

# **Nanotechnology: Potential for Agriculture**

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## **Introduction**

Nanoscale science, engineering, and technology, which is more widely known using the novel term ‘nanotechnology’, is an emerging multidisciplinary field that can have enormous potential impact on our society. Globally, an estimated \$9 billion per year is allocated to research and development in nanotechnology, with the expectation that this investment will lead to significant advances in a variety of applications including medicine, material science, computing and electronics, industrial manufacturing, environmental remediation, energy production, military applications, among others (Hood, 2004). The purpose of this paper is to provide an overview of nanotechnology and its applications, with particular focus on agriculture and food. Additionally, the main issues and concerns regarding the societal implications of rapid development in nanoscale science will be discussed.

## **What is nanotechnology?**

The term ‘nano’ is used as a prefix to denote one billionth, i.e., 1 nanometer means 1 billionth of a meter. Various definitions of nanotechnology has been put forward, but the current widely accepted definition of nanotechnology covers a number of fundamental aspects: 1. research and technology development at the atomic, molecular, or macromolecular levels using a length scale of approximately 1 to 100 nanometers in at least one dimension; 2. the creation and use of structures, devices and systems that have novel properties and functions because of their small size; and 3. the ability to control or manipulate matter on an atomic scale (EPA, 2007). An essential aspect of nanotechnology is the nanometer scale of dimensions involved. At this scale, the classical rules of physics and chemistry ordinarily valid at larger, macro scales no longer apply; instead nanoscale materials exhibit unique quantum properties that may be radically different from the properties of the same material at macro-scale. For instance, the characteristics and properties of a typical material observed at macro-scale such as colour, strength, electrical conductivity, thermal properties, and reactivity, can be significantly different at the nano-scale (Anonymous, 2003). Additionally, as structured materials are created in smaller dimensions, the ratio of the exposed surface to the volume of the material increases rapidly, thereby making the material more reactive. These scale-related phenomena open up the range of possibilities which enable nano-scale researchers to come up with novel materials and processes with unique functions and properties that were previously not available at larger scales.

## **Historical timeline**

The concept of manipulating molecules and atoms has been postulated in 1860s, but the first experiments with actual observations and measurements in the nanometer range have not been done until the early 1900s. In 1959, physicist Richard Feynman foretold the benefits that can be realized by being able to manipulate materials at the atomic and molecular scale and described a conceptual framework to achieve it (Feynman, 1959). The term ‘nanotechnology’ was first used by Norio Taniguchi in 1974 in describing the significant improvement in dimensional accuracy (in the order of 1 nanometer) for manufacturing processes at that time (Taniguchi, 1974). In 1980s, development in this field was greatly enhanced with advances in electron microscopy, which allowed scientists to ‘see’ and manipulate individual atoms and molecules. One defining

moment in nanotechnology happened in 1989 when Donald Eigler used a scanning tunneling microscope (STM) to produce the now widely-popular image of individual xenon atoms arranged to spell out the letters 'IBM' (Eigler and Schweizer, 1990). Another milestone is the discovery of a new form of carbon by Harold Kroto, Richard Smalley and Robert Curl. Formed out of 60 carbon atoms and shaped like a ball, it was named Buckminsterfullerene (or often called 'buckyball') and earned the three scientists Nobel Prize in Chemistry (Kroto et al., 1985). Since then, various advances were made in atomic and molecular manipulation, which gave rise to different nano-scale materials and devices with multitude of applications. An overview of the scale of materials produced with nanotechnology (Figure 1), relative to nano-scale things that occur in nature, is available from the website of the U.S. National Nanotechnology Initiative ([www.nano.gov](http://www.nano.gov)).

