SUSTAINABLE NANOTECHNOLOGY

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1. Introduction

The long-term vision of all nanotechnologists has been the fabrication of a wider range of materials and products with atomic precision. However, experts in the field have had strong differences of opinion on how rapidly this will occur. It is uncontroversial that expanding the scope of atomic precision will dramatically improve high-performance technologies of all kinds, from medicine, sensors, and displays to materials and solar power. Applying Moore's law it is reasonable to assume all this will happen in the next 15 years or less [1].

Nanotechnology is considered to be the fifth industrial revolution. Unlike any other industrial revolution, its benefits are likely to reach a major portion of the inhabitants of the planet since many nations share a common market driven capitalist economic structure. Experts around the globe agree that we have tipped the scale of population vs. resources, probably for all time, and the balance of resources and their use is no longer in our favor [2]. , in April 2005, the Millennium Ecosystem Assessment carried out by the United Nations [1] indicated that "*...the ability of ecosystems to sustain future generations can no longer be taken for granted.*" In spite of the pervasive economic notion that technology will allow further production gains, accessible global oil production is estimated to have peaked. By 2020 the Middle East will control 83% of global oil supplies, and by 2070, there may be no more cost effective oil supplies available [3,4]. About 75% of the existing prescription drugs in the United States are synthetic [5], and for the remaining 25% derived from nature, they too rely on organic solvents (made from poetroleum) for their extraction and purification. From where will the medicinal agents of the future be derived as the living biomaterials are depleted and the global competition for oil increases on a daily basis? Therefore, we cannot be satisfied scientific discoveries based on non-renewable resources. It is becoming increasingly important to know the outcome of the products of a process at the end of their life time. Today, we are more aware that the innovations we come up with must not destroy the fundamentals that sustain the entire ecosystem including the humans.

2. Nanotechnology and sustainability

It is important to put nanotechnology side by side with sustainability considering the seemingly insurmountable challenges faced by the human race in the coming decades due to population increase and resource depletion. For nanotechnology to make an impact on sustainability, it must come up with solutions to the problems created by technology in general in the last two centuries. Such an analysis makes it easier to understand how nanotechnology could benefit mankind: Nano-scale manufacturing platforms could make geography, raw materials, as well as labour, irrelevant. By employing nanotechnology to build from the bottom-up rather than processing down, the quantity of raw materials required could be sharply reduced. In short, nano-scale technologies are poised to become the strategic platform for global control of materials, food, agriculture and health in the immediate years ahead. With respect to nanotechnology, emerging dictum for the developing world should be: *more from less for more*. Undoubtedly, efficient systems of production and getting more from less is closely related to sustainability.

Nanotechnology can become a sustainable technology only if there is societal acceptance, minimal risk and maximum benefit. Nanotechnology by definition is diverse, enabling, evolving, inter disciplinary and in general generic. Sustainable nanotechnology can be looked at in two ways: producing nanomaterials and products which are not toxic,and producing nano-products that remedy environmental problems. Such an enterprise should at transformations at low temperatures using less energy and renewable inputs wherever possible, and using lifecycle thinking in all design and engineering stages.

In addition to making nanomaterials and products with less impact to the environment, sustainable nanotechnology should strive to make current manufacturing processes for non-nano materials and products more environmentally friendly. For example, nanoscale membranes can help separate useful chemicals from waste. Nanoscale catalysts can drive chemical reactions more efficiently with less waste. Sensors at the nanoscale can be integrated into process control systems, working with nano-enabled information systems.

Secondly, Nanomaterials or products can offer sustainability if they can clean hazardous waste sites, desalinate water, treat pollutants, or sense and monitor environmental pollutants. Furthermore, lightweight nanocomposites can offer fuel savings and material reduction in the transportation sector. Nanotechnology-enabled fuel cells and light-emitting diodes (LEDs) could lead to the conservation of fossil fuels and lead to less environmental pollution. Self-cleaning nanosurface coatings could reduce or eliminate the use of conventional cleaning agents and enhanced battery life could lead to less material use and less waste. Thus, sustainable nanotechnology should take a broad analysis of nanomaterials and products, in order to ensure that unforeseen consequences are minimized and that impacts are anticipated and controlled throughout their full life cycle.

Applications of nanotechnology are enabled by nanomaterials, which have novel optical, electric or magnetic properties. The building blocks of nanotechnology are semiconductors, metals, metal oxides, carbon materials and organics. The emerging commercial growth areas in nanotechnology are nanomaterials and nanomaterials processing, nanobiotechnology, software, nanophotonics, nanoelectronics and nanoinstrumentation. Nanomaterials and nanomaterials processing companies develop the materials and methods to manipulate and manufacture products based on nano materials. Clearly, the raw materials for these industries must come from renewable or non-renewable resources of the planet. Therefore, if the raw materials are not replenished the nanotechnologies will perish before it can yield benefits to successive generations.

