ACHIEVING SUSTAINABLE DEVELOPMENT GOALS THROUGH NANOTECHNOLOGY IN POLYMER AND TEXTILE

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ABSTRACT

One of the greatest challenges facing society in the twenty-first century is providing better living standards to all people while minimizing the impact of human activities on the global environment and climate as the world population increases. This paper discusses copiously on achieving sustainable development goals through the utilization of nanotechnology in polymer and textile. It examines recent advances and opportunities of utilizing nanotechnology to address global challenges in water purification, clean energy technologies, agriculture, greenhouse gases management, materials supply and utilization, green manufacturing and textile. In addition to the technical challenges listed above, societal perspectives and an outlook of the role of nanotechnology in the convergence of knowledge, technology and society for achieving sustainable development are also discussed. Nanotechnology has emerged as a general platform with economical and ecological advantages that could provide acceptable solutions to the global sustainability challenges facing society.

Keywords: Nanotechnology, nanomaterials, nanoscale, polymer, sustainable development and textile.

INTRODUCTION

The use of nanomaterials- and nanotechnology-based processes is growing at a tremendous rate in all fields of science and technology. Nanotechnology has emerged as a versatile platform that could provide efficient, cost-effective and environmentally acceptable solutions to the global sustainability challenges facing society. According to Richard Smalley, a nanotechnology pioneer who was awarded the Nobel Prize in chemistry in 1996 for his discovery of fullerenes, "the impact of nanotechnology on health, wealth, and the standard of living for people will be at least the equivalent of the combined influences of microelectronics, medical imaging, computer-aided engineering, and man-made polymers in this century" (Smalley, 1999). Textile industry is also experiencing the benefits of nanotechnology in its diverse field of applications.

As Sustainable development Goals (SDGs) follow and expand on the Millennium development goals (MDGs), which were formally agreed by the governments in 2012 with MDGs due to expire at the end of 2015 (UN, 2014). The United Nations (UN) Conference on Environment and Development in Rio de Janeiro in 2012 made sense of the interactions of three complex systems:

- the world economy
- the global society and
- the earth's physical environment

The development is sustainable if economic progress is widespread, extreme poverty is eliminated, social trust is encouraged through policies that strengthen the community, and the environment is protected from human-induced degradation.

A global scientific and societal endeavor was set in motion by the nanotechnology vision formulated in 1999 that inspired the National Nanotechnology Initiative (NNI) and other national and international Research and Development (R&D) programs. Establishing foundational knowledge at the nanoscale has been the main focus of the nanotechnology research community in the first decade (NSF, 2001). As of 2009, this new knowledge underpinned about a quarter of a trillion dollars worldwide market, of which about $91 billion was in US products that incorporate nanoscale components. Nanotechnology is already evolving toward becoming a general-purpose technology by 2020, encompassing four generations of products with increasing structural and dynamic complexity:

- passive nanostructures
- active nanostructures
- nanosystems
- molecular nanosystems

By 2020, the increasing integration of nanoscale science and engineering knowledge and of nanosystems promises mass applications of nanotechnology in industry, medicine, and computing, textile and in better comprehension and conservation of nature. Nanotechnology's rapid development worldwide is a testimony to the transformative power of identifying a concept or trend and laying out a vision at the synergistic confluence of diverse scientific research areas.

Greater repeatability, reliability and robustness are the main advantages of nanotechnological advancements in textiles. Textile-based nanoproducts starting from nanocomposite fibers, nanofibers to intelligent high-performance polymeric nanocoatings are getting their way not only in high performance advanced applications but nanoparticles are also successfully being used in conventional textiles to impart new functionality and improved performance. Nanoparticle application during conventional textile processing techniques, such as finishing, coating and dyeing, enhances the product performance manifold and imparts hitherto unachieved functionality.

This paper is focused on achieving sustainable development goals through nanotechnology in polymer and textile. It discusses the development and potential applications of nanotechnology in developing new and multifunctional polymeric and smart nanocomposite products.

SUSTAINABLE DEVELOPMENT GOALS (SDGS): CHANGING THE WORLD IN 17 STEPS

The Sustainable Development Goals (SDGs) are a proposed set of targets relating to future international development. They are to replace the Millennium Development Goals once they expire at the end of 2015. The SDGs were first formally discussed at the United Nations Conference on Sustainable Development held in Rio de Janeiro in June 2012 (Rio+20). SDGs are to replace the Millennium Development Goals once they expire at the end of 2015. They are a new, universal set of goals, targets and indicators that the United Nations (UN) member states will be expected to use to frame their agendas and political policies over the next 15 years (UN, 2015).