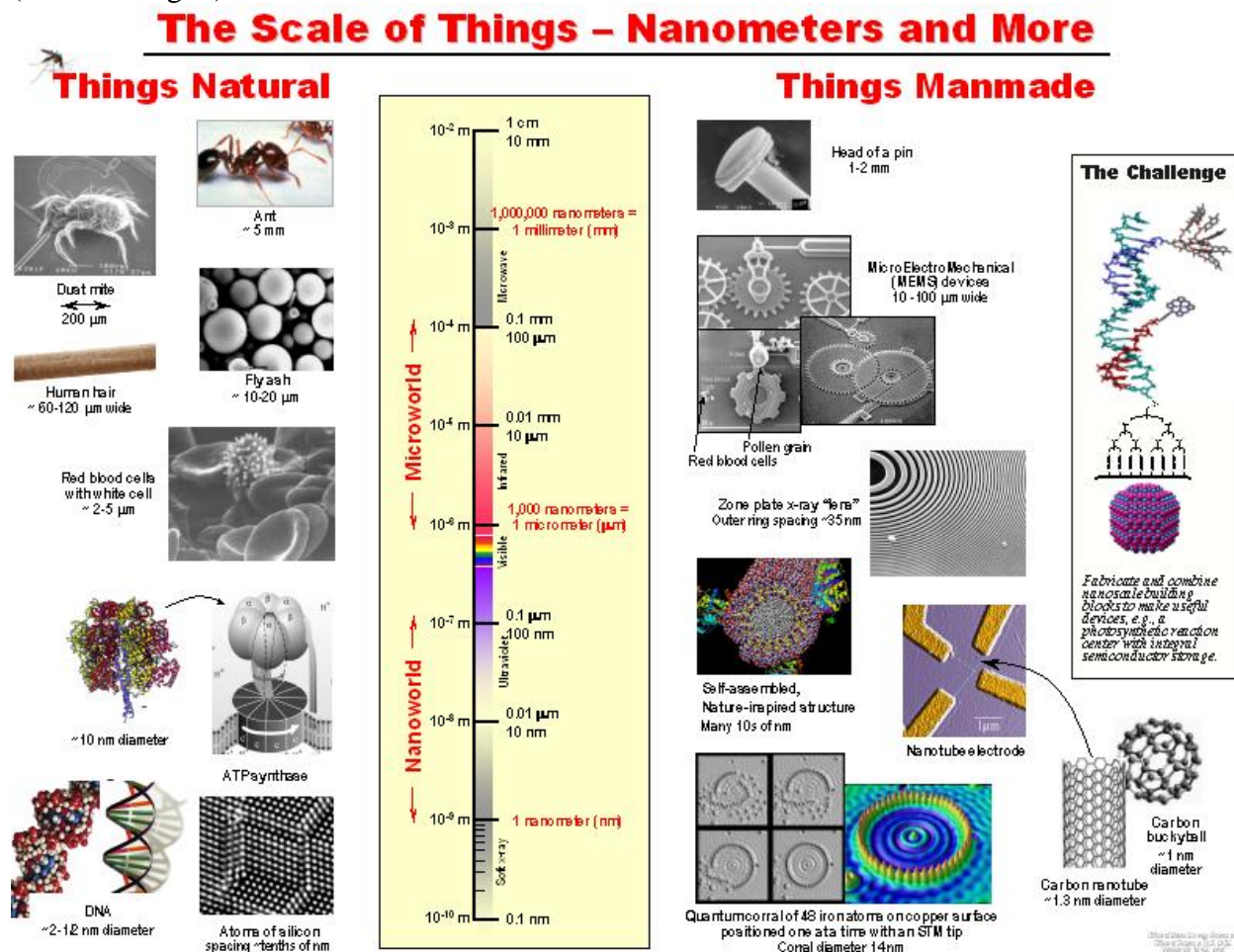


Figure 1. Natural and manmade nano-scale materials.

Source: National Nanotechnology Initiative website; courtesy: Office of Basic Energy Sciences, Office of Science, U.S. Department of Energy ([http://www.nano.gov/html/facts/The\\_scale\\_of\\_things.html](http://www.nano.gov/html/facts/The_scale_of_things.html))

### Top-down vs. bottom-up approach

There are two fundamental approaches to nanotechnology, pertaining mostly to the manner in which the novel nanomaterials are created (EPA, 2007). 'Top-down' approach involves creating nano-scale materials by physically or chemically breaking down larger materials using micro- and nano-lithography and etching techniques. Currently, this is the well-established but more expensive process of creating nanomaterials.

