NANOTECHNOLOGY WITH WIDE APPLICABILITY FOR DEVELOPMENT AND HOW IT IS CONTRIBUTING TO ACHIEVING NATIONAL GOALS

INTRODUCTION

Nanotechnology involves the creation of material derived from the manipulation of particles as smaller than atoms. Manipulations of these microscopic particles allow scientists create all kinds of products that we use on a regular basis.

Nanoscale science and engineering activities are flourishing in the United States. The National Nanotechnology initiative (NNI) is a long-term research and development (R&D) program that began in fiscal year 2001. And today coordinates 25 departments and independent agencies, including the National Science Foundation, the Department of Defense, the Department of Energy, the National Institutes of Health, the National Institute of Standards and Technology, and the National Aeronautical and Space Administration. The government voted about 4 billion dollars between 2001 -2005 fiscal year towards research and development. The outcome of this investment is the formation of an interdisciplinary nanotechnology community with about 50,000 contributors. With such a growth and complexity, participation of a coalition of academic, industry, business, civil organizations, government and NGOs to nanotechnology development becomes essential as an alternative to the centralizes approach. The role of government continues in basic research but its emphasis is changing while private sector becomes increasingly dominant in funding nanotechnology application. In the case of the U.S. a key factor that contributed to establishing NNI was the preparation work for identifying core nanotechnology concept and challenges. Secondly, the orchestrated effort to assemble fragmented disciplinary contributions and application domain contributions has led to broad support from various stakeholders. Finally, the long-term view in planning and setting priorities was essential in the transformative governance of nanotechnology. Nanotechnology holds the promise to increase the efficiency in traditional industries and bring radically new applications through emerging technologies. Several potential R&D targets by 2015-2020 are presented in this paper.

The promise of nanotechnology, however, will not be realized by simply supporting research. A specific governing approach is necessary for emerging technologies and in particular for nanotechnology by considering its fundamental and broad implications. Optimizing societal interactions, R&D policies and risk governance for nanotechnology development can enhance economical competitiveness and democratization.

Nanotechnology operates at the first level of organization of atoms and molecules for both living and anthropogenic systems. This is where the properties and functions of all systems are defined. Such fundamental control promises a broad and revolutionary technology platform for industry, biomedicine, environmental engineering, safety and security, food, water resources, energy conversion, and countless other areas.

The first definition of nanotechnology to achieve some degree of international acceptance was developed after consultation with experts in over 20 countries in 1987-1898 (Siegel et al., Roco, 1999). However, despite its importance, there is no globally recognized definition. Any nanotechnology definition would include three elements:

- The size range of the material structures under consideration -- the intermediate length scale between a single atom or molecule, and about 100 molecular diameters or about 100nm. This condition alone is not sufficient because all natural and manmade systems have a structure at the nanoscale;

- The ability to measure and transform at the nanoscale; without it we do not have new understanding and a new technology; such ability has been reached only partially so far, but a significant progress was achieved in the last five years.

- Exploiting properties and functions specific for nanoscale as compared to the macro or micro scales; this is a key motivation for researching nanoscale.

According to National Science Foundation and NNI, nanotechnology is the ability to understand, control, and manipulate matter at the level of individual atoms and molecules, as well as at the "supramolecular" level involving clusters of molecules (in the range of about 0.1 to 100 nm), in order to create materials, devices, and systems with fundamentally new properties and functions because of their small structure. The definition implies using the same principles and tools to establish a unifying platform for science and engineering at the nanoscale, and using the atomic and molecular interactions to develop efficient manufacturing methods.

There are at least three reasons for the current interest in nanotechnology.

First, the research is helping us fill a major gap in our fundamental knowledge of matter. At the small end of the scale -- single atoms and molecules -- we already know quite a bit by using tools developed by conventional physics and chemistry. And at the large end, likewise, conventional chemistry, biology, and engineering have taught us about the bulk behavior of materials and systems. Until now, however, we have known much less about the intermediate nanoscale, which is the natural threshold where all living and man-made systems work. The basic properties and functions of material structures and systems are defined here and, even more importantly, can be changed as a function of the organization of matter via 'weak' molecular interactions (such as hydrogen bonds, electrostatic dipole, van der Waals forces, various surface forces, electro-fluidic forces, etc.). The intellectual drive toward smaller dimensions was accelerated by the discovery of size-dependent novel properties and phenomena. Only since 1981 have we been able to measure the size of a cluster of atoms on a surface (IBM, Zurich), and begun to provide better models for chemistry and biology selforganization and selfassembly.

