THE FUTURE OF THE WESTERN CAPE AGRICULTURAL SECTOR IN THE CONTEXT OF THE 4TH INDUSTRIAL REVOLUTION

Review: Nanotechnology

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1. What is nanotechnology?

Introduction

Nanotechnology is the engineering of functional systems at the molecular scale. In its original sense, 'nanotechnology' refers to the projected ability to construct items from an atomic level up using techniques and tools being developed today to make complete, high performance products[1]. Nanotechnology will mean constructing molecules and other structures that are able to be applied in an extremely precise way. The technology has uses from medicine to robotics.

Nanotechnology was envisioned as the task of creating machines on the molecular scale. Nanotechnology is generally accepted to be technologies at the scale of 1-100 nanometers. So at a high level, nanotechnology can be considered engineering at an atomic level. One nanometer is a billionth of a meter, or 10^{-9} of a meter. Here are a few illustrative examples:

- There are 25,400,000 nanometers in an inch
- A sheet of newspaper is about 100,000 nanometers thick
- If a marble was 1 nanometer, a meter would be the size of the earth

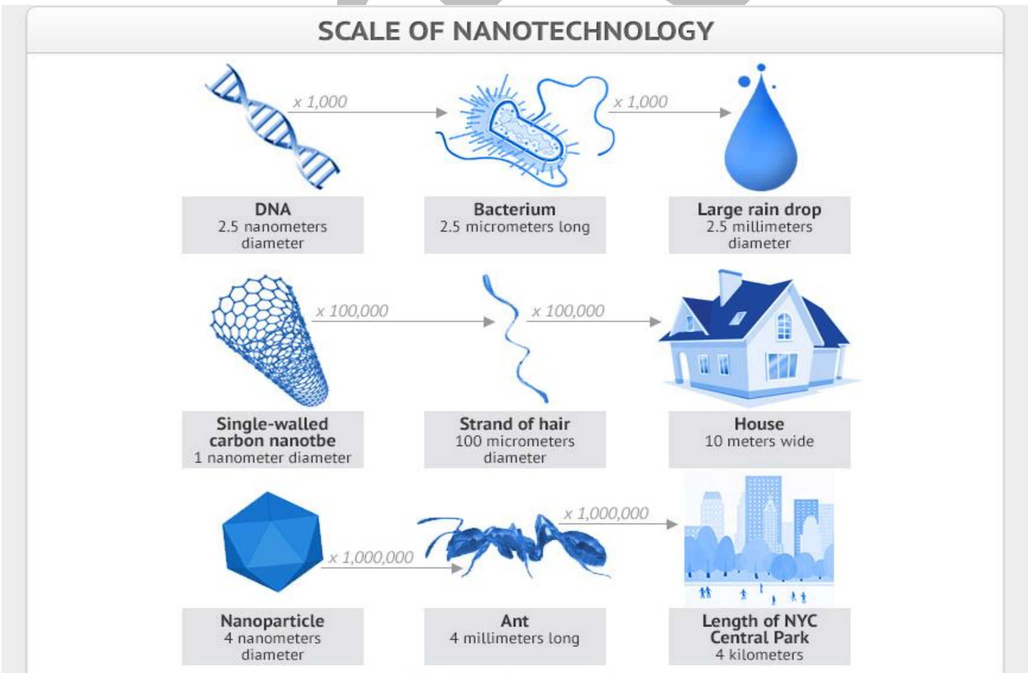


Figure 1: Infographic showing relative scale of nanotechnology
Source: http://keywordsuggest.org/gallery/1188156.html.

The natural equivalent of nanotechnology is found in cellular biology. Each cell contains nanoscale factories and machines which produce proteins, fats, convert energy and other inputs to carbohydrates and other fuels. Nanotechnology aims to design similar structures for tasks determined by the designers. These nanofactories, could replicate themselves like cells do so that a vast array of these nanoscale technologies could be created at very low cost.

