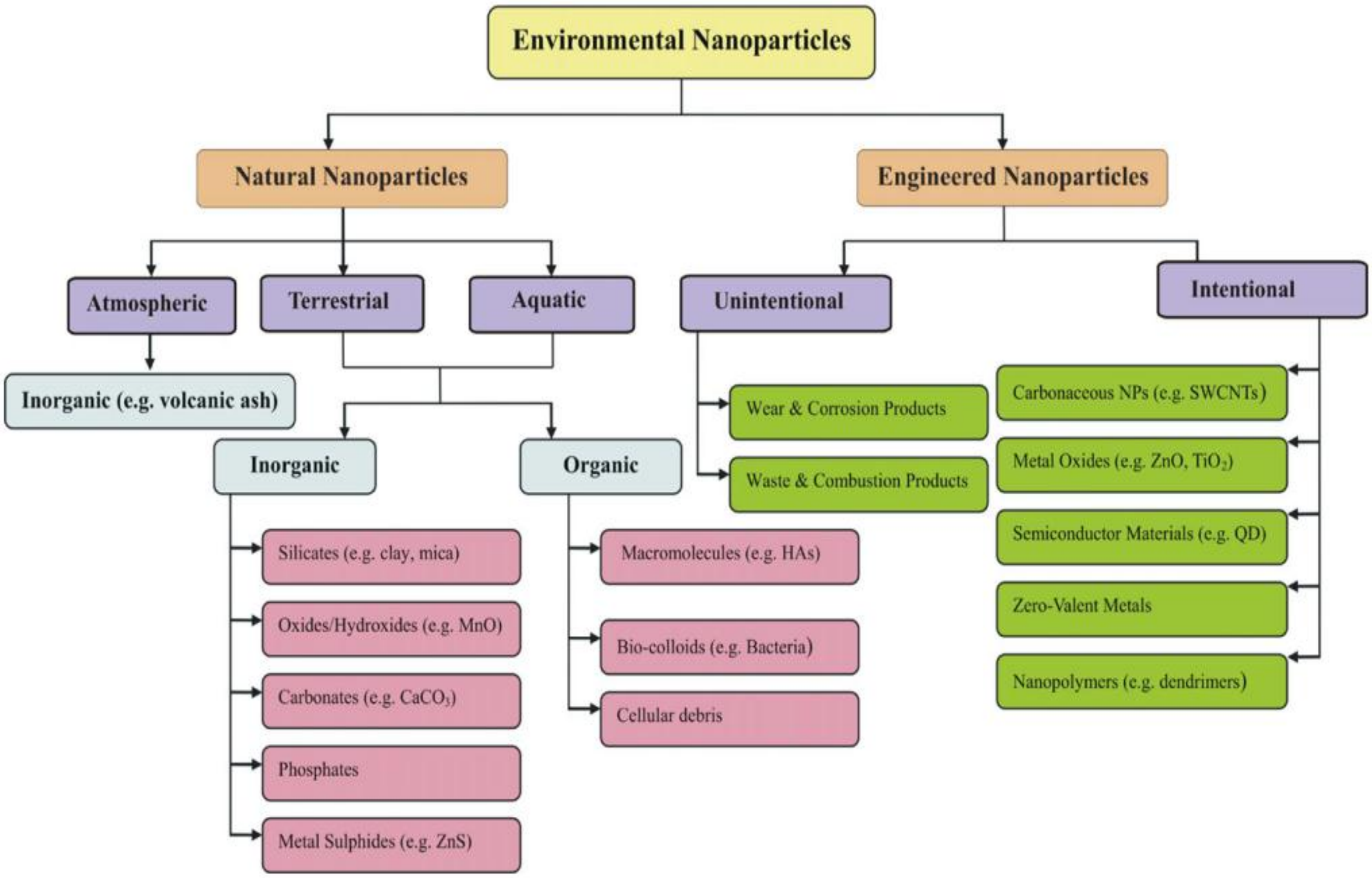

Figure 1: A detailed sorting of nanoparticles existing in the environments[15] .

As current nanoscale materials are becoming smaller, it is more difficult to detect toxic nanoparticles from waste which may contaminate the environment (Figure 2). Nanoparticles may interact with environment in many ways: it may be attached to a carrier and transported in underground water by bio-uptake, contaminants, or organic compounds. Possible aggregation will allow for conventional transportation to sensitive environments where the nanoparticles can break up into colloidal nanoparticles. As Dr. Colvin says "we are concerned not only with where nanoparticles may be transported, but what they take with them"[16]. There are four ways that nanoparticles or nanomaterials can become toxic and harm the surrounding environment[17]:

- Hydrophobic and hydrophilic nanoparticles: Nanocoating researchers are currently working on TiO_2 powder as a coating inclusion that will reduce the weathering effects, such as salt rain degradation on composite materials. Ivana Fenoglio, et al.[18] expressed their concern that the effect of TiO_2 nanoparticles to be assessed when leaked into the environment.

