The Future of Nanotechnology
Abstract

The discovery of nanotechnology has had presence in the scientific world as early as 1959 and the manipulation on the molecular scale was possible in 1981. However the limited understanding of how nanotechnology could realistically be applied in a useful and feasible way was not so clear. Now society has grown technologically so has nanotechnology, lab tests and environments show promising uses and we come to the stage when funding and commercial applications are a more serious concern. Therefore the analysis of the most feasible application of nanotechnology: (Telecommunication, Bio-engineering, Medical Electronics and Robotics) has to be careful, serious and cover all aspects for a company, institute or government body to consider funding and supporting now or in the near future.

Introduction

This report aims to provide a feasibility analysis for the investment in one of the following main applications of nanotechnology: Telecommunication, Bio-engineering, Medical Electronics and Robotics. This feasibility analysis is restricted by the lack of commercialisation of these applications and the lack of testing out of a controlled lab environment. Therefore it is based on current and predicted funding, theorised applications in the future and successful trials in labs.

The definition of nanotechnology is the study and manipulation of matter on the nanoscale of 1 to 100 nanometers. Manipulation on the molecular scale is very different from larger scales as the laws of physics, electrical properties and the behaviour of matter changes. However, greater awareness of nanotechnology in the early 2000’s demanded a need for governments to fund and guide the development of nanotechnology.

Nanotechnology in Biological engineering – technical

Introduction

Biomedical nanotechnology has been identified to have main applications in: Diagnostic sensors, ‘lab-on-chip’ techniques, drug delivery and molecular imaging. Biomedical nanotechnology is based on the understanding on naturally occurring molecules, structures and behaviours. Based on this knowledge it has been identified and proved to be possible to create nanostructures such as carbon Buckyballs and nanotubes or nanoprobes to improve on traditional methods such as drug delivery and molecular imaging.

Diagnostics

On the nanoscale, it is possible to create nanostructures that bind to particular nucleic acids or identified genes. What this means is that diagnosing can be tailored to each individual’s needs. For example, this type of technique is implemented in the drug trastuzumab – a monoclonal antibody designed to target the HER2 tyrosine kinase receptor which is only found in 30% of breast cancers.
This type of specific identification of single molecules can be applied to ‘lab-on-chip’ to analyse how much of a risk that person has in developing or redeveloping a disease.

**Molecular imaging**

Targeting of particular molecules in cells is achievable with nanotechnology. Quantum dots instead of traditional methods of molecular imaging provide unique properties such as being size-tunable in light emission, superior signal brightness and also to simultaneously excite multiple fluorescent colours.

**Drug delivery**

One of the most focussed and feasible areas of nanotechnology has been in drug delivery. It has been proven that traditional methods of drug delivery face problems such as drugs being insoluble, unstable, no targeting, intestinal absorption and side effects. However, nanotechnology in drug delivery has proven to overcome most of these problems because of the design at a molecular level.

In nano drug delivery the construction of nano capsules are implemented as they have the ability to either have functional polyelectrolytes or nanoparticles between the layers. This allows the capsule to be tailored to encapsulate a specific drug and therefore also tailored for the treatment of a particular disease. In addition to this, the capsule protects the drug from hydrolytic and enzymatic degradation in the gastrointestinal and are able to deliver drugs that are very insoluble in water. This results in a bypass of the liver and another way the nanostructure prevents the drug from being broken down in metabolism. Another reason why nanostructures can deliver drugs effectively is because of their size they are able to penetrate tissues and cells; delivering specifically to the activity in the cell.