'Bottom-up' approach applies to assembling nanomaterials atom-by-atom or molecule-by-molecule, also known as molecular nanotechnology described by Eric Drexler in 1980s (Drexler, 1986). Using forces of nature for 'self-assembly' or by individually manipulating atoms or molecules (i.e., using the probe tip of a STM), materials with desired structure and form can be 'grown' in an organized manner. Typically, this approach allows the incorporation of specific features into the final form and is considered less expensive since only the required amount of the basic element is used (unlike in top-down approach wherein a large amount of material taken out of the base material is discarded).

### **Types of nanomaterials**

As shown in Figure 1, nano-scale materials can occur in nature; both natural and manmade processes (such as volcanic activity or diesel combustion) can also give rise to nanometer-sized materials unintentionally. For the remainder of this paper, 'nano-scale materials' or 'nanomaterials' refer to engineered or manufactured nanomaterials that are produced intentionally using the approaches described above. Currently, these intentionally produced nanomaterials can be categorized as follows (EPA, 2007):

Carbon-based materials – composed mostly of carbon, typically in the form of a hollow sphere, ellipsoid, or tube. Spherical and ellipsoidal carbon nanomaterials are called fullerenes (e.g., buckyball), while the cylindrical forms are known as nanotubes. These nanomaterials are used in improved films and coatings, stronger and lighter materials, and in electronics.

Metal-based materials – include metal oxides (i.e., titanium dioxide), nanogold, nanosilver, and quantum dots. A quantum dot is a closely packed semiconductor crystal made of a few hundred or thousands of atoms (Steigerwald et al., 1988). Varying its size changes the optical properties of the quantum dot, thus these are useful in tagging specific molecules or cells.

Dendrimers – are nanosized polymers with surface that has numerous chain ends which can be tailored to perform specific functions such as catalysis. Three-dimensional dendrimers can have a hollow interior cavity which can be filled with specific molecules, thus these may be useful as carriers such as in controlled drug delivery.

Composites – are nanomaterials that are combined with larger, bulk-type materials to enhance the properties of traditional materials. Nanoscale structures and morphology are interfaced with bulk materials (e.g., clay) to give rise to a composite material (e.g., nanoclay) with improved characteristics (e.g., stronger, lighter, with better barrier properties).

In general, the unique properties of these various types of nanomaterials give them novel electrical, catalytic, magnetic, mechanical, thermal, or imaging features that are highly desirable for a variety of scientific and commercial applications.

### **Overview of nanotechnology applications**

Various nanomaterials, techniques, and processes arising from nanotechnology can have significant benefits in diverse fields. Some examples of the current and potential applications of nanotechnology are as follows (Chen et al., 2007; Hood, 2004; Salamanca-Buentello et al., 2005):

**Medicine** – medical application of nanotechnology (i.e., nanomedicine) covers the areas of disease diagnostics, drug delivery, disease treatment, and various potential uses of molecular nanotechnology (Freitas, 2005). Presently, the most important innovations are in drug delivery,

which focuses on maximizing bioavailability of drugs at specific places in the body and their release at the right time. Nanoscale drug delivery systems can target the diseased cells only and not the surrounding healthy tissues, reducing the overall dose required and consequently the associated side effects. Highly sensitive disease detectors made out of nanomaterials can identify multiple pathogens and disease vectors and help in accurately diagnosing diseases, in some cases even before actual symptoms are exhibited. Nanoscale building blocks can help repair skin, cartilage, and/or bones, and in creating artificial parts and implants that are not rejected by the body.

***Chemistry and Environment*** – nanomaterials that are highly reactive to specific compounds are being used for catalysis and treatment of environmental contaminants. Nanomaterials are developed to detect and neutralize a wide variety of common contaminants. For example, researchers are developing nano-composite materials that can detect and absorb mercury vapor in the air. Another study used nanoparticles for remediation of toxic contaminants in the soil (Zhang, 2003). Photocatalytic properties of nanomaterials applied as coating on glass surfaces help in keeping glass buildings clean and in breaking down gaseous pollutants. Filters with aluminum oxide nanofibers which can remove viruses, bacteria, and protozoan cysts have been developed for water purification.