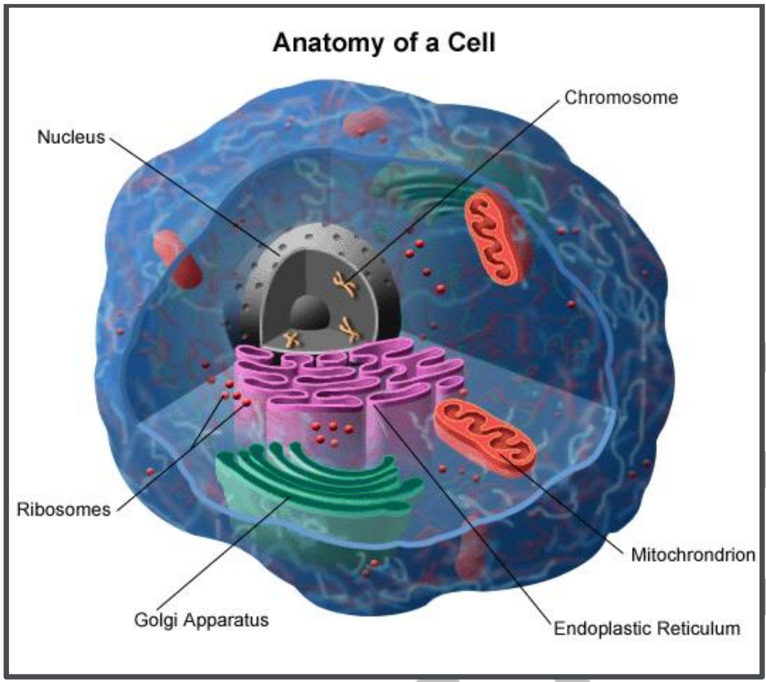


Figure 2: Anatomy of an animal cell - a natural nanotechnology
Source: http://home.windstream.net/hughesnw/HealthDocs/Cell_Biology.htm.

Two main approaches are used in nanotechnology. In the "bottom-up" approach, materials and devices are built from molecular components which assemble themselves chemically by principles of molecular recognition. In the "top-down" approach, nano-objects are constructed from larger entities without atomic-level control. This is analogous to additive vs subtractive manufacturing, which is discussed in our report on 3D Printing.

Types of nanotechnology

There are a number of branches of nanotechnology: nanomechanics, nanoelectronics, nanophotonics and nanoionics, which are all areas of research into the manipulation of matter at the nanoscale.

- Nanomechanics: focus on the mechanical properties of engineered nanostructures and nanosystems e.g. nanowires, nanotubes, nanomotors
- Nanoelectronics: refer to the use of nanotechnology in electronic components, particularly in computing technology.

- Nanophotonics: study of the behavior of light on the nanometer scale, and of the interaction of nanometer-scale objects with light.
- Nanoionics: study and application of phenomena, properties, effects and mechanisms of processes connected with fast ion transport (FIT) in all-solid-state nanoscale systems. Conduction is a central focus.

2. Why is Nanotechnology important now?

Many benefits of nanotechnology depend on the fact that it is possible to tailor the structures of materials at extremely small scales to achieve specific properties, thus greatly extending the materials science toolkit. Using nanotechnology, materials can effectively be made stronger, lighter, more durable, more reactive, more sieve-like, or better electrical conductors, among many other traits[2].

Nanotechnology is enabling a number of important applications e.g. increasing the number of transistors on a silicon chip which has enabled computing power to grow at an exponential rate. This alone is a reason to place importance on the advancement of nanotechnology. Most of the technologies in this review have in some way or another been enabled by the immense computing power we now have on very small chips. Beyond current binary computers, nanotechnology is empowering the development of quantum computing[3].

Another reason nanotechnology is so interesting, is that there are many properties of matter at the nanoscale which are not present at larger sizes of molecules. For instance, carbon nanotubes are much less chemically reactive than carbon atoms and combine the characteristics of the two naturally occurring bulk forms of carbon, strength (diamond) and electrical conductivity (graphite). Furthermore, carbon nanotubes conduct electricity in only one spatial dimension, that is, along one axis, rather than in three dimensions, as is the case for graphite[4]. The smaller nanostructure thus has properties that neither the larger structures have, this allows for novel use cases previously not possible.

As our understanding of matter at the nanoscale improves and our capacity to manipulate matter accurately on that scale advances, we should see exciting developments in the space.

3. What are the applications of Nanotechnology today?

Manufacturing and Textiles

Nanotechnology allows us to create "smart" materials, which are essentially materials that have been modified on a nanolevel to achieve certain goals. For instance, antibacterial fabrics are a result of nanotechnology at play in the clothing industry. It is also used in body armour and other applications where regular lightweight materials can have extraordinary toughness and durability. For example, a nano-battlesuit is being developed by The Institute for Soldier Nanotechnologies (ISN) that could be as thin as spandex and contain health monitors and communications equipment. Nanomaterials can also provide strength that far surpasses currently available materials, providing bullet shielding that's much more effective[5].