Further manipulation of the nanostructure; with controlled thickness and composition can result in the active substance being manipulated to deliver (and at a certain duration) to a specific site. This type of targeted therapy is important in preventing healthy cells from being damaged by the drugs. Lastly, this type of non-invasive approach of drug delivery can aid in the treatment of neurodegenerative disorders by breaking the blood brain barrier. [1] [2]

**Nanotechnology in Biological engineering – feasibility**

**Strengths**

The ability to identify particular molecules with nanotechnology has shown that diagnosis and treatment can be personal. The future of healthcare service can be described in 4 P’s. Preventive, Personalised and Participatory and participatory diagnosis and treatment. Nanotechnology in Biological engineering has proven and has promises in detecting disease at earlier stages (e.g. when there is little to none evidence of disease on the molecular level) with molecular imaging and lab-on-chip techniques. In nanotechnology treatment can be specific on the molecular level, therefore reducing treatment type, side affects and wasted drugs. All these technologies that have been applied in the lab are paving the way to hastening these 4 P’s. [3]
Opportunities

Biological engineering on the nano scale opens up the opportunity to allow healthcare to be more mobile and less intrusive.

In drug delivery treatments will become less obtrusive, more effective and being at a molecule scale can open up the ability to treat neurodegenerative diseases and bring more understanding to the different types of cancers.

In addition, the mapping of DNA can eventually be instantaneous and therefore allowing for the early identification of faulty genes and analysis of the risks of particular diseases.

Threats/Risks/Ethics

The general threat that all areas of nanotechnology pose is the lack of understanding how it will react to an environment outside of a controlled lab environment.

This is a particularly great risk in biological engineering, as manipulation of specific molecules could be subject to sudden changes in environment as the human body is still not fully understood itself.

Also eliminating diseases quicker with the aid of nanotechnology could potentially see rise to dangerous “super-bugs” like those that have already threaten the healthcare system. In addition to this the human immune system could become less exposed to viruses, diseases etc. than it already is in what is described as a “bubble” society. This meaning that society is over concerned with bacteria and viruses on a great and maybe over the stop scale.

By being able to diagnose at an earlier stage, treatment being quicker and more effective will naturally result in a healthier society with an even more extended life span. With current traditional methods of treatment societies are already under the strain of supporting people who live longer. With the introduction of commercial treatment through nanotechnology, it could tip the scales in a more extreme sense of a panic of a lack of resources and a new generation faced with global problems.

In an ethical sense nanotechnology in biological engineering could spur extreme groups of protests against the interference of technology in the human body. In addition, funding to the commercialisation of nanotechnology in biological engineering could see the split between the rich and the poor become a great issue.

Introduction

In the area of medical services, more specifically medical electronics there is a demand for more accurate and quicker diagnostics. It has also been theorised that in the future neuron damaged or neuron degenerating diseases could be overcome by the use of Nano electronics to communicate nerve impulses to an external computer. Medical electronics in theory and
practicability is very possible and the first evidence of this is the presence of Nanomotors, Nanodevices and Nanotransistors in biology.

Nanomotors are present in very primitive life; the Myosin, Kinesin and rotatory motors for flagella which provides motion to bacteria through liquid media.

**How the devices in biology work**

An example of how a biological motor works can be seen from the spasmoneme. This was first observed by the microscopist Leeuwenhoek in 1676, where when extended the spring may be mm’s in length but when exposed to calcium (which neutralises the net negative charge) the stalk contracts in a few ms to 40% its length.

The transistors of biology are Ion Channels which act as communicators from a cell to the extracellular environment. The ion channels are essential in this communication as they only allow specific ion species to enter or leave the cell. There are two specific types of protein ion channels; Ca++ gated potassium channel and the voltage-gated potassium channel, which is essential to the generation of nerve impulses. These transmembrane proteins are similar to their close relatives scale wise, which are characterised as 8nm in diameter and 14nm in length.

**How to work in manipulating/creating these devices**

Being on the nanometer scale these biological devices are invisible and therefore require the use of a Scanning tunnelling Microscope (STM). The tip of this is used as an assembly tool while at the same time allowing the product to be imaged. This method is a way of creating some of these nanostructures. However, the tip of the STM can only be used to nudge the atoms in place and not to pick up atoms as this would disturb the STM’s ability to provide images.