***Energy*** – nanotechnology can contribute to reduction in energy consumption and increased energy use efficiency. Reduced energy use can arise from better insulation systems, more efficient lighting (e.g., LEDs), and use of lighter and stronger materials for vehicles. Nanoscale catalysts are being designed to aid in refining petroleum to derive the useful components (e.g., gasoline) using less energy input (Davis, 2004); similar materials are also designed to catalyze reactions to improve efficiency of internal combustion engines and reduce exhaust pollutants. Nanoscale solar cells that are less expensive to make are being developed, resulting in solar panels capable of harnessing both visible light and the infrared spectrum, thus doubling the energy output. New fuel cell membranes and other nanomaterials are being developed to replace highly expensive platinum parts in current fuel cells, and nanotubes hold promise as hydrogen delivery systems, resulting to substantially increased energy output.

***Electronics and information technologies*** – the tools and processes used in nanotechnology as well as novel nanomaterials have led to advances in electronic devices, displays, optoelectronic devices, and computing. Using techniques that allow precise control of constructing materials at very small length scales, novel semiconductor devices (e.g., transistors, integrated circuits) are being made with enhanced capabilities that led to better computer processors, memory chips, and data storage devices. Carbon nanotubes have been used in new generation of display screens with low energy consumption and enhanced resolution. Traditional analog electrical devices are being replaced by optoelectronic devices using nanoscale photonic crystals and quantum dots (such as in lasers). Molecular electronics dealing with single-molecule devices is one area currently under research with significant potential benefits, i.e., computer hard-disks with ultra-high density data capacity.

***Military and security applications*** – a significant proportion of R&D investment in nanotechnology is aimed at developing enhanced defense and security applications. This area includes biodetection systems to warn against potential bioterrorism threats, nanomaterials that

can be used to detoxify an area or human exposed to biological toxins and chemical warfare agents, and novel encoding structures that can be used to secure computer systems. Nanomaterials have been investigated for use in the battlefield to clear military smokes and to enhance visibility in the infrared spectrum. The United States Army has established the Institute for Soldier Nanotechnologies, the goal of which is to use nanotechnology to create uniforms and gear that will help protect the troops.

**Industry** – lighter and stronger materials arising from nanotechnology have significant use in the aerospace and automobile industries, leading to lighter, safer, and more efficient aircraft and vehicles. Nanomaterials used to create polymers and fibres with enhanced properties result in better synthetic rubber (for tyres) and raw materials for the textile industry. Nanotechnology is being used in industrial refineries to remove impurities in the production of bulk materials such as steel and aluminum.

**Consumer goods** – various consumer products that incorporate nanotechnology are already available in the market. An online database maintained by the Woodrow Woodrow Wilson International Center for Scholars (<http://www.nanotechproject.org/inventories>) which tracks the inventory of this type of consumer products showed about 580 items from more than 20 countries at present; a few examples of these products are listed in Table 1.

Table 1. Examples of commercial products that use nanotechnology and nanomaterials.

Health and Fitness	Electronics and Computers	Home and Garden	Food and Beverage	Other
Wound dressing Pregnancy test kit Toothpaste Golf club Tennis Racket Skis Antibacterial socks Waste and stain resistant pants Cosmetics Sunscreen Baby bottle brush	Video displays Television Computer hardware Mobile devices Cameras and film Games	Anti-mildew paint Antimicrobial pillows Laundry and clothing care Antibacterial door knob Insulation Self-cleaning glass Jewelry	Non-stick coatings for pans Antimicrobial cooking ware Antibacterial refrigerator Canola oil Food supplements	Coatings Lubricants Automotive parts Fuel catalyst HVAC air purifier

Source: Woodrow Wilson Center Consumer Products Inventory (<http://www.nanotechproject.org/44/consumer-nanotechnology>)

### Applications in agriculture and food

Although the main thrust of previous R&D investment in nanotechnology focused mainly on applications in medicine, electronics, military, manufacturing, and other life sciences, the knowledge and tools gained from development of novel nanoscale materials and technologies in general have also led to significant benefits to food and agriculture systems (Joseph and Morrison, 2006). A number of these developments are due to the convergence of progress in other disciplines such as biotechnology and food sciences with advances in nanotechnology. Various projects dealing with nanotechnology applications in agrifood systems have been reviewed and an inventory of these projects was compiled (Kuzma and Verhage, 2006).