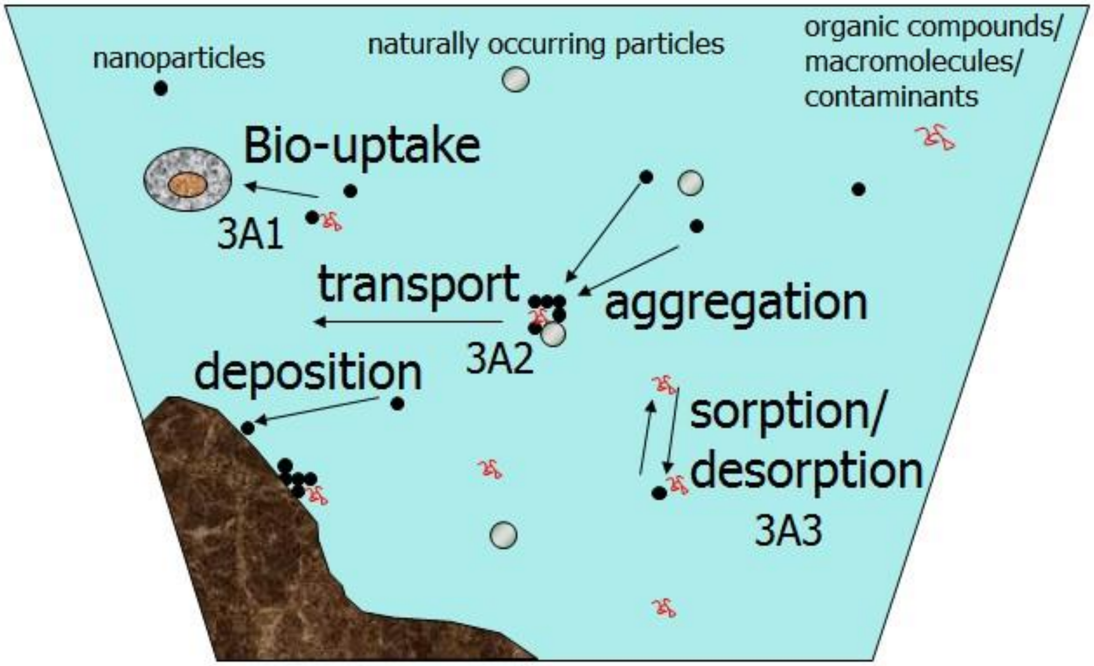

Figure 2: Nanoparticles in a liquid environment [16].

- Mobility of contaminants: There are two general methods that nanoparticle can be emitted into atmosphere.[19] Nanoparticles are emitted into air directly from the source called primary emission, and are the main source of the total emissions. However, secondary particles are emitted naturally, such as homogeneous nucleation with ammonia and sulfuric acid presents. As Figure 2 demonstrates that nanoparticles can easily be attached to contaminations and transported to a more sensitive environment such as aqueous environments. For example, nuclear waste traveled almost 1 mile from a nuclear test site in 30 years[20]. However, after 40 years of the incident the first flow mechanism model is being developed to describe the methods of nanoparticle based waste travels[21].
- Solubility: Nanoparticles are invented and developed in advance of the toxic assessment by scientists. Many of the nanoparticles are soluble in water, and are hard to separate from waste if inappropriately handled.
- Disposal: Any waste product, including nanomaterials, can cause environmental concerns/problems if disposed inappropriately.

3. Environmental Analysis

Several nanoscale inclusions have been used for various applications. Among these nanoscale inclusions, graphene has the higher priority for various reasons. Graphene is one of the most advanced materials for structural improvement, substitution of silicon for electronic devices, as well as thermal transferring, and fire retardant. Three papers have been published describing the benefits of altering graphene to be more environmentally friendly. One study by Marcano, D.C., et al., improved the process of making graphene oxide (GO) by increasing amount of $KMnO_4$ and eliminate $NaNO_3$ that improves the process efficiency, and produces less toxic emission[21]. Salas, E.C., et al.,[22] and Kotchey, G.P., et al.,[23] have also shown that shewanella bacteria and some other bacteria can decompose graphene and make graphene less toxic to the environment.

3.1 Positive Effects on Environment

Nanotechnology offers potential economic, societal and environment benefits. Nanotechnology also has the potential to help reduce the human footprint on the environment by providing solutions for energy consumption, pollution, and green gas emissions. Nanotechnology offers the potential for significant environmental benefits, including:

- Cleaner, more efficient industrial processes
- Improved ability to detect and eliminate pollution by improving air, water, and soil quality
- High precision manufacturing by reducing amount of waste
- Clean abundant power via more efficient solar cells
- Removal of greenhouse gases and other pollutants from the atmosphere
- Decreased need for large industrial plants
- Remediating environmental damages.