In Nano electronics in general the construction of Nano devices requires wires, transistors. The free movement of electrons through molecular wires is the main problem when trying to obtain a good electrical contact with electrodes. It is common for molecules in molecular electronics to contain a lot of alternating double and single bonds as this pattern delocalizes the molecular orbitals and in result allowing electrons to move freely over the area. This is a characteristic of Nano wires, one these being carbon nanotubes and has promising electrical properties.

The greatest difference in Nano transistors to its bulk counterpart in electronics is how it determines the conductance between the source and drain. The gate in a conventional transistor determines this by controlling the density of charge carriers between them, whereas a single molecule transistor controls the transition of an electron by modifying the energy of the molecular orbitals. This therefore results in an almost binary behaviour; the transistor is either on or off, its bulk counterparts have quadratic responses to gate voltage.

**In the medical field – nano electronics**
In the medical field the development of nano electronic devices is of great interest and can push forward the performance in medical diagnostics; through nanosensors. This is possible through the translation of bio molecule events into electronic signals.

On the nano scale, Nano-structured MicroElectrodes (NMEs) are used to monitor electronic activity. They work almost identical to Micro Electronodes; detect a change in charge due to different concentrations in ions, cell membranes act as the plate of a capacitor (CM) but in the case of a NME the change in charge due to the presence of a nano particle can be detected. [4]

An NME is created using nanosensors and there are different types of nanosensors, such as:

Semiconducting nanowires: the nanowires are spotted with molecules designed to bind with a specific antibody. When this molecule comes in contact with the specific antibody the charge on the wire changes and this change creates a signal that can be detected and analysed.

Carbon nanotubes are cylindrical carbon molecules which exhibit extraordinary strength and unique electrical properties and are efficient conductors of heat. Therefore they can be applied and used as nanosensors to allow or prevent the flow of particular molecules. [18]

Carbon nanotubes (CNTs): This sensor can be of either single or multi-walled CNTs. The ends of CNTs can have single molecules attached to them for the detection of single molecules or DNA. They are often referred to as biological probes.

Blue crab sensor: Chitosan is a biological compound found on some crustaceous shells that readily binds to negatively charged surfaces. These types of sensors can be developed to detect minute quantities of substances such as bioagents and chemicals. It is implemented by coating mini vibrating cantilevers coated in chitosan and an optical sensing technology that is used to see changes in the vibrations of the cantilevers. [5]

NMEs are greatly applied to the research of cancer diagnosis and in more recent years the identification of biomolecules specific to a particular type of tumour.

An example of this application of this would be to identify cancers that are caused by specific genes and to the identification of a specific type of cancer. One such study applied this to the detection of nucleic acids that are identified to cause prostate cancer.

NMEs were attached to a chip –based platform and the NMEs had to be made to specifically select the nucleic acid associated with prostate cancer. This was achieved through the design of Peptide Nucleic probes which is man-made and designed to complement the naturally occurring prostate cancer related mRNA in cells. These PNA molecules are then modified to bind to noble metals and coat the electrodes before sensing is commenced.

To retrieve an electronic output from the presence of the nucleic acid on the probes the amount of electrostatic charge is measured. Each block of DNA (a nucleotide) has a negative charge associated with it, so the modified NMEs would have an increase in negative
charge (as the PNA is uncharged – neutralised before application to the probes) when a nucleotide (in this case the nucleotide associated with prostate cancer) becomes attached to a probe. However, what was truly unique in this particular study is the implementation of NMEs in parallel not serial. What this means is that a chip of this type can analyse multiple nucleic acid sequences in parallel. [6]

Nanotechnology in Medical Electronics – feasibility

Strengths

Nanotechnology in Medical Electronics opens up the ability to communicate events on the molecular level to an understandable format for human beings. Biosensors allow for the detection of specific molecules and this can be essential in ensuring safety in military operations (the detection of dangerous chemicals in chemical warfare) and health care (being able to detect an outbreak of a disease or dangerous molecules).