Sustainable development of nanotechnology covers several areas. These include:

2.1. Development of "intelligent" materials and reduction of materials use in production;

With nanotechnology, a large set of materials and improved products rely on a change in the physical properties when the feature sizes are shrunk. Nanoparticles, for example, take advantage of their dramatically increased surface area to volume ratio. Their optical properties, e.g. fluorescence, become a function of the particle diameter. These nano-materials or nanocomposite materials made by incorporating nanoparticles into polymers have applications in faster computers, advanced pharmaceuticals, controlled drug delivery, biocompatible materials, nerve and tissue repair, crack proof surface coatings, better skin care and protection, more efficient catalysts, better and smaller sensors, even more efficient telecommunications [6.] Such nanomaterial products, in addition to using lesser raw materials in their production will become an all pervasive technology in the decade to come.

2.2. Development of specific nanotechnologies and new materials for use in water treatment or for energy and transport and agriculture applications;

Only 30% of all freshwater on the planet is not locked up in ice caps or glaciers (not for much longer, though). Of that, some 20% is in areas too remote for humans to access and of the remaining 80% about three-quarters comes at the wrong time and place - in monsoons and floods - and is not always captured for use by people. The remainder is less than 0.08 of 1% of the total water on the planet. The problem is that we don't manage this small quantity very well. Currently, 600 million people face water scarcity. Depending on future rates of population growth, between 2.7 billion and 3.2 billion people may be living in either water-scarce or water-stressed conditions by 2025 [7]. Many areas, especially in developing countries, are seriously contaminated or damaged with consequent impoverishment of natural resources and serious effects on human health. Remediation of contaminated water – the process of removing, reducing or neutralizing water contaminants that threaten human health and/or ecosystem productivity and integrity – is a field of technology that has attracted much interest recently.

Membrane processes are considered key components of advanced water purification and desalination technologies and nanomaterials such as carbon nanotubes, nanoparticles, and dendrimers are contributing to the development of more efficient and cost-effective water filtration processes.

There are two types of nanotechnology membranes that could be effective: nanostructured filters, where either carbon nanotubes or nanocapillary arrays provide the basis for nanofiltration; and nanoreactive membranes, where functionalized nanoparticles aid the filtration process.

In the area of agriculture, in conventional fertilizers the loss of the macronutrient nitrogen to the environment during application is one of the major problems which has not received much attention. Loss of nitrogen exceeding 50 – 60% is due to conversion to water soluble nitrates, gaseous ammonia and incorporation into the soil with the aid of soil microorganisms [8]. Attempts to solve this loss, causing direct and indirect environmental pollution have met with little success. However, application of nanotechnology involving slow release fertilizer can increase the nitrogen utilization efficiency. In an attempt to address this problem, SLINTEC has come up with two slow release fertilizer compositions: In the first solution [9], an inorganic inner nano-core consisting hydroxyapatite nanoparticles which contain the macronutrient phosphorus coated with nitrogen containing urea has been encapsulated within a natural cellulose based outer core [*Gliricidia sepium* (albesia) stem] containing micro/nano porous cavities. In the second project, the fertilizer system is based on urea modified hydroxy apatite nanoparticles intercalated in montmorilonite [10]. The nanocomposites prepared by this processes when applied to aqueous and terrestrial environments releases the macronutrient compound in a slow and sustained manner. The nanocomposite acts as a reservoir for slow and sustained release of nitrogen macronutrient through the soil medium. The soil medium acts as a conduit for providing the pH for release and transport of the macronutrients such as urea to the roots of the plant. Such solution, properly adapted can have a profound impact on energy, the economy and the environment.

2.3. *Development of biosensors for environmental applications;*

Various kinds of nanomaterials such as gold, carbon nanotubes, magnetic nanoparticles and quantum dots are increasingly used as biosensors because of the unique physical, chemical, mechanical, magnetic and optical properties which aid in the enhancement of selectivity and sensitivity of detection [11]. One dimensional nanostructures such as carbon nanotubes are attractive for bioelectronic sensing applications. Of particular importance are electrochemical sensors which are capable of interfacing at the molecular level, applications of enzyme electrodes where direct electron transfer from the enzyme to the electrode surface can open avenues for reagentless biosensors and bioaffinity biosensors such as DNA hybridization biosensors [12].

