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REVIEW ARTICLE

NANOTECHNOLOGY AND ITS APPLICATION IN ENVIRONMENTAL REMEDIATION-AN OVERVIEW

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Abstract

The study of nanotechnology and its application in environment remediation was carried out to reveal the aspects and future of nanotechnology and following aspects were covered under the study i.e. history, concepts and application of nano materials in the world. The review study revealed that the nano era was the great revolution in the field of technology and many transformations in te world were seen in the world. Health implications and potential risks of the nano technology were also briefly discussed in the study. Most near term (1-5 years) applications of nanotechnology are in the form of nanomaterials. These include materials such as lighter and stronger nanocomposites, antibacterial nanoparticles, and nanostructured catalysts. Nanodevices and nanoelectronics are farther off, perhaps 5-15 years, and will have applications in medical treatments and diagnostics, faster computers, and in sensors. The overview of nanotechnology also elucidated that the nano era will come up with huge transformations and will have a great scope in future.

INTRODUCTION

Nanotechnology shortened to "nanotech", is the study of the controlling of matter on an atomic and molecular scale. Generally nanotechnology deals with structures of the size 100 nanometers or smaller in at least one dimension, and involves developing materials or devices within that size. Nanotechnology is very diverse, ranging from extensions of conventional device physics to completely new approaches based upon molecular self-assembly, from developing new materials with dimensions on the nanoscale to investigating whether we can directly control matter on the atomic scale. The current approach of simply reducing the transistor size seems to come to an end by about 2015 due to the limitations of the manufacturing technology (Anonymous, 2005a). By 2020, the traditional silicon CMOS is expected to reach a density of 1010 devices per cm2, switching speed of 12 THz, circuit speed of 61 GHz, and switching energy of 3x10-18J (Anonymous, 2005b). This should be considered a benchmark for new approaches based on nanotechnology. Such approaches include new materials leading to transistors with improved properties (for example Intel's recent announcement on metal gate high-k transistors (http://www.intel.com) and combination of new type of nano elements with traditional circuits (Snider and Williams, 2007).

Nanotechnology is a new set of techniques for engaging with and reconstructing nature at the level of atoms and molecules. Nanotechnology is not so much a distinctly new techno-scientific field, but a new platform and paradigm for enabling a range of existing techno-sciences to shift further down into the nano-atomic level, including chemistry, physics, biotechnology, information technology and engineering.

Nanotechnology has the potential to create many new materials and devices with a vast range of applications, such as in medicine, electronics and energy production. On the other hand, nanotechnology raises many of the same issues as with any introduction of new technology, including concerns about the toxicity and environmental impact of nanomaterials, and their potential effects on global economics, as well as speculation about various dooms day scenarios.

History of nanotechnology

Nanotechnology and nanoscience got started in the early 1980s with two major developments; the birth of cluster science and the invention of the scanning tunneling microscope (STM). This development led to the discovery of fullerenes in 1985 and carbon nanotubes a few years later. In another development, the synthesis and properties of semiconductor nanocrystals was studied; this led to a fast increasing number of metal and metal oxide nanoparticles and quantum dots. The atomic force microscope was invented six years after the STM was invented. In 2000, the United States National Nanotechnology Initiative was founded to coordinate Federal nanotechnology research and development.

Fundamental concepts:

One nanometer (nm) is one billionth, or 10^{-9}, of a meter. By comparison, typical carbon-carbon bond lengths, or the spacing between these atoms in a molecule, are in the range0.12–0.15 nm, and a DNA double-helix has a diameter around 2 nm. On the other hand, the smallest cellular life-forms, the bacteria of the genus mycoplasma, are around 200 nm in length.

Two main approaches are used in nanotechnology. In the "bottom-up" approach, materials and devices are built from molecular components which assemble themselves chemically by principles of molecular recognition. In the "top-down" approach, nano-objects are constructed from larger entities without atomic-level control.

Nanomaterials

This includes subfields which develop or study materials having unique properties arising from their nanoscale dimensions. Interface and Colloid Science has given rise to many materials which may be useful in nanotechnology, such as carbon nanotubes and other fullerenes, and various nanoparticles and nanorods.

- Nanoscale materials can also be used for bulk applications; most present commercial applications of nanotechnology are of this flavor.
- Progress has been made in using these materials for medical applications; see Nanomedicine.
- Nanoscale materials are sometimes used in solar cells which combats the cost of traditional Silicon solar cells.
- Development of applications incorporating semiconductor nanoparticles to be used in the next generation of products, such as display technology, lighting, solar cells and biological imaging; Quantum Dots.