On 19 July 2014, the UN General Assembly's Open Working Group on Sustainable Development Goals (OWG) forwarded a proposal for the SDGs to the Assembly. The proposal contained 17 goals with 169 targets covering a broad range of sustainable development issues. These included ending poverty and hunger, improving health and education, making cities more sustainable, combating climate change, and protecting oceans and forests. On 4 December 2014, the UN General Assembly accepted the Secretary-General's Synthesis Report which stated that the agenda for the post-2015 SDG process would be based on the OWG proposals. (UN, 2014)

Background of Sustainable Development Goals

Up to 2015, the development agenda was centered on the Millennium Development Goals (MDGs), which were officially established following the Millennium Summit of the United Nations in 2000. The MDGs encapsulated eight globally agreed goals in the areas of poverty alleviation, education, gender equality and empowerment of women, child and maternal health, environmental sustainability, reducing HIV/AIDS and communicable diseases, and building a global partnership for development. The MDGs were supposed to be achieved by 2015 so a further process was needed to agree and develop development goals from 2015-2030. Discussion on the post 2015 framework for international development began well in advance. Formal debate concerning the SDGs first occurred at the 2012 United Nations conference in Rio de Janeiro. (Ferdinando, 2015). The 192 UN member states agreed at the Rio+20 summit to start a process of designing sustainable development goals, which are "action-oriented, concise and easy to communicate, limited in number, aspirational, global in nature and universally applicable to all countries while taking into account different national realities, capacities and levels of development and respecting national policies and priorities" (UN, 2013).

REVIEW OF NANOTECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

Nanotechnology involves the investigation and design of materials or devices at the atomic and molecular levels. One nanometer, a measure equal to one billionth of a meter, spans approximately 10 atoms. Formulating a precise definition of nanotechnology, however, is a difficult task. Even scientists in the field maintain that it "depends on whom you ask. For example, some researchers use the term to describe almost any research where some critical size is less than a micron (1,000 nanometer) while other scientists reserve the term for research involving sizes between 1 and 100 nanometer (Gary, 2001). There is also debate over whether naturally occurring nanoparticles, such as carbon soot, fall under the rubric of nanotechnology. Finally, some reserve the term "Nanotechnology" exclusively for manufacturing with atomic precision whereas others employ the term to describe the use of nanomaterials to construct materials, devices, and systems. The National Science Foundation, on the other hand, defines nanotechnology as "research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1–100 nanometer range, to provide a fundamental understanding of phenomena and materials at the nanoscale and to create and use structures, devices and systems that have novel properties and functions because of their small and/or intermediate size (NNI, 2015).

Nanomaterials exhibit key physicochemical properties that make them particularly attractive as functional materials for sustainable technologies. On a mass basis, they have much larger and more active surface areas than bulk materials. Nanomaterials can be functionalized with various chemical groups to increase their affinity toward a given compound including dissolved solutes and gases. They can also be functionalized with chemical groups that selectively target key biochemical constituents and metabolic/signaling networks of waterborne bacteria and viruses. Nanomaterials are also providing unprecedented opportunities to develop functional materials with superior electronic, optical, catalytic and magnetic properties. These novel functional materials can be processed into various form factors including water-soluble supramolecular hosts, particles, fibers and membranes. Some recent advances in the utilization of nanotechnology to address global sustainability challenges are stated thus:

- water purification
- clean energy technologies
- agricultural applications of nanotechnology
- greenhouse gases management
- materials supply and utilization and
- green manufacturing and chemistry
- applications of nanotechnology based textiles

Water Purification

The availability of clean water has emerged as one of the most critical problems facing society and the global economy in the twenty-first century (Savage and Diallo 2005; Shannon et al. 2008; Diallo and Brinker, 2011). Many regions of the world face multiple challenges in sustainably supplying potable water for human use and clean water for agriculture, food processing, energy generation, mineral extraction, chemical processing, and industrial manufacturing (Shannon et al. 2008; Diallo and Brinker, 2011). Demand for water is increasing due to population growth at the same time as water supplies are being stressed by the increasing contamination and salinization of freshwater sources including lakes, rivers and groundwater aquifers. A report published by the Intergovernmental Panel on Climate Change (Bates et al. 2008) suggests that global climate change will adversely impact the world's freshwater resources in several ways:

- increase the frequency of droughts and floods
- decrease the amount of water stored in snowpack and glaciers; and
- decrease the overall water quality due to salinity increase and enhanced sediment, nutrient, and pollutant transport in many watersheds throughout the world.