In general, the potential benefits of nanotechnology applications to agriculture are realized in the following areas:

***Agricultural production*** – nanotechnology can contribute to enhancing agricultural productivity in a sustainable manner, using agricultural inputs more effectively, and reducing by-products that can harm the environment or human health. Nanotechnology-based biosensors deployed in crop fields and in the plants to monitor soil conditions, growth, and disease vectors, can expand the concept of precision farming in which productivity can be optimized while providing inputs (i.e., fertilizer, pesticide, irrigation, etc.) and conditions (i.e., temperature, solar radiation) only in precise levels necessary (Joseph and Morrison, 2006). Similarly, nanotube sensors implanted in the skin of livestock animals can detect changes in hormone levels or unusual amounts of antibodies, thereby helping to optimize breeding procedures and to initiate veterinary interventions before the onset of diseases that can hamper growth (Scott, 2005). Similar to nanomedicine applications, pesticides and herbicides can be formulated with nanoparticles to enhance the effectiveness of the active ingredients and allow targeted delivery and release, thereby requiring less dosage per application and minimizing runoff of unutilized excess chemicals.

On the other hand, nanotechnology can also benefit from agriculture. Researchers in University of Texas – El Paso have shown that plants grown in gold-rich soil formed gold nanoparticles which can be isolated from its roots and shoots (Kalaugher, 2002). Other types of plants and growth media are also being investigated. This opens up the possibility of ‘particle farming’ in the future, wherein plants grown on medium rich in specific compounds are harvested for nanoparticles, rather than using the current conventional production techniques which are expensive and can be harmful to the environment.

***Enhanced fibre and rubber products*** – electrospinning techniques have been developed to produce nanofibres from cellulose derived from scrap materials from current techniques of spinning cotton (Frazer, 2004). Carbon nanotube-based fibers have been synthesized which are 17 times stronger than Kevlar (Dalton et al., 2003). Researchers at Clemson University in South Carolina are developing carbon nanofibre fabrics that generate electrical charge from the motion of the wearer, possibly leading to charging of small electronic devices. Glass nanofibres that change in colour depending on thickness are being developed at MIT; when woven into clothing, this could enable the wearer to change the colour of their clothes on demand.

Natural rubber impregnated with nanoparticles has been developed by Cabot tyre manufacturing company in collaboration with Nanoproducts Corporation to enhance the strength and wear properties of automobile tyres. Nanoclay composites (made by Inmat and Nanocor companies) mixed with rubber are also used to create a better seal on the inside surface of tyres. These advances result in tyres that require less amount of rubber to make, plus they are lighter and cheaper and with longer useful life, thus reducing the burden on the environment from discarded tyres. A lightweight nanomaterial called aerogel, which is composed of nano-air bubbles in a silica matrix, is being looked at for incorporation into tyre treads or possibly replacing rubber entirely in making tyres (ETC Group, 2005).

***Environment*** – developments in nano-bioprocessing can lead to conversion of agricultural waste into energy and other useful by-products, thereby transforming waste that can adversely impact the environment into valuable end-products (Moraru et al, 2003). Nanotechnology processes are used in converting waste fibers from cotton spinning into biodegradable cellulose mats that can absorb pesticides and fertilizers. Nanomaterials have also been used in the remediation of agricultural lands and groundwater contaminated by farm run-off. Photocatalysis using nanoparticles can be used to degrade pesticides and to treat wastewater (Warad and Dutta, 2005). Nanoscale iron particles can be used to catalyze the breakdown and oxidation of organic compounds such as trichloroethene, dioxins and PCBs in contaminated groundwater, after which the nanoparticles are degraded into a harmless form of naturally-occurring iron found in the soil (Zhang, 2003). Lanthanum nanoparticles that absorb phosphates in aqueous environments can be used for clean-up of ponds and lagoons; these may also have applications in preventing algae growth in commercial fish ponds (Joseph and Morrison, 2006). Current research at Prairie Swine Centre is looking at using various types of nanoparticles to control gases emitted from swine manure slurry, thereby potentially reducing emissions of odour and gaseous contaminants to the environment (Asis and Predicala, 2006).