Not enough data exists to know for sure if nanoparticles could have undesirable effects on the environment. Two areas are relevant here:

(1) In free form nanoparticles can be released in the air or water during production (or production accidents) or as waste by-product of production, and ultimately accumulate in the soil, water or plant life.

(2) In fixed form, where they are part of a manufactured substance or product, they will ultimately have to be recycled or disposed of as waste. It is not known yet whether certain nanoparticles will constitute a completely new class of non-biodegradable pollutant. In case they do, it is not known how such pollutants could be removed from air or water because most traditional filters are not suitable for such tasks (their pores are too big to catch nanoparticles).

Nanometrology

It is a subfield of metrology, concerned with the science of measurement at the nanoscale level. Nanometrology has a crucial role in order to produce nanomaterials and devices with a high degree of accuracy and reliability in nano manufacturing.

A challenge in this field is to develop or create new measurement techniques and standards to meet the needs of next-generation advanced manufacturing, which will rely on nanometer scale materials and technologies.

Nano particle

Nanotechnology, a particle is defined as a small object that behaves as a whole unit in terms of its transport and properties. It is further classified according to size: in terms of diameter, fine particles cover a range between 100 and 2500 nanometers, while ultrafine particles, on the other hand, are sized between 1 and 100 nanometers. Similar to ultrafine particles, nanoparticles are sized between 1 and 100 nanometers. Nanoparticles may or may not exhibit size-related properties that differ significantly from those observed in fine particles or bulk materials. Although the size of most molecules would fit into the above outline, individual molecules are usually not referred to as nanoparticles.

List of nanotechnology applications

Nano optimists, including many governments, see nanotechnology delivering benefits such as:

- Environmentally benign material abundance for all by providing universal clean water supplies.
- Atomically engineered food and crops resulting in greater agricultural productivity with fewer labour requirements.
- Nutritionally enhanced interactive 'smart' foods.
- Cheap and powerful energy generation.
- Clean and highly efficient manufacturing.
- Radically improved formulation of drugs, diagnostics and organ replacement.
- Much greater information storage and communication capacities.
- Interactive 'smart' appliances; and increased human performance through convergent technologies.

Potential risks

Potential risks of nanotechnology can broadly be grouped into four areas:

- **Health issues** - the effects of nanomaterials on human biology.
- **Environmental issues** - the effects of nanomaterials on the environment.
- **Societal issues** - the effects that the availability of nanotechnological devices will have on politics and human interaction.
- **Grey goo** - the specific risks associated with the speculative vision of molecular nanotechnology.

Environmental benefits of nanotechnology (Green nanotechnology)

1. Energy applications of nanotechnology

Nanotechnology could potentially have a great impact on clean energy production. Research is underway to use nanomaterials for purposes including more efficient solar cells, practical fuel cells, and environmentally-friendly batteries. The most advanced nanotechnology projects related to energy are: storage, conversion, manufacturing improvements by reducing materials and process rates, energy saving (by better thermal insulation for example), and enhanced renewable energy sources.

Current commercially available solar cells have low efficiencies of 15-20%. Research is ongoing to use nanowires and other nanostructured materials with the hope of to create cheaper and more efficient solar cells than are possible with conventional planar silicon solar cells. It is believed that these nanoelectronics-based devices will enable more efficient solar cells, and would have a great effect on satisfying global energy needs.

Another example for an environmentally friendly form of energy is the use of fuel cells powered by hydrogen. Probably the most prominent nanostructured material in fuel cells is the catalyst consisting of carbon supported noble metal particles with diameters of 1-5 nm. Suitable materials for hydrogen storage contain a large number of small nanosized pores.

Nanotechnology may also find applications in batteries. Because of the relatively low energy density of conventional batteries the operating time is limited and a replacement or recharging is needed, and the huge numbers of spent batteries represent a disposal problem. The use of nanomaterials may enable batteries with higher energy content or super capacitors with a higher rate of recharging, which could be helpful for the battery disposal problem.