In view of this, a significantly larger amount of clean water needs to be produced from impaired water (e.g., wastewater, brackish water and seawater) to meet the growing demand throughout the world in the next decade and beyond. The convergence between nanotechnology and water science and technology is leading to revolutionary advances in water treatment, desalination and reuse technologies (Savage and Diallo, 2005; Shannon et al. 2008; Diallo and Brinker, 2011).

Pressure-driven membrane processes such as reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF) and microfiltration (MF) are becoming the key components of advanced water treatment, reuse and desalination systems worldwide (Savage and Diallo, 2005; Shannon et al. 2008). Pore geometry, surface charge and nonlinear electrokinetic effects arising from the interplay between surface charge density and surface energy control the transport of ions and charged particles in nanopores with diameters below 100 nm. These membrane systems are providing new opportunities for sustainable applications of nanotechnology to make clean and quality water available to mankind.

Clean Energy Technologies

Global climate change is one of the greatest challenges facing the twenty-first century (Solomon et al. 2007). During the last two decades, a consensus has gradually emerged that increasing emissions of greenhouse gases such as carbon dioxide (CO_2) from the combustion of fossil fuels (e.g., coal and petroleum) are the key drivers of global climate change (Solomon et al. 2007). Meeting the growing demand for energy while significantly reducing CO_2 emissions will require the deployment of orders of magnitude more clean and renewable energy systems than what is now in place as the world population reaches 8–10 billion by 2050 (Brinker and Ginger, 2011; Fromer et al. 2011; Diallo et al. 2013). Nanotechnology provides unprecedented opportunities to advance the development of clean and renewable energy technologies (Fromer and Diallo, 2013). Solar photovoltaics has emerged the most attractive source of renewable electrical energy due to its abundance, versatility, and ease of implementation with minimum environmental impact in terms of water consumption and land usage (Lewis, 2007; Brinker and Ginger, 2011). Choi et al. (2012) discusses hydrogen generation by solar water splitting using organic contaminants in wastewater as sacrificial electron donors. This work is potentially important since solar radiation is intermittent and the large-scale implementation of solar power will require efficient systems that convert solar energy into high density chemical fuels. The authors demonstrated the feasibility of a scaled-up rooftop prototype of a hybrid photovoltaic electrolysis system which utilizes semiconductor nanoparticles coated onto metal substrates as electrodes for the generation of hydrogen coupled with the oxidation of organic compounds in wastewater.

In industrialized countries such as the United States of America (USA), transportation is responsible for approximately 66 % of oil consumption and 33 % of CO_2 emissions (Davis et al. 2008; EPA, 2008). Thus, fuel cell cars could meet the world's growing demand for transportation vehicles while significantly reducing CO_2 emissions. Polymer electrolyte membrane fuel cells (PEMFCs) have emerged as the most promising energy conversion devices for automotive applications.

Agricultural Applications of Nanotechnology

Cost-effective agricultural applications of nanotechnology could decrease hunger, malnutrition, and childhood mortality, in part by increasing soil fertility and crop productivity. Crop health can be monitored using nanosensor arrays. Nanosensors can raise the efficiency of crop monitoring activities. Sensors applied to the skin of livestock or sprayed on crops can help detect the presence of pathogens. Nanoporous materials such as zeolites, which can form well controlled stable suspensions with absorbed or adsorbed substances, can be employed for the slow release and efficient dosage of fertilizers for plants and of nutrients and drugs for livestock (Calestous and Lee, 2005).

Nanobiotechnology, the convergence of nanotechnology and biotechnology, can be harnessed to enrich biodiversity. Researchers at Chiang Mai University, in Thailand, are using nanotechnology to develop a strain of rice that has shorter stems and that is not sensitive to sunlight, thereby reducing vulnerability to wind damage and decreasing storage related costs (Calestous and Lee, 2005).