2.4. *Life Cycle Assessment of the potential benefits, health, safety, and environmental risks associated with nanotechnology-based materials and their processing, and with chemicals processing;*

Life cycle assessment (LCA) of nanoparticles and nano-enabled products are important in finding answers to issues such as [13]:

(a) How do life cycles of products/devices using nanomaterials compare to those made by conventional materials particularly in the area of energy consumption;
(b) What particular phase in the life cycle use the largest amount of energy;
(c) Identification of particular end-of-life management issues specific to nanomaterials such as recovery, reuse and recycling;
(d) Identification eco-toxicity and human toxicity of nanomaterials;

Several types of nanoparticles have shown unintended consequences. For example silver nanoparticles, which are bacteriostatic, may destroy beneficial bacteria which are important for breaking down organic matter in waste treatment plants or farms [14]. Similar concerns have been expressed about TiO_2 and carbonanotubes. Aerosols resulting from nanoparticles and their manipulation, the resulting agglomerates and their degradation aerosols and suspensions should be cleared of any potential harm to humans and the ecosystem. If we rely only on exposure controls, such attempts will fail in the long term. Therefore, research must strive for performance without toxicity with the implicit assumption that innovation is not attractive enough until we reach that point [15]. While conventional technologies may use a compartmentalized model where chemists do the synthesis, epidemiologists and toxicologists document the side effects and find mechanisms of ensuing diseases and hygienists will recommend ways to minimize risk. Because of nanotechnologies complex and emerging nature with high social cost, they must employ a holistic model where risk based and application based research must be integrated thus proactively minimizing health and eco risks.

In the area of using green solutions to nanotechnology based research, SLINTEC has been successful in inventing process for producing a nanocomposite containing exfoliated organically modified montmorillonite clay and maleic anhydride grafted elastomer in a dispersion of natural rubber and inert filler which completely avoids the use of reinforcing and environmentally hazardous carbon black [16].

Public participation with nanotechnologies is often described as ‘upstream’ in nature, reflecting its occurrence before commercialization in real-world applications and before significant social controversy [17]. Thus potential problems are being addressed while research on nanotechnology continues so as not to embrace the controversies that GM foods were subjected to. Risk perception analysis indicates that technology’s acceptability will depend upon people’s perceptions of both benefit and risk, with the balance between the two depending upon the particular technology or the context within which judgments are formed. Nanotechnology survey research in the United States and United Kingdom to date shows two clear findings. The first is that most people know little or nothing about nanotechnologies. Second, notwithstanding this, many feel that nanotechnology’s future benefits will outweigh its risks.

In April 2005, the Project on Emerging Nanotechnologies (PEN) was established as a partnership between the Woodrow Wilson International Center for Scholars and the Pew Charitable Trusts. The main objective of the project is to ensure that as nanotechnologies continue, possible risks are minimized, public and consumer engagement remains strong, and the potential benefits of these technologies are recognized. One of the PEN reports, entitled “Nanotechnology: A Research Strategy for Addressing Risks”, was released in July 2006 [18]. It prioritizes research area needs in order to evaluate risks associated with nanotechnologies. Immediate research needs are sources of exposure, exposure routes and exposure measurement methods. This PEN report also recommends early investment in medium-term and long term-research needs, including risk assessment, life cycle analysis, computational toxicology, nanomaterials release into the environment and ecotoxicology.

In addition to the more direct human and environmental and toxicology issues, some have also suggested that nanotechnologies will raise wider social, ethical and governance issues. These include concerns over long-term unintended consequences, the means by which governments and society might control the technologies, social risks from covert surveillance arising from nano-based sensors and systems, and financial or other detrimental impacts upon the developing world. In the health arena, in particular, longer term developments in nanotechnologies is poised to raise a range of fundamental ethical issues regarding the possibilities for human enhancement, to draw up a demarcating line between 'enhancement' and 'therapy', and the impacts of these ideas on the identity of individuals [19-21].

In the context of sustainable nanotechnology, the research carried out by the Sri Lanka Institute of Nanotechnology is noteworthy. The nanotechnology initiative in Sri Lanka launched through Nanotechnology Company (NANCO) and the Sri Lanka Institute of Nanotechnology (SLINTEC) is unique because the government and the private sector have invested equally in the project. SLINTEC by definition provides platform research solutions in sustainable nanotechnology to the Sri Lankan industries. In its commitment to the Triple Bottom Line in business, all research projects undertaken by SLINTEC are subjected to a sustainability screen to ensure that research output is in conformity with social sustainability, environmental sustainability and economic sustainability.

Finally, sustainability of nanotechnology will depend on valid questions being asked about the new technology and coming up with scientific answers which will enable society at large shed their confusions and embrace it with reserved acceptance.

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