***Plant and animal health*** – nanotechnology can help in diagnosis, treatment, and monitoring of diseases of crops and livestock to ensure timely intervention when necessary. Nanoparticles have been designed to adhere irreversibly to target pathogenic bacteria, reducing infectivity of food-borne enteropathogens in poultry products (Qu et al., 2005). Thin films and nanoemulsions have been used to prevent adhesion of bacteria on surfaces of equipment. Additionally, selected nanoparticles of magnesium oxide and zinc oxide were found to be highly effective at destroying microorganisms; coatings made from these nanomaterials can impart anti-microbial and biocidal properties on surfaces. This application has important uses at food production sites, in particular abattoirs and meat processing plants (Joseph and Morrison, 2006).

Nanoshells with attached antigens were designed to seek out cancer cells and bind with them; when illuminated with infrared light, the nanoshells are heated, raising the temperature of the bound cancer cells and destroying them (Scott, 2005). Non-invasive bioanalytical nanosensors are being developed that could be placed in an animal's salivary gland to detect the presence of pathogenic bacteria and viruses before these had a chance to multiply and develop disease symptoms that become visible to the farmer. These smart nanodevices will act both as a preventive and an early warning system and can also be used to deliver drugs and vaccines in a controlled and targeted manner.

***Food manufacturing and processing*** – nanotechnology can be applied in the food industry through precise manipulation of food molecules to create healthier, tastier, and safer food products. Nanoscale materials and techniques have been used in the development of novel and functional foods and in safe processing and handling of food (Moraru et al., 2003). Nanotube membranes were used in the separation of food biomolecules with functional value (e.g., proteins, vitamins, minerals, flavour and nutraceuticals) (Lee and Martin, 2002). Nano-based filters were also used for removing undesirable compounds from foods and beverages as well as in the purification of biofuels (i.e., ethanol). Nanoparticles are also being used to advance the concept of functional, 'on-demand' foods, wherein nanocapsules store flavours and nutrients inside food and are released at designated organs in the body when needed by the consumer

(Moraru et al., 2003). Nano-encapsulation of nutrients is also being looked at as a means to deliver more efficiently to cells or organs those nutrients such as vitamins, omega fatty acids or compounds that are degraded by normal digestive processes. Nanospheres can be used to encapsulate functionalized DNA fragments and can be effective delivery vehicles for oral immunization to treat food allergies (Roy et al., 1999).

**Food packaging** – various packaging materials have been developed using nanotechnology to ensure safe handling of food items, to extend the shelf-life of food products, and to address the environmental burden from non-biodegradable packaging materials currently used in the food industry. Composite materials with silicon nanoparticles used for packaging were found to be more airtight, thus preventing food decay and extending the shelf-life of food products (Moore, 1999). Nanocomposite foam of potato starch and calcium carbonate has been developed; this material is lightweight and biodegradable, hence it can be used to replace polystyrene ‘clam shells’ currently used widely in the fast-food industry (Stucky, 1997). Nanocomposite plastic can be manufactured with better strength and barrier properties (i.e., permeabilities to various gases and moisture); as a result these materials can fit the requirements of specific products such as fruits, vegetables, beverage and wine, thus improving the preservation of flavour and colour of the product and extending their shelf-life. Plastics with incorporated nanomaterials were developed to have the required mechanical and barrier properties to replace the more expensive bottles and cans currently used for beers. Research using nanotechnology is being done not only to modify the permeation behaviour and the mechanical, thermal, chemical, and microbial properties of packaging materials but also to incorporate nanobiosensors to detect microbiological and biochemical changes in food items (Moraru et al., 2003).

**Food safety and security** – nanotechnology applications in the food industry is also contributing towards addressing the increasing consumer awareness of food safety and security concerns. Chip-based micro-arrays have been developed for rapid detection of biological pathogens in food. Quantum dots have been used for rapid detection of E. coli and other food-borne pathogens (Su and Li, 2004). Researchers are looking at nanobiosensors for detecting contamination in water supplies, food materials, and agricultural products. Biosensors have a biological component that reacts to changes in substances or presence of specific cells, and then produce a signal in a linked transducer. Nanobiosensors can be designed to detect changes in the food, presence of pesticides and possibly genetically modified crops within the food system.