Greenhouse Gases Management

Currently, fossil fuels provide approximately 80% of the energy used worldwide (IPCC, 2005). Although many non-CO_2 emitting energy sources are being developed, the world will continue to burn significant amounts of fossil fuels in the foreseeable future. Thus, carbon capture and storage is emerging as a viable short-to-medium term alternative for reducing the amounts of anthropogenic CO_2 released into the atmosphere (IPCC 2005). Nanotechnology has the potential to provide efficient, cost-effective and environmentally acceptable solutions for CO_2 separation, capture and storage (Diallo and Brinker, 2011). Thermally rearranged (TR) polymer membranes with nanoengineered cavities tuned for CO_2 separation by Kim and Lee (2012) reviews recent developments in CO_2 separation technologies utilizing various membranes including thermally rearranged (TR) polymeric membranes with CO_2 selective nanocavities. The authors reported that these new TR polymeric membranes show high gas permeability as well as good selectivity, especially in CO_2 separation from post-combustion flue gases.

Materials Supply and Utilization

Innovations in the sustainable supply and utilization of materials will also be critical to developing the next generation of sustainable technologies and products (Diallo et al. 2013). Metals are used to fabricate the critical components of numerous products and finished goods, including airplanes, automobiles, cell/smart phones and biomedical devices (NRC, 2008; Diallo and Brinker, 2011). Carbon-based materials derived from petroleum are also the building blocks of a broad range of essential products and finished goods, including plastics, solvents, adhesives, fibers, resins, gels, and pharmaceuticals (Diallo et al. 2013). Sustainable utilization and supply of critical materials by Fromer and Diallo (2013) discusses the utilization of nanotechnology to achieve and improve materials sustainability for energy generation, conversion and storage. In their perspectives, the authors argue that many current problems involving the sustainable utilization and supply of critical materials in clean/renewable energy technologies could be addressed using nanostructured materials with enhanced electronic, optical, magnetic and catalytic properties and nanotechnology-based separation materials and systems that can recover critical materials from non-traditional sources including mine tailings, industrial wastewater and electronic wastes with minimum environmental impact.

Nanotechnology has also emerged as a versatile platform for addressing materials sustainability in agriculture through the development of smart systems for controlled/precision release of nutrients, fertilizers and pesticides (Scott and Chen 2003; Diallo and Brinker, 2011).

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Green Manufacturing and Chemistry

Manufacturing is critical to a sustainable world economy. It is the key engine that drives innovation and creates higher value jobs in both developed and developing countries (Liveris, 2012). Industrial manufacturing has a heavy environmental footprint. First, it requires a significant amount of materials, energy and water. Second, it generates a lot of wastes (gaseous, liquid and solid) and toxic by-products that need to be disposed of or converted into harmless products. Nanotechnology is emerging as an enabling platform for green manufacturing and chemistry in the semiconductor, chemical, petrochemical, materials processing, pharmaceutical and many other industries (Schmidt, 2007; Diallo and Brinker, 2011). Busnaina et al. (2013) discusses the state-of-the-art of nanomanufacturing. The authors argue that rapid and directed assembly based processes, which are carried out at room temperature and ambient pressure, could significantly decrease the cost of manufacturing equipment and tools and achieve ‘‘long-term sustainability’’ by reducing the consumption of materials, water, energy and the generation of wastes. The convergence between nanotechnology and biotechnology is also providing new opportunities to develop non-toxic and environmentally acceptable ‘‘green chemistry’’ routes for the synthesis of functional nanomaterials using bacteria, fungi and plants (Mohanpuria et al. 2008).

Applications of Nanotechnology Based Textiles

The reduction in water consumption during nanotechnology applications in textile processing has the potential to control the effluent problems of a textile process house. Textile-based nanoproducts starting from nanocomposite fibers, nanofibers to intelligent high-performance polymeric nanocoatings are getting their way not only in high performance advanced applications but nanoparticles are also successfully being used in conventional textiles to impart new functionality and improved performance. New coating techniques like sol-gel, layer-by-layer, plasma polymerization etc. can develop multi- functionality, intelligence, excellent durability and weather resistance to fabrics (Guy, 2010).