Weaknesses

The electronic structures on the nanoscale have to be compatible with the human immune system so that there is no risk of rejection or attack from the human body. This could hinder potential nano structures and slow down construction and production.

In addition for the application of nano structured medical electronics in the human nervous system is difficult. The structures would have to be placed precisely to allow for the flow of communication between neurons.

Opportunities

Cancer diagnosis through nanostructures “lab-on-a-chip” shows potential in analysing quickly and electronically. This means that diagnosis on the nano scale could be translated to signals that can be represented by computer – opening up the opportunities of specific hardware/software on a human scale to deal particularly with a more sensitive diagnosis of cancer or/and other diseases.

Nanotechnology in Medical electronics has been theorised in the future to be able to overcome failures in neuron communication. As nanowires could connect, divert signals from neurons away from damaged areas of the nervous system. This could cure paralysis, degenerative brain diseases and increase the speed of communication from the brain to the rest of the body and vice a versa.

Threats

Nano structures constructed to interface with ion current in the human body have to be able to sustain a particular flow and allow for backward currents. Ion channels are essential to the human nervous system and the construction of ATP/energy; therefore the risk of interfering unintentionally in these important electrical flows could be harmful and pose a greater risk than the intended advantages/treatment of nano medical electronics.
Introduction

Nanorobotics is the emerging technology field of creating machines or robots whose components are at or close to the microscopic scale of a nanometre ($10^{-9}$ meters). More specifically, nanorobotics refers to the nanotechnology engineering discipline of designing and building nanorobots, with devices ranging in size from 0.1-10 micrometers and constructed of nanoscale or molecular components. The names nanobots, nanoids, nanites, nanomachines or nanomites have also been used to describe these devices. [8]

Nanomachines are largely in the research-and-development phase, but some primitive molecular machines have been tested. An example is a sensor having a switch approximately 1.5 nanometers across, capable of counting specific molecules in a chemical sample. [9]

Strengths

At this moment Nanorobotics is still an development and testing phase and therefore not much advancement has been made in this field of nanotechnology. However, basic machines have been created that can count the amount of a specific molecules in a chemical compound. Based on this application and on theories many strengths have been identified for the application of Nanorobotics in the medical field, military and manipulating an environment.

Weakness

From the above definition, it is evident that the fully implemented physical nanorobots are invisible to the human eye. Therefore they can only be manufactured by precisely controlled and accurate manufacturing equipment. This equipment has to be extremely sensitive to the nanometric movements and have to be able to carry out nanometric welding, joining or shaping processes. Current manufacturing facilities and technology does not allow such operations to be done, but I believe that due to the advancement in the microelectronics and microcontrol systems, nanometric control of the manufacturing operations can be achieved in 20 years’ time.

However one of the biggest problems that these nanorobots would face is the amount of energy stored in their bodies. According to the laws of physics; every motion, force,
physical operation or work requires an energy source. This required energy would have to be supplied to the nanorobots via a battery that must be embedded into the body of the nanorobot. Depending on the application, these nanorobots would have to perform tasks which result in energy consumption. Take a medical application as an example where the nanorobot is assigned to identify and destroy a cancer cell. In order to fulfill this duty, the robot has to penetrate and travel around the human body until it finds the cancer cell and then destroy it. Considering the size of the robot, it has to travel great distances and therefore requires a great amount of energy which could not be embedded into the nanometric body size of the robot. Storage of this energy requires much more space. In addition if the robot is required to wirelessly transmit information, it would also be then impossible to provide this amount of energy storage space into the nanometric body of the robot.