A second reason for the interest in nanotechnology is that nanoscale phenomena hold the promise for fundamentally new applications. Possible examples include chemical manufacturing using designed molecular assemblies, processing of information using photons or electron spin, detection of chemicals or bioagents using only a few molecules, detection and treatment of chronic illnesses by sub-cellular interventions, regenerating tissue and nerves, enhancing learning and other cognitive processes by understanding the “society” of neurons, and cleaning contaminated soils with designed nanoparticles. It has been projected that $1 trillion in products incorporating nanotechnology and about 2 million jobs worldwide will be affected by nanotechnology by 2015 (Roco and Bainbridge, 2001). Extrapolating from information technology, where for every worker another 2.5 jobs are created in related areas, nanotechnology has the potential to create 7 million jobs overall by 2015 in the global market. Indeed, the first generation of nanostructured metals, polymers, and ceramics have already entered the commercial marketplace.

Finally, a third reason for the interest is the beginning of industrial prototyping and commercialization and that governments around the world are pushing to develop nanotechnology as rapidly as possible. Coherent, sustained R&D programs in the fieldhave been announced by Japan (April 2001), Korea (July 2001), EC (March 2002), Germany (May 2002), China (2002) and Taiwan (September 2002). However, the first and largest such program was the U.S. National Nanotechnology Initiative, announced in January 2000.

CONTENT/APPLICATION

NANOTECHNOLOGY IN AGRICULTURE

PRECISION FARMING

The process of maximizing crop yields and minimizing the usage of pesticides, fertilizers, and herbicides through efficient monitoring procedures is referred to as precision farming. Precision farming utilizes remote sensing devices, computers and global satellite positioning systems to analyze various environmental conditions in order to determine the growth of plants under these conditions and identify problems related to crops and their growing environments. Precision farming helps determine plant development, soil conditions, usage of water and chemicals, fertilizers and seeding and controls environmental pollution to a minimum extent by reducing agricultural waste. The implementation of nanotechnology in the form of small sensors and monitoring devices will create a positive impact on the future use of precision farming methodologies. Nanotechenabled systems help in increasing the use of autonomous sensors that are linked into GPS systems to provide efficient monitoring services focused on crop growth and soil conditions. The usage of smart sensors in precision farming will result in increased agricultural productivity by providing farmers with accurate information that will enable them to make accurate decisions related to plant growth and soil suitability.

NANO DELIVERY SYSTEMS

There are many regulatory restrictions placed on pesticides in agriculture today. Pesticides such as DDT, which have caused extreme environmental hazards, have increased public and regulatory awareness of the use of chemicals in farming, shifting the industry's focus on to the use of integrated pest management systems, combining smarter and more targeted use of chemicals with granular monitoring of plant health. These agricultural systems can make excellent use of nanotech-enabled “smart” devices that can perform a dual role of being a preventive and early warning system. These devices can identify plant related health issues even before they become visible to the farmers and simultaneously provide remedial measures. These nanotech systems can also be used to monitor the delivery of chemicals. User-friendly and eco-friendly nano delivery systems for nutrients and pesticides have started to find their place in the market. These can allow the use of pesticides with the absolute minimum risk of environmental damage. Companies have implemented nanoemulsions in commercial pesticide products. Syngenta, a leading agrochemical corporation, produces a quick-release microencapsulated product, which is available under the name Karate® ZEON.

NANOTECHNOLOGY IN FOOD

Nanotechnologists are hoping that nanotechnology will transform the entire food industry by bringing about changes in the production, processing, packaging, transportation and consumption of food. Usage of nanotechnology in these processes ensures safety of food products, creates a healthy food culture and enhances the nutritional quality of foods. Smart food packaging systems can be developed using nanotechnology that in turn increases the shelf-life of food products by developing active antifungal and antimicrobic surfaces, improving heat-resistance and mechanical properties, modifying the permeation behavior of foils and detecting and signaling biochemical and microbiological changes. A number of companies have started to develop Smart Packaging systems - one such company is Bayer Polymers, who developed the Durethan KU2-2601 packaging film whose key purpose is to prevent drying of food content and protect the food content from oxygen and moisture. This packaging film is made from a number of silicate nanoparticles. Usage of nanotechnology in food processing is creating a tremendous impact on the development of interactive and functional foods that deliver nutrients and respond to the body's requirements in an efficient manner. Nanocapsules are added into food products in order to deliver nutrients and nanoparticles when added to food increase the absorption of nutrients. An increasing number of companies are researching on additives that can be easily absorbed by the body and increase product shelf life. Biodelivery Sciences International developed coiled nanoparticles called nanocochleates that deliver nutrients and omega fatty acids to cells without causing any changes to the taste and color of food.