Active Areas of Textile Research and Development (R&D): Functional Textiles

- Fragrance release textiles
- Photocatalytic textile coatings
- Shape Memory Polymers for Intelligent textiles
- Self-Cleaning Fabrics
- Carbon Nanotubes for Electronic Textiles
- Multifunctional Coatings for Medical Textile Applications
- Textile switches and sensors, and electronic noses
- Bioactive wound dressings
- Electrically conductive textiles
- Stain and water repellent textiles
- Healing textiles

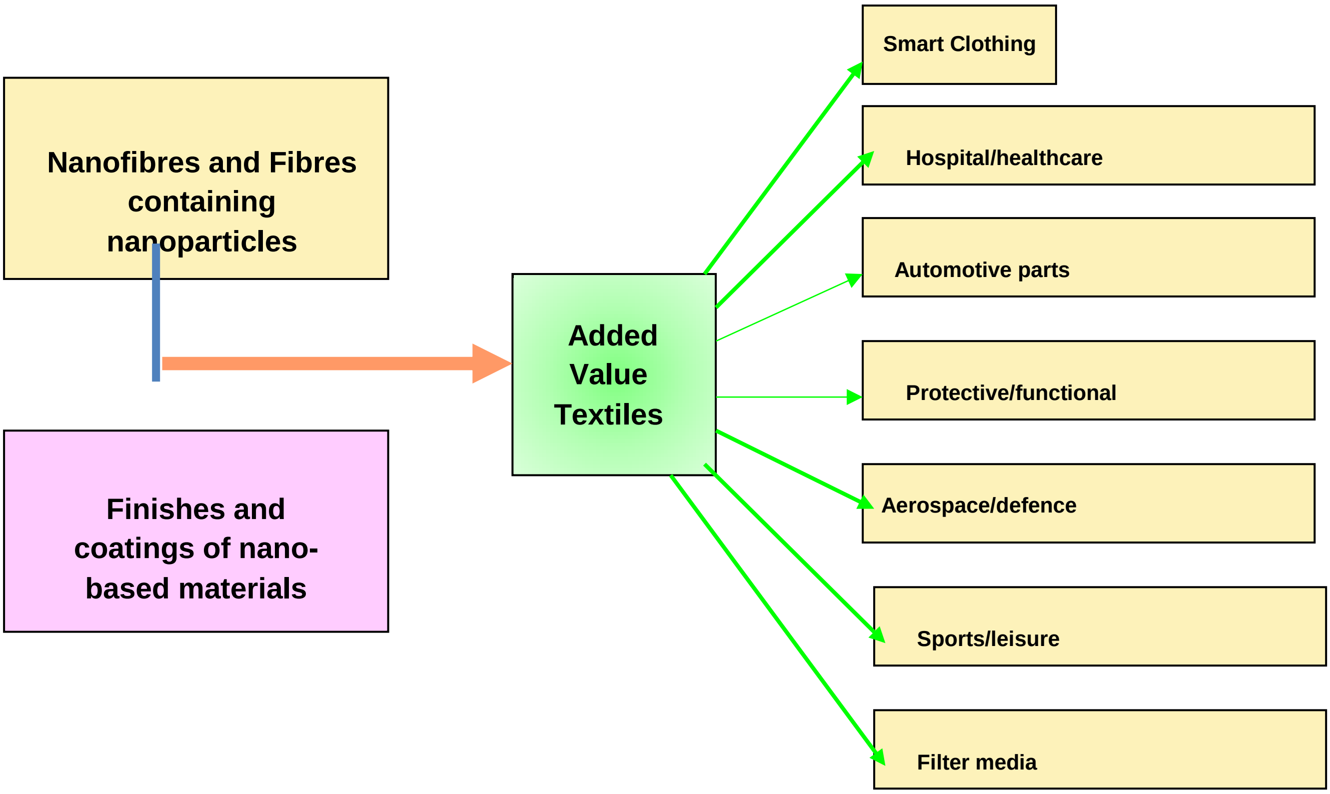

Fig 1: Nanotechnology Based Textiles Applications

Nanotechnology presents a tremendous opportunity for the global textile industry to generate new products that could energize the economy, solve major societal problems, revitalize existing industry, and create entirely new businesses (Umer, 2009).

CONCLUSION

Nanotechnology economic and ecological sustainability opportunities are numerous and stakes are high in economic front. It is for us to embrace nanotechnology positively and proactively and give value for money and man. Because sustainability entails considering social, economic and environmental factors, it is critical in all cases to integrate fundamental science (e.g., materials synthesis, characterization and modeling) with engineering research (e.g., system design, fabrication and testing), commercialization (e.g., new products) and societal benefits (e.g., new jobs and cleaner environment). Nanotechnology is simply, small things creating big businesses and sustaining developments.

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