Similar to the concept of the ‘electronic nose’, researchers are developing an ‘electronic tongue’ with sensors comprised of small electrodes coated with a polymer to detect small amounts of a wide range of chemicals, such as gases released when food is spoiled (Gardner, 2002). This electronic sensor strip can potentially be incorporated into food packages, which will change in colour when the food product is no longer fit to consume.

Nanobarcodes (i.e., cylindrical nanoparticles of varying width) can be used in tagging and tracking of food and agriculture products (Warad and Dutta, 2005). Nanoscale monitors can also be linked to recording and tracking devices to monitor temperature and other conditions to which the food items are exposed to from the food processing plant to the consumer (Scott, 2005).

### **Concerns and issues regarding nanotechnology**

While numerous applications of nanotechnology in various fields have been identified, the actual state of the art is such that the attributed benefits are just beginning to be realized. Development of nanotechnology has been categorized into the following stages (EPA, 2007):

1st generation: Passive nanostructures

2nd generation: Active nanostructures

3rd generation: Three-dimensional nanosystems with heterogeneous nanocomponents

4th generation: Heterogeneous molecular nanosystems, where each molecule in the nanosystem has a specific structure and plays a different role.

Presently, the actual products and applications currently available are based on 1st generation nanomaterials and processes, and 2nd generation work is still being conducted in the laboratory. Nanoscale applications that belong to the later generations (i.e., advanced molecular machine systems, independent nanorobotic machines) are at the conceptual and modeling stages, which might be realized in 10 to 20 years or more.

***Perceived risks and benefits*** - Scheufele et al. (2007) conducted a survey on scientists familiar with essential aspects of nanotechnology and the general public; the plots from their results (Figure 2) showed interesting disparity in perception of the benefits and risks from nanotechnology. The main benefits attributed to nanotechnology are related to medicine, environment, energy, computing, and security. Perceived risks are mainly related to health, environment, privacy, abuse of technology, and economic implications. The potential scenario of being overrun by a 'grey goo' of self-replicating nanorobots raised by Drexler (1986) was considered to be a remote risk.

Various groups have raised serious concerns regarding the benefits and risks associated with nanotechnology (Hood, 2005). A report by ETC Group on the impact of nanotechnology on agriculture and food described the various relevant nanotechnology applications and the corresponding issues arising from them (ETC Group, 2004). Some of the main areas of concern are:

***Health issues*** – various products containing nanomaterials are already available commercially but the potential impact of exposure to these nanomaterials on human health is not yet fully known. Because of the inherent properties of nanomaterials, i.e., extremely small size and could be highly reactive, the possible routes of exposure and entry into the human body or other species must be investigated as well as the effects on normal metabolic processes.

***Environment*** – while nanotechnology can help in environmental remediation, the fate and transport of nanomaterials released (either accidentally or intentionally) to the environment need to be investigated. Currently, there is not enough information known about how these materials will behave in air, soil, and water bodies, or how they would react with other naturally occurring compounds.

***Oversight*** – due to rapid advancement in nanotechnology, development of appropriate policies and regulatory mechanisms is lagging behind. The proper agencies are now developing testing and evaluation guidelines; policies and procedures regarding labeling of products with

nanomaterial components, safeguard against possible abuse of nanotechnology applications, as well as contingencies for emergency situations need to be formulated.