Carbon Nanotubes are single-walled, double walled and multi-walled black nano scale cylindrical tubes of graphitic carbon with numerous applications. Carbon Nanotubes are the stiffest and strongest known fibers and have unique electrical properties. Carbon Nan tubes™ include in flat screen displays, scanning probe microscopes in brushes for commercial electric motors, and in sensing devices and because of their strength in numerous aerospace and automotive uses, in body armor and tear-resistant cloth fibers and textiles and stronger and lighter sports equipment. Carbon nanotubes can behave like a conductive metallic or semiconductor depending on their structure, which is useful for nanoscale electronic devices and in electrically conductive films in coatings, plastics, nanowire, nano fiber and in certain bioscience applications. Recently, carbon nanotubes have been demonstrated to create the "darkest" known material absorbing all wavelengths or "colors" of light which will prove useful in solar and electronic applications.

Silicon nanoparticles have been shown to dramatically expand the storage capacity of lithium ion batteries without degrading the silicon during the expansion-contraction cycle that occurs as power is charged and discharged. Silicon has long been known to have an excellent affinity for storage of positively charged lithium cations making them ideal candidates for next generation lithium ion batteries. However, the quick degradation of silicon storage units has made them commercially unfeasible for most applications. Silicon nanowires however, cycle without significant degradation and present the potential for use in batteries with greatly expanded storage times. Carbon nanohorns provide a unique combination of strength, electrical conductivity, high surface area and open gas paths making them an ideal next generation electrode for various fuel cell applications.

2. Water filtration and remediation

Nanofiltration

A strong influence of nanochemistry on waste-water treatment, air purification and energy storage devices is to be expected. Mechanical or chemical methods can be used for effective filtration techniques. One class of filtration techniques is based on the use of membranes with suitable hole sizes, whereby the liquid is pressed through the membrane. Nanoporous membranes are suitable for a mechanical filtration with extremely small pores smaller than 10 nm (nanofiltration) and may becomposed of nanotubes. Nanofiltration is mainly used for the removal of ions or the separation of different fluids.

Magnetic nanoparticles offer an effective and reliable method to remove heavy metal contaminants from waste water by making use of magnetic separation techniques. Using nanoscale particles increases the efficiency to absorb the contaminants and is comparatively inexpensive compared to traditional precipitation and filtration methods. Some water-treatment devices incorporating nanotechnology are already on the market, with more in development. Low-cost nanostructured separation membranes methods have been shown to be effective in producing potable water in a recent study. Nanoscale iron particles have also shown potential as a detoxifying agent for cleaning environmental contaminents from brownfield sites.

Nanopollution

Nanopollution is a generic name for all waste generated by nanodevices or during the nano materials manufacturing process. This kind of waste may be very dangerous because of its size. It can float in the air and might easily penetrate animal and plant cells causing unknown effects. Most human-made nanoparticles do not appear in nature, so living organisms may not have appropriate means to deal with nanowaste. It is probably one great challenge to nanotechnology: how to deal with its nanopollutants and nanowaste.

Health issues

Health implications of nanotechnology

The health implications of nanotechnology are the possible effects that the use of nanotechnological materials and devices will have on human health. As nanotechnology is an emerging field, there is great debate regarding to what extent nanotechnology will benefit or pose risks for human health. Nanotechnology's health implications can be split into two aspects: the potential for nanotechnological innovations to have medical applications to cure disease, and the potential health hazards posed by exposure to nanomaterials.

Nanotoxicology is the field which studies potential health risks of nanomaterials. The extremely small size of nanomaterials means that they are much more readily taken up by the human body than larger sized particles. How these nanoparticles behave inside the organism is one of the big issues that need to be resolved. The behavior of nanoparticles is a function of their size, shape and surface reactivity with the surrounding tissue. Apart from what happens if non-degradable or slowly degradable nanoparticles accumulate in organs, another concern is their potential interaction with biological processes inside the body: because of their large surface, nanoparticles on exposure to tissue and fluids will immediately adsorb onto their surface some of the macromolecules they encounter. The large number of variables influencing toxicity means that it is difficult to generalise about health risks associated with exposure to nanomaterials – each new nanomaterial must be assessed individually and all material properties must be taken into account. Health and environmental issues combine in the workplace of companies engaged in producing or using nanomaterials and in the laboratories engaged in nanoscience and nanotechnology research. It is safe to say that current workplace exposure standards for dusts cannot be applied directly to nanoparticle dusts.

Nanomedicine is the medical application of nanotechnology. The approaches to nanomedicine range from the medical use of nanomaterials, to nanoelectronic biosensors, and even possible future applications of molecular nanotechnology. Nanomedicine seeks to deliver a valuable set of research tools and clinically helpful devices in the near future. The National Nanotechnology Initiative expects new commercial applications in the pharmaceutical industry that may include advanced drug delivery systems, new therapies, and in vivo imaging. Neuro-electronic interfaces and other nanoelectronics-based sensors are another active goal of research. Further down the line, the speculative field of molecular nanotechnology believes that cell repair machines could revolutionize medicine and the medical field.