Opportunities

Recently, Rice University has demonstrated a single-molecule car developed by a chemical process and including buckyballs for wheels. It is actuated by controlling the environmental temperature and by positioning a scanning tunneling microscope tip. [10]

The motorized model of the nanocar is powered by light. Its rotating motor, a molecular framework that was developed by Ben L. Feringa at the University of Groningen in the Netherlands, was modified by Tour's group so that it would attach in-line with the nanocar's chassis. When light strikes the motor, it rotates in one direction, pushing the car along like a paddlewheel. [11]

From this research it is evident that it is possible that nanometric mechanical devices can be implemented. Although it has been addressed that there may be an issue of how the nanorobots would be powered, the Rice University implemented an easily accessible power source that is not restricted by the size of the robot. The source of the energy that is used in the single-molecule car is light which means that this form of energy source doesn’t necessarily have to be on the body of the nanorobot. In this particular case the light source is external and is needed to control the movement and the direction of the nanorobot. However when the nanorobot is far away from the light source, a physical medium is needed in order to guide the emitted signal to the nanorobot. This can only be achieved by building nanometric optical fibres to be used as a medium but when considering the length of the fibre that would have to be used, it would be very impractical and not feasible at all. Probably the biggest danger of such a medium would be its fragility.

Some other possible applications of Nanorobotics would be the detection of toxic chemicals and the measurement of their concentrations in the surrounding environment. This would be achieved by sensing the nanoparticles of the toxic chemicals via the nanomaterials used in the surface of the product. This interaction of the particles would cause a chemical reaction to take place that would be detected and measured by the product. Current research and development works by Nokia Research Center (NRC) in collaboration with the Cambridge Nanoscience Centre (United Kingdom) are concentrating on what is called the Nokia Morph Concept project. [12]

This project is a promising possible future application of nanotechnology in mobile phones in which the mobile phone can sense the surrounding environmental conditions.
Nanorobots will enable the nanometric control of the manufacturing facilities so that much stronger materials can be made by bringing the molecules of the metals or plastics much closer together. Some chemical bonds could be manipulated or a variety of chemical materials could be joined together with the help of the nanorobots which would result in really interesting and useful material characteristics (e.g. ductility, high tensile strength, high resistance to scratching and wearing out and so on).

In addition, Nanorobots would be able to penetrate through the human body, may identify the cancer cells and destroy them. Or targeted drug delivery to certain molecules or tissues would be possible. By achieving these objectives, only the targeted parts of the human body will be affected by the applied drug and will cause no harm to the other molecules or tissues (especially the nearby tissues).

In the future nanorobots could also perform Nano-metric scale imaging and sensing. This might be achieved by using special sensory materials on the surface of the robot which will take the images and transmit them to the receiver to be rendered. These images would be very useful for biochemistry or materials science to be able to find out the interactions of the atoms.

Finally, Nanorobots could replace some of the information or signal carrying cells in the human body in the case of disability or paralysis. They could remove disabilities and paralysis that is due to the lack of signal reception coming from the brain or some other organs. Damages to the human nervous system due to accidents or degenerative diseases can cause damage which prevents the signals to reach its destination when travelling through the nervous system. The malfunctioning part can be identified and can be replaced by the robot which will act as a bridge to enable the signal to reach its destination.
Threats

The ‘2004 Strategy’ made a clear statement of balanced awareness of the possibly harmful side of nanotechnologies:

*It is essential that the aspects of risk are addressed upfront as an integral part of the development of these technologies from conception and R&D through to commercial exploitation, in order to ensure the safe development, production, use and disposal of products from nanotechnology. Nanotechnologies present new challenges also for the assessment and management of risks. It is therefore important that, in parallel with technological development, appropriate R&D is undertaken to provide quantitative data on toxicology and ecotoxicology (including human and environmental dose response and exposure data) to perform risk assessments and, where necessary, to enable risk assessment procedures to be adjusted. (European Commission, 2004b, section 1.3)*

There are some possible health risks of using nanorobots in human body. If the targeted tissue or the cell is not identified correctly by the nanorobot, it may harm other cells which will in turn harm the patient. Another issue is that the anatomy of every individual differs slightly. Some people have more fat in their body and some have more protein and some have more blood and so on. These may cause some disturbances when the targeted cells are being identified. The targeted cell may produce slightly different chemicals or may react differently to the chemicals carried by the robot for destruction purposes.