The nanoscale products that utilize graphene in an industrial use or research can benefit the environment in several ways:

- Graphene based nanocomposites reduce the weight of airplanes by substituting traditional metals and composites, and the consequence of the weight saving results in a reduction of a thousand tons of gasoline
- Graphene thin films or graphene buckypapers can be substituted in place of metal meshes around the fuselage of airplane used to prevent the direct and indirect effects of lightning strikes
- The eminent properties of graphene increases the efficiency of advanced renewable energy processes, such as reducing the weight of a wind turbine blades and increasing the energy converse efficiency.

3.2 Negative Effects on Environment

Understanding of the environmental effects and risks associated with nanotechnology is very limited and inconsistent. The potential environmental harm through nanotechnology can be summarized as follows:

- High energy requirements for synthesizing nanoparticles causing high energy demand
- Dissemination of toxic, persistent nanosubstances originating environmental harm
- Lower recovery and recycling rates
- Environmental implications of other life cycle stages also not clear
- Lack of trained engineers and workers causing further concerns.

Graphene has outstanding properties and its products can benefit the environment and economy; unfortunately, graphene based composites may also harm the environment in other ways:

- The toxic property of graphene is unknown, and is difficult to remove graphene from waste.
- Graphene could react with materials and biological systems in environment in a way that is unexpected.
- Graphene has a good thermal conductivity, and fire retardancy of the polymer nanocomposites is already well researched. However, scientists warn that it may cause fire risk if graphene is contaminated with other substances during the process[24].

3.3 Educational Issues

Industry and education, including public schools, community colleges, and universities, will have to respond to the change in dynamics/composition of the workforce. This is to change curriculum to match changes in society with emphasis on science, technology, and engineering fields. Advances in miniature electronics could result in changes in the classroom[25]. Having organized education or training systems to college students and researchers in laboratories is a key factor of reducing the negative impacts of nanotechnology. Educational progress follows nanotechnology research progress. Researchers or college students do not fully realized and understand how nanoparticles affect a system. One of the important causes is the lack of toxicity information from manufacture and could easily be handled safely with appropriate protection equipment[26, 27]

Developing new nanotechnology classes, providing nano safety seminar and conference could not only benefit college students, but also engineers and industrial manufacture scientists in other fields. For a new student research assistant, who is going to be handling nanoscale materials should be trained in a general safety course and a course associated with that specific nanomaterials. Public media is an ideal way to populate the information of nanomaterial and to educate public of advantages and disadvantages of nanomaterial for the commercial products which contains nanomaterials.

Research funding should be raised from government agencies (such as, Food and Drug Administration, the Environmental Protection Agency, the National Institutes of Health) to provide more nanotechnology researches in educational purposes.

4. Conclusion:

There is no doubt that nanotechnology will continue to be develop, be a benefit to society and improve the environment in various ways. Nanoscale materials will make the products better in terms of functionality, weight savings, less energy consumption and a cleaner environment. Shortcomings always exist when new unproven technology is released. Nanomaterial may help clean certain environmental wastes, but contaminate environment in other ways. Choosing the right nanoscale materials is one of the key parameters for the future direction of nanotechnology. Engineering ethics need to be defined before the commercial use of nanotechnology. Risk assessment on new nanomaterial based application is important to evaluate potential risk to our environment when the products are in use. Full life cycle evaluation and analysis for all difference applications should be conducted with constant attention.

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Biographical Information:

BANGWEI ZHANG
Mr. Zhang is a PhD student in the Department of Mechanical Engineering at Wichita State University, and has been working on highly conductive nanocomposite top layer coatings on the nanocomposite surfaces against the lightning strikes. In the meantime, he is also working on characterization of various composite materials at Advance composite materials lab in NIAR.

HEATH E. MISAK
Mr. Misak is a PhD student in the Department of Mechanical Engineering at Wichita State University, and has been working on 5-Fu loaded nanocomposite spheres for the skin cancer.

PUTTAGUNDER DHANASEKARAN SWAMINATHAN
Mr. Dhanasekaran is a PhD student in the Department of Mechanical Engineering at Wichita State University, and has been working on Nanocomposite PEEK Scaffolds for the bone repairment. He has 27 years of industrial experience in different R&D and product design & development, tooling design and development for various applications.

DEVI K. KALLA
Dr. Kalla has been an Assistant Professor in the Department of Engineering Technology at Metropolitan State College of Denver, and has a strong experience on composite manufacturing, machining and modeling.

RAMAZAN ASMATULU
Dr. Asmatulu has been an Assistant Professor in the Department of Mechanical Engineering at Wichita State University for five years. He has conducted several research programs in the area of nanotechnology, biotechnology, composite and education, and published over 140 journal articles and conference proceedings. He has developed nanotechnology research and teaching laboratories, and taught courses in his areas.