Rare earth nanoparticles and rare earth oxide nanopowders are finding application in uses as varied as enhanced fiber optic amplification (EDFA) to the removal of phosphate in the blood of patients with Hyperphosphatemia. Iron Nanoparticles, Iron Oxide Nanopowder, Cobalt Nanoparticles, and several other elemental nanoparticles and alloys form a group of "Magnetic Nanoparticles" with promising application in medical treatment of cancer, magnetic storage and magnetic resonance imaging (MRI).

The biomedical and bio-science fields have found near limitless uses for nanoparticles. Nanoparticles made of peroxalate ester polymers with a fluorescent dye (pentacene) encapsulated into the polymer have been found to be capable of detecting cancer. This is due to the fact that hydrogen peroxide is generated in human cells that are pre-cancerous. The dye in the nanoparticles fluoresces when they come in contact with the hydrogen peroxide which can then be detected as light on medical imaging equipment. Artificial bone composites are now being manufactured from calcium phosphate nanocrystals. These composites are made of the same mineral as natural bone, yet have strength in compression equal to stainless steel. Tungsten Oxide Nanoparticles are being used in dental imaging because they are sufficiently radiopaque (impervious to radiation) for high quality X-ray resolution. The group of Magnetic Nanoparticles discussed above is being used to both kill cancer cells in malignant tumors and in MRI medical imaging. Coat tungsten particles with DNA and inject them into plant cells or plant embryos. Some genetic material will remain in the cells and transform them. This method allows transformation of plant plastids. The transformation efficiency is lower than in agro bacterial mediated transformation. The anti-bacterial and anti-microbial effects of many nanoparticles are well understood technology. Fluorescent nanoparticles are being used by biologists to stain and label cellular components. By changing the size of the quantum dot the color emitted can be controlled. With a single light source, one can see the entire range of visible colors, an advantage over traditional organic dyes.

Recent research has led to serious concern about the potential impacts of carbon nanotubes on human health. Nanotubes are complex materials, however, and there is significant potential to influence both hazard and risk by intelligent engineering of nanotube structure, purity, and surface properties. This presentation examines the underlying mechanisms through which nanotubes interact with biological structures and the role of specific material features that include length, biopersistence, surface chemical activity, and metals content and release behavior. A major concern for carbon nanotubes is their postulated adherence to the fiber pathogenicity paradigm, whose key material features are diameter, length, and biopersistence. New experiments will be described, in which nanotubes are undergo long-term exposure to oxidant-generating physiological simulants in a new assay designed to assess biopersistence. The assay is being used to search for covalent functionalization schemes that improve nanotube safety by promoting physiological degradation. The possibilities for length and aggregation control in nanotubes will also be discussed as additional methods for avoiding the pathogenic fiber classification.

A number of nanotoxicology studies have reported that carbon nanotubes induce oxidative stress, which is an imbalance between the generation and destruction of intracellular reactive oxygen species (ROS). From the fundamental chemical interactions between nanotubes and the key antioxidant, glutathione. It is found that single-wall nanotubes deplete GSH in buffers, and that GSH can be regenerated by addition of the physiological reducing reagent NADPH along with glutathione reductase, which provides strong evidence for an oxidation mechanism. The GSH reaction is significantly inhibited under conditions of low dissolved di-oxygen, further suggesting that the graphenic nanotube surface reduces molecular oxygen to reactive peroxide intermediates, which are the direct oxidants for GSH.

Societal implications of nanotechnology

Beyond the toxicity risks to human health and the environment which are associated with first-generation nanomaterials, nanotechnology has broader societal implications and poses broader social challenges. Social scientists have suggested that nanotechnology's social issues should be understood and assessed not simply as "downstream" risks or impacts. Rather, the challenges should be factored into "upstream" research and decision making in order to ensure technology development that meets social objectives.

Many social scientists and organizations in civil society suggest that technology assessment and governance should also involve public participation.

Societal risks from the use of nanotechnology have also been raised. On the instrumental level, these include the possibility of military applications of nanotechnology (for instance, as in implants and other means for soldier enhancement like those being developed at the Institute for Soldier Nanotechnologies at MIT as well as enhanced surveillance capabilities through nano-sensors.