RECENT DEVELOPMENTS IN AGRICULTURE

With nanotechnology gaining recognition in the agricultural and food sectors, scientists and experts in the scientific field have recently showcased their nanotechnology expertise to farmers in Africa. Three significant innovations were demonstrated: The scientists have planned to develop a plastic storage bag lined with nanoparticles that are capable of reacting with oxygen and preventing cassava from rotting. In this way, the African farmers can prolong the shelf life of cassava and prevent wastage of this vegetable. A milk container was designed with a nanopatterned, antimicrobial coating that helps the diary farmers in Africa to preserve milk for a prolonged time period as they take almost a whole day to reach the cooling centers. These nanotechnology-based milk containers replace the currently used plain plastic bags. The scientists have also planned to develop nanopatterned paper sensors to detect bovine pregnancy in order to enable the dairy farmers determine if their cows will run dry without milk due to udder infection or pregnancy.

NANOTECHNOLOGY IN MEDICINE

The use of nanotechnology in medicine offers some exciting possibilities. Some techniques are only imagined, while others are at various stages of testing, or actually being used today. Nanotechnology in medicine involves applications of nanoparticles currently under development, as well as longer range research that involves the use of manufactured nano-robots to make repairs at the cellular level (sometimes referred to as *nanomedicine*).

Whatever you call it, the use of nanotechnology in the field of medicine could revolutionize the way we detect and treat damage to the human body and disease in the future, and many techniques only imagined a few years ago are making remarkable progress towards becoming realities.

DRUG DELIVERY

One application of nanotechnology in medicine currently being developed involves employing nanoparticles to deliver drugs, heat, light or other substances to specific types of cells (such as cancer cells). Particles are engineered so that they are attracted to diseased cells, which allows direct treatment of those cells. This technique reduces damage to healthy cells in the body and allows for earlier detection of disease. For example, nanoparticles that deliver chemotherapy drugs directly to cancer cells are under development. Tests are in progress for targeted delivery of chemotherapy drugs and their final approval for their use with cancer patients is pending. One company, CytImmune has published the preliminary results of a Phase 1 Clinical Trial of their first targeted chemotherapy drug and another company, BIND Biosciences, has published preliminary results of a Phase 1 Clinical Trial for their first targeted chemotherapy drug. Another technique delivers chemotherapy drugs to cancer cells and also applies heat to the cell. Researchers are using gold nanorods to which DNA strands are attached. The DNA strands act as a scaffold, holding together the nanorod and the chemotherapy drug. When Infrared light illuminates the cancer tumor the gold nanorod absorbs the infrared light, turning it into heat. The heat both releases the chemotherapy drug and helps destroy the cancer cells. Researchers have developed nanoparticles that release insulin when glucose levels rise. The nanoparticles contain both insulin and an enzyme that dissolve in high levels of glucose. When the enzyme dissolves the insulin is released. In lab test these nanoparticles were able to control blood sugar levels for several days.

ANTI-MICROBIAL TECHNIQUES

One of the earliest nanomedicine applications was the use of nanocrystalline silver which is as an antimicrobial agent for the treatment of wounds, as discussed on the Nucryst Pharmaceuticals Corporation website. A nanoparticle cream has been shown to fight staph infections. The nanoparticles contain nitric oxide gas, which is known to kill bacteria. Studies on mice have shown that using the nanoparticle cream to release nitric oxide gas at the site of staph abscesses significantly reduced the infection. Burn dressing that is coated with nanocapsules containing antibotics. If a infection starts the harmful bacteria in the wound causes the nanocapsules to break open, releasing the antibotics. This allows much quicker treatment of an infection and reduces the number of times a dressing has to be changed. A welcome idea in the early study stages is the elimination of bacterial infections in a patient within minutes, instead of delivering treatment with antibiotics over a period of weeks. You can read about design analysis for the antimicrobial nanorobot used in such treatments in the following article: Microbivores: Artifical Mechanical Phagocytes using Digest and Discharge Protocol.