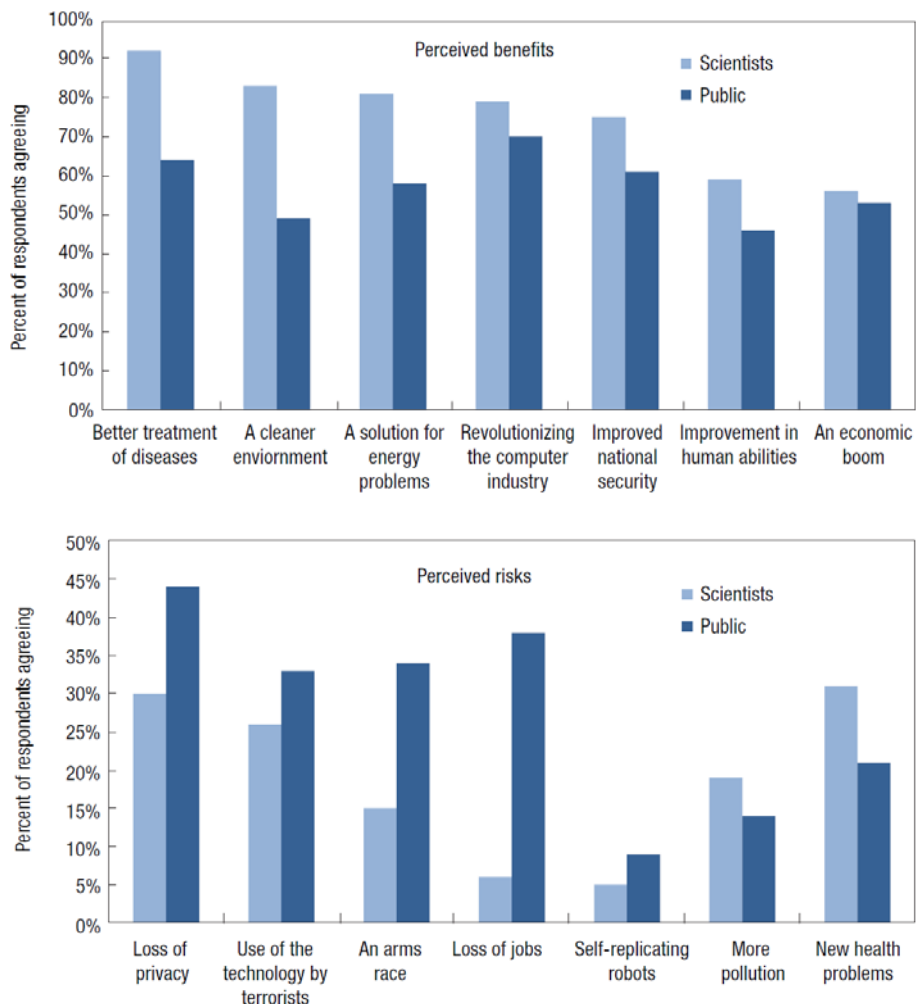


Figure 2. Results of survey of perception of nanotechnology benefits and risks by nanoscientists and the general public. Source: Scheufele et al., 2007. (<http://www.nature.com/naturenanotechnology>)

**Societal and ethical issues** – development of ‘smart’ nanobiosensors that can be used to track and monitor individuals can lead to concerns with invasion of privacy. With new materials that can be used to replace commodity items such as cotton and rubber, there are concerns that this will lead to loss of livelihood and severe economic consequences to developing countries that are dependent on these commodities (ETC Group, 2005). Nanotechnology applications involving manipulation of atoms or molecules, especially when DNA and genes are involved, may raise similar issues and concerns as with ‘GMOs’. It was strongly recommended that various stakeholders in the society engage in a full discussion of the role of nanotechnology in food and agriculture (ETC Group, 2004).

Government agencies are responding to address these concerns regarding the impact of nanotechnology development through increased funding to investigate these issues and to develop appropriate policies (Roco, 2003). Various groups are working on establishing protocols

for evaluating the toxicological interactions of manufactured nanoscale materials in biological systems to address health and safety issues associated with nanotechnology (NTP, 2004).

## Summary

Advances in nanotechnology have produced novel nanomaterials, techniques, and tools that resulted in significant benefits in various industrial, medical, and technological applications. Agriculture and food can strongly benefit from nanotechnology in the areas of sustainable production, plant and animal health, food processing and packaging, and in reducing the environmental impact of agricultural operations. However, various issues and concerns have been raised, particularly on the lack of full understanding of the impact of nanomaterials on health and the environment, as well as on the inadequacy of current regulations to cope with rapid advances in nanotechnology. Various stakeholders are cognizant of these and are now responding to address these concerns.

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