Nanotechnology is used to create coating and films in a variety of uses, one of which is protection of machines and delicate parts: nanostructured ceramic coatings exhibit much greater toughness than conventional wear-resistant coatings for machine parts. Nanotechnology-enabled lubricants and engine oils also reduce wear and tear, which can significantly extend the lifetimes of moving parts in everything from power tools to industrial machinery[6].

Nanoparticles are also used increasingly in catalysis to boost chemical reactions. This reduces the quantity of catalytic materials necessary to produce desired results, saving money and reducing pollutants. Two big applications are in petroleum refining and in automotive catalytic converters[7].

Electronics

Nanotechnology has greatly contributed to major advances in computing and electronics, leading to faster, smaller, and more portable systems that can manage and store larger and larger amounts of information. These continuously evolving applications include:

Transistors, the basic switches that form the foundation of computer processors, have shrunk in size thanks to nanotechnology. At the turn of the century, a typical transistor was 130 to 250 nanometers in size. In 2014, Intel created a 14 nanometer transistor, then IBM followed with the first seven nanometer transistor in 2015, and then the Lawrence Berkeley National Lab demonstrated a one nanometer transistor in 2016[8]. This radical decrease in the size of the core component of computers has allowed as to fit exponentially more of these transistors onto a CPU chip, thus increasing the processing power of the chip. Nanotechnology is one of the driving forces behind Moore's law.

Flexible, bendable, foldable, rollable, and stretchable electronics are reaching into various sectors and are being integrated into a variety of products, including wearables, medical applications, aerospace applications, and the Internet of Things. Flexible electronics have been developed using, for example, semiconductor nanomembranes for applications in smartphone displays[9]. Samsung and other manufacturers have incorporated a form of this in their flagship phones and TVs.

Medicine

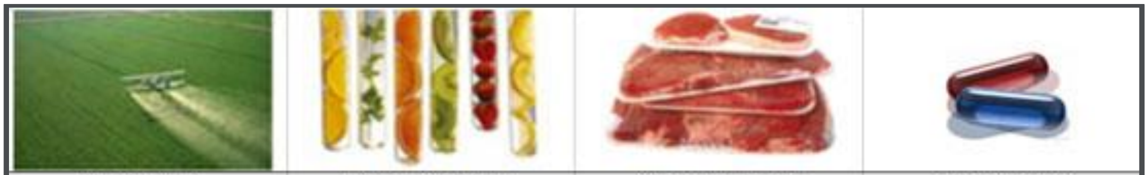
Nanomedicine, the application of nanotechnology in medicine, draws on the natural scale of biological phenomena to produce precise solutions for disease prevention, diagnosis, and treatment[10].

An application of nanomedicine that is currently under development 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 allow direct treatment of those cells. This technique reduces damage to healthy cells in the body and allows for earlier detection of disease[11].

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. A company currently pursuing this is CytImmune. They describe their product, Aurimune, as follows: "CytImmune's nanotherapy platform, Aurimune, is a tumor-targeted Trojan horse. It is engineered to travel safely and stealthily through the body and enter tumors through their most vulnerable points – the leaky blood vessels that make up the nutritional support structures.[12]" The nanomedicine is currently in clinical trials.

Agriculture

There are several applications of nanotechnology in agriculture and related food industries:



Agriculture	Food Processing	Food Packaging	Supplements
• Single molecule detection to determine enzyme/ substrate interactions • Nanocapsules for delivery of pesticides, fertilizers and other agrichemicals more efficiently • Delivery of growth hormones in a controlled fashion • Nanosensors for monitoring soil conditions and crop growth • Nanochips for identity preservation and tracking • Nanosensors for detection of animal and plant pathogens • Nanocapsules to deliver vaccines • Nanoparticles to deliver DNA to plants (targeted genetic engineering)	• Nanocapsules to improve bioavailability of neutraceuticals in standard ingredients such as cooking oils • Nanoencapsulated flavor enhancers • Nanotubes and nanoparticles as gelation and viscosifying agents • Nanocapsule infusion of plant based steroids to replace a meat's cholesterol • Nanoparticles to selectively bind and remove chemicals or pathogens from food • Nanoemulsions and –particles for better availability and dispersion of nutrients	• Antibodies attached to fluorescent nanoparticles to detect chemicals or foodborne pathogens • Biodegradable nanosensors for temperature, moisture and time monitoring • Nanoclays and nanofilms as barrier materials to prevent spoilage and prevent oxygen absorption • Electrochemical nano-sensors to detect ethylene • Antimicrobial and antifungal surface coatings with nanoparticles (silver, magnesium, zinc) • Lighter, stronger and more heat-resistant films with silicate nanoparticles • Modified permeation behavior of foils	• Nanosize powders to increase absorption of nutrients • Cellulose nanocrystal composites as drug carrier • Nanoencapsulation of neutraceuticals for better absorption, better stability or targeted delivery • Nanocochleates (coiled nanoparticles) to deliver nutrients more efficiently to cells without affecting color or taste of food • Vitamin sprays dispersing active molecules into nanodroplets for better absorption