CELL REPAIR

Nanorobots could actually be programmed to repair specific diseased cells, functioning in a similar way to antibodies in our natural healing processes. Read about design analysis for one such cell repair nanorobot in this article: The Ideal Gene Delivery Vector: Chromallocytes, Cell Repair Nanorobots for Chromosome Repair Therapy.

NANOTECHNOLOGY IN SECURITY

Nanotechnology holds strong promises for use in the defence industry. Current thinking is that nanotechnology can be used in two main ways by soldiers. The first is miniaturisation of existing equipment to allow it to be not only smaller, but lighter, use less energy and be more readily concealable. The second is to develop and adapt new materials for military purposes.

UNIFORM, HELMET, EQUIPMENT

Nanotechnology for the soldier is directly related to new functionalities in his suit, helmet or other portable equipment. Technologies with potential use for the soldier are: integrated sensors (RFID+) and actuator arrays: body, health & environmental monitoring, directed RF tracking-tracing-identification, anti-ballistic protection (flexible, lightweight), BC-sensing and protection, adaptive: switchable insulation, camouflage. The underlying basis for this initial choice is the fact that key elements of the future (Dutch) soldier will be his equipment and in particular his helmet, his uniform and the intelligent systems he is wearing on or in his uniform and helmet. These intelligent systems should inform him whether there are nuclear, biochemical or radiation threats, should tell the soldier and his commander/medic/fellow soldier about his physical and eventually also about his mental condition and should give the right insulation when needed and ventilation. Traditionally the Dutch industry has a strong position in fiber development and application for all kinds of fabrics and composite structures. This implies that it seems logical to focus on nano and micro research and development projects which include the use of existing fibers which will be adapted or differently incorporated in end-materials for the uniform and helmet.

MILITARY RESEARCH

Although nanotechnology based military research is being done both publically and secretly by numerous agencies around the world, the most high profile organisation is the Institute for Soldier Nanotechnologies (ISN) at MIT. ISN is looking to “pursue a long-range vision for how technology can make soldiers less vulnerable to enemy and environmental threats. The ultimate goal is to create a 21st century battlesuit that combines high-tech capabilities with light weight and comfort.”

SOLDIER BATTLESUIT

A battlesuit such us that being developed by ISN would be required to remain lightweight and comfortable while stopping bullets, protecting against toxins, monitoring vital signs and administering first aid where possible.

Battlesuit research is still in its infancy but has already made some advancement in the fields of communications, strength and soldier protection.

COMMUNICATIONS

Just as communications from ships at sea used to utilise coded messages transmitted by means of flashing lights specially coated polymer threads woven into the suit can allow silent communication between soldiers. The system can be tuned to different light wavelengths to prevent eavesdropping or detection by enemy units.

STRENGTH

Polymer molecular muscle ribbons in the suit can magnify a soldiers strength by up to ten times. At present the muscles are slow to react and therefore not practical in most battlefield applications.

PROTECTION

Kevlar is already the material of choice for protection against bullets and other ballistics and nanotechnology is being applied to further increase its functionality. Testing is underway on a shock-resistant material five times stronger than steel and more than twice as strong as any other impact-resistant material currently in use.

Protection from chemical and biological agents is being provided for with the use of special molecules called dendrimers. The dangerous chemicals stick to dendrimers and are rendered harmless.

AEROSPACE APPLICATIONS

In aerospace based defence applications the primary concern is improving strength to weight ratios. As an example, nanotechnology is being applied to aluminium to change phases and microstructure in order to make it perform like titanium – but without the weight.

COATINGS

High strength, corrosion resistant coatings are another military use for nanotechnology in order to improve durability, corrosion resistance and reliability. These materials can sense damage or corrosion and automatically initiate repair of some damage. The potential is also there for coatings to change colour when required. This could include adaptive camouflage for tanks moving from jungle to open fields or into urban areas.

CARBON NANOTUBE COMPOSITES

Further to improving strength to weight ratios, several companies are developing high strength, light weight composite materials using carbon nanotubes. Applications for these composites include aircraft wings.