On the structural level, critics of nanotechnology point to a new world of ownership and corporate control opened up by nanotechnology. The claim is that, just as biotechnology's ability to manipulate genes went hand in hand with the patenting of life, so too nanotechnology's ability to manipulate molecules has led to the patenting of matter. The last few years has seen a gold rush to claim patents at the nanoscale. Over 800 nano-related patents were granted in 2003, and the numbers are increasing year to year. Corporations are already taking out broad-ranging patents on nanoscale discoveries and inventions. For example, two corporations, NEC and IBM, hold the basic patents on carbon nanotubes, one of the current cornerstones of nanotechnology. Carbon nanotubes have a wide range of uses, and look set to become crucial to several industries from electronics and computers, to strengthened materials to drug delivery and diagnostics. Carbon nanotubes are poised to become a major traded commodity with the potential to replace major conventional raw materials. However, as their use expands, anyone seeking to (legally) manufacture or sell carbon nanotubes, no matter what the application, must first buy a license from NEC or IBM.

Potential benefits and risks for developing countries

Nanotechnologies may provide new solutions for the millions of people in developing countries who lack access to basic services, such as safe water, reliable energy, health care, and education. The United Nations has set Millennium Development Goals for meeting these needs. The 2004 UN Task Force on Science, Technology and Innovation noted that some of the advantages of nanotechnology include production using little labor, land, or maintenance, high productivity, low cost, and modest requirements for materials and energy.

Potential opportunities of nanotechnologies to help address critical international development priorities include improved water purification systems, energy systems, medicine and pharmaceuticals, food production and nutrition, and information and communications technologies. Nanotechnologies are already incorporated in products that are on the market. Other nanotechnologies are still in the research phase, while others are concepts that are years or decades away from development.

Protection of the environment, human health and worker safety in developing countries often suffers from a combination of factors that can include but are not limited to lack of robust environmental, human health, and worker safety regulations; poorly or unenforced regulation which is linked to a lack of physical (e.g., equipment) and human capacity (i.e., properly trained regulatory staff). Often, these nations require assistance, particularly financial assistance, to develop the scientific and institutional capacity to adequately access and manage risks, including the necessary infrastructure such as laboratories and technology for detection.

Producers in developing countries could also be disadvantaged by the replacement of natural products (including rubber, cotton, coffee and tea) by developments in nanotechnology. These natural products are important export crops for developing countries, and many farmers' livelihoods depend on them. It has been argued that their substitution with industrial nano-products could negatively impact the economies of developing countries that have traditionally relied on these export crops.

Regulation of nanotechnology

There is significant debate about who is responsible for the regulation of nanotechnology. While some non-nanotechnology specific regulatory agencies currently cover some products and processes (to varying degrees) – by "bolting on" nanotechnology to existing regulations – there are clear gaps in these regimes.

The Royal Society report identified a risk of nanoparticles or nanotubes being released during disposal, destruction and recycling, and recommended that "manufacturers of products that fall under extended producer responsibility regimes such as end-of-life regulations publish procedures outlining how these materials will be managed to minimize possible human and environmental exposure". Reflecting the challenges for ensuring responsible life cycle regulation, the Institute for Food and Agricultural Standards has proposed standards for nanotechnology research and development should be integrated across consumer, worker and environmental standards. They also propose that NGOs and other citizen groups play a meaningful role in the development of these standards.

What is the future of Nanotechnology?

Nanotechnology is expected to have an impact on nearly every industry. The U.S. National Science Foundation has predicted that the global market for nanotechnologies will reach $1 trillion or more within 20 years. The research community is actively pursuing hundreds of applications in nanomaterials, nanoelectronics, and bionanotechnology. Most near term (1-5 years) applications of nanotechnology are in the form of nanomaterials. These include materials such as lighter and stronger nanocomposites, antibacterial nanoparticles, and nanostructured catalysts. Nanodevices and nanoelectronics are farther off, perhaps 5-15 years, and will have applications in medical treatments and diagnostics, faster computers, and in sensors.

REFERENCES:

Anonymous (2005a): International Technology Roadmap for Semiconductors, Emerging Research Devices.

Anonymous (2005b): International Technology Roadmap for Semi-conductors, Emerging Research Devices.

Snider, G. S. and Williams, R. S. (2007): Nano/CMOS architectures using a field-programmable nanowire interconnect*," Nanotechnology*, **18**: 1-11.