Figure 2: Summary of nanotechnology use cases in agricultural industries. Source: Nanowerk

Agricultural use-cases typically involve the shrinking of current applications of plant protection products, minimize nutrient losses in fertilization, and increase yields through optimized nutrient management[13]. Other uses which offer promise is in IoT and sensor technology, where nanosensors can be used to optimise farming conditions as discussed in our review on AI and Machine Learning.

An interesting use case for nanotechnology in agriculture is the development of intelligent nanosystems for the immobilization of nutrients and their release in soil. Such systems have the advantage to minimize leaching, while improving the uptake of nutrients by plants, and to mitigate eutrophication by reducing the transfer of nitrogen to groundwater. Nanomaterials could also be utilised to improve structure and function of pesticides by increasing solubility, enhancing resistance against hydrolysis and photodecomposition, and/or by providing a more specific and controlled-release toward target organisms.[14]

Some specific nano-products for the agricultural sector have been put on the market by technology-oriented smaller companies, like soil-enhancer products that promote even water distribution, storage and consequently water saving[15]. However, it appears that the high cost involved with the development of the nanotechnology restricts large scale commercial adoption by farmers due to the lower margins achieved in agriculture. The applications are, thus, not widely used. Areas such as medicine and electronics that achieve higher margins make the technology more profitably, therefore we find that the usage in those areas appears to be more advanced.

4. What is the Future of Nanotechnology?

Nanotechnology will undoubtedly yield tremendous advances for people into the future, as our materials become better, medicines improve and computers increase in power. There are a few areas to which nanotechnology appears to be moving toward.

Textiles

Nanotechnology will continue to advance in textiles, with materials used for building, clothing and manufacturing becoming increasingly strong, light and having special properties. For instance, our clothes could soon become crease free, and stain resistant as a matter of course. Waterproofing of materials will become more advanced. Temperature control and insulation ability of materials could improve how we keep warm or cool in the winter. There are already some prototypes of clothes which can heat up or cool down with the use of a small battery pack[16].

Medicine

The medical use case for nanotechnology is possibly the most compelling, with the possibility of creating nanobots (nanoscale machine type objects) that are able to be injected into the body and seek out disease and destroy infection or make repairs. While this is only a hypothetical use case at this stage, there is research into the creation of cell-like nanofactories which are able to autonomously produce these kind of nano-machines that self-assemble. (See report on 3D Printing)

Computing

We expect computing technology to progress toward quantum computing, where computers no longer use the binary bits that current processors are limited to. Rather than store information using bits represented by 0s or 1s as conventional digital computers do, quantum computers use quantum bits, or qubits, to encode information as 0s, 1s, or both at the same time. This superposition of states, along with the other quantum mechanical phenomena of entanglement and tunneling, enables quantum computers to manipulate enormous combinations of states at once[17]. This kind of computing will be game-changing and will have impacts across almost every field. However, to successfully produce a fully useful quantum computer, advanced nanotechnology will need to be developed as memory and processing will take place at an atomic level[18].

5. Nanotechnology Application Life Cycle

Nanotechnology is very much in its innovation phase. Whilst there is a great deal of progress being made in the field, nanotechnology is not yet on a scale where widespread adoption for agricultural purposes in the Western Cape is feasible.

6. Business Eco-System View

Due to the early stage of nanotechnology, the business ecosystem for the technology is still very immature. The majority of participants are large research and development divisions in corporate companies, universities and research institutes. This ecosystem is sure to flourish once nanotechnology reaches a more accessible price point.

7. Benefits and Risks

The benefits and risks of nanotechnology remain to be fully realised as the technology progresses.

8. Potential Economic, Social, Ecological and Political Developments and Impacts

The impact of nanotechnology from an economic, social, ecological and political viewpoint remain to be fully realised as the technology progresses.

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