NANOTECHNOLOGY IN ENERGY

Here are some interesting ways that are being explored using nanotechnology to produce more efficient and cost-effective energy thereby helping us achieve our national goal of ensuring that energy services are readily available to meet all demand at any particular time far into the future; that Energy is used in the most efficient manner; and also to ensure energy is produced and supplied at competitive prices (affordable tariffs).

Firstly, generating steam from sunlight: Researchers have demonstrated that sunlight, concentrated on nanoparticles, can produce steam with high energy efficiency. The "solar steam device" is intended to be used in areas of developing countries without electricity for applications such as purifying water or disinfecting dental instruments.

Producing high efficiency light bulbs: A nano-engineered polymer matrix is used in a new style of high efficiency light bulbs. The bulbs produce white light, similar to sunlight and can be made in any shape. The new bulbs have the advantage of being shatterproof and twice the efficiency of compact fluorescence light bulbs.

Increasing the electricity generated by windmills: An epoxy containing carbon nanotubes is being used to make windmill blades. Stronger and lower weight blades are made possible by the use of nanotube-filled epoxy. The resulting longer blades increase the amount of electricity generated by each windmill.

Generating electricity from waste heat: Researchers have used sheets of nanotubes to build thermocells that generate electricity when the sides of the cell are at different temperatures. These nanotube sheets could be wrapped around hot pipes, such as the exhaust pipe of your car, to generate electricity from heat that is usually wasted.

Storing hydrogen for fuel cell powered cars: Researchers have prepared graphene layers to increase the binding energy of hydrogen to the graphene surface in a fuel tank, resulting in a higher amount of hydrogen storage and therefore a lighter weight fuel tank. Other researchers have demonstrated that sodium borohydride nanoparticles can effectively store hydrogen.

Clothing that generates electricity: Researchers have developed piezoelectric nanofibers that are flexible enough to be woven into clothing. The fibers can turn normal motion into electricity to power your cell phone and other mobile electronic devices.

Reducing friction to reduce the energy consumption: Researchers have developed lubricants using inorganic buckyballs that significantly reduced friction.

Reducing power loss in electric transmission wires: Researchers at Rice University are developing wires containing carbon nanotubes that would have significantly lower resistance than the wires currently used in the electric transmission grid. Richard Smalley envisioned the use of nanotechnology to radically change the electricity distribution grid. Smalley's concept these upgraded transmission wires, which could transmit electricity thousands of miles with insignificant power losses, with local electricity storage capacity in the form of batteries in each building that could store power for 24 hours use.

Reducing the cost of solar cells: Companies have developed nanotech solar cells that can be manufactured at significantly lower cost than conventional solar cells.

Improving the performance of batteries: Companies are currently developing batteries using nanomaterials. One such battery will be as good as new after sitting on the shelf for decades. Another battery can be recharged significantly faster than conventional batteries.

Improving the efficiency and reducing the cost of fuel cells. Nanotechnology is being used to reduce the cost of catalysts used in fuel cells. These catalysts produce hydrogen ions from fuel such as methanol. Nanotechnology is also being used to improve the efficiency of membranes used in fuel cells to separate hydrogen ions from other gases, such as oxygen.

Making the production of fuels from raw materials more efficient: Nanotechnology can address the shortage of fossil fuels, such as diesel and gasoline, by making the production of fuels from low grade raw materials economical. Nanotechnology can also be used to increase the mileage of engines and make the production of fuels from normal raw materials more efficient. All these can contribute significantly to economic growth and development in Ghana and other parts of the world.

CONCLUSION

In the nut shell, nanotechnology is seen as a technology of national importance to the economy and security of Ghana. There is a strong belief that nanotechnology will bring many innovations to industry in many sectors and will create strong economic power. The impact is expected to be broad over many sectors:

- agriculture and food: secure production, processing and shipment; improved agricultural efficiency; reduced waste and waste conversion into valuable products
- national defence and internal security: high speed and high capacity systems for command, control, communication,

- energy: high performance batteries, fuel cells, solar cells, thermoelectric converters; catalysts for efficient conversion
- environmental improvement: improved monitoring; reduce pollution by new “green” technologies; remediation and removal of contaminants
- information technologies: improved computer speed; further scaling of nanoelectronics; reduced power
- medicine and health: novel sensor arrays for rapid diagnostics; composite structures for tissue replacement; targeted, highly effective medicine transportation and civil infrastructure: new material composite structure; efficient vehicles; improved safety.

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