Nanorobots due to their invisible size may cause very serious security issues. Especially in military applications, they can be used to obtain some information about your enemies political, or war plans.

Throughout the development, implementation and the commercial application stages of the nanorobots the society should be informed about these in order to prevent sceptical, rumours and any possible privacy worries. Otherwise the people in society may oppose these developments if they feel that it is going to harm them and the society that they live in.

**Nanotechnology in Telecommunications — technical**

Introduction

Telecommunication is the transmission/exchange of information over significant distances to communicate. In earlier times, it involved the use of visual signals such as beacons, smoke signals, signal flags and optical heliographs. Or through the use of audio messages via loud whistles, for example. In the modern age of electricity and electronics, telecommunications now also includes the use of electrical devices such as telegraphs, telephones and teleprinters. [14]

A telecommunications circuit consists of two stations, each equipped with a transmitter and a receiver. The transmitter and receiver at any station may be combined into a single device called a transceiver. The medium of signal transmission can be electrical wire, optical fibre or electromagnetic fields. The free-space transmission and reception of data by means of electromagnetic fields is called wireless. [15]
The telecommunication industry is responsible for radio, television, voice communications, and broadband services. The growth and innovation of the telecommunication industry has enabled people to communicate across the globe and access endless amounts of information over the internet. [16]

The world’s effective capacity to exchange information through two-way telecommunication networks grew from 281 petabytes (unit of information, equal to one quadrillion bytes or 1000 terabytes) of information in 1986 to 65 exabytes (unit of information, equal to one quintillion bytes or one million terabytes) in 2007. This is the informational equivalent of 2 newspaper pages per person per day in 1986, and 6 entire newspapers per person per day by 2007. Given this growth, telecommunications play an increasingly important role in the world economy and the worldwide telecommunication industry’s revenue was estimated to be $3.85 trillion in 2008. The service revenue of the global telecommunications industry was estimated to be $1.7 trillion in 2008, and is expected to touch $2.7 trillion by 2013. [17]

Why Nanotechnology in Telecommunications

In order to have computation and communication always available and ready to serve the user in an intelligent way, the devices are required to be mobile. Mobile devices together with the intelligence that will be embedded in human environments – home, office, public places – will create a new platform that enables ubiquitous sensing, computing, and communication. Core requirements for this kind of ubiquitous ambient intelligence are that the devices are: autonomous and robust, can be deployed easily, and survive without explicit management or care. This mobility also implies limited size and restrictions on the power consumption. Seamless connectivity with other devices and fixed networks is a crucial enabler for ambient intelligence systems – this leads to requirements for increased data rates of the wireless links. Intelligence, sensing, context, awareness, and increased data rates require more memory and computing power, which together with the size limitations leads to severe challenges in thermal management.

All these requirements lead to a situation which cannot be resolved with current technologies. However, nanotechnology could provide solutions for sensing, actuation, radio, embedding intelligence into the environment, power efficient computing and memory. [18]

Applications of Nanotechnology in Telecommunications

Nanotechnology will enable manufacturers to produce computer chips and sensors that are considerably smaller, faster, more energy efficient, and cheaper to manufacture than their present-day counterparts. [19]

Current advances in nanotechnology have resulted in new approaches for improvements in telecommunications and information processing. Traditional electronic devices are increasingly being replaced by optoelectronic devices such as photonic crystals and quantum dots. Displays with low energy consumption can be produced using carbon nanotubes. Components based on the microelectromechanical system (MEMS) and
A nanoelectromechanical system (NEMS) hold significant promises for future developments in wireless communications. [20]

**Nanostructured Materials**

Kodak is producing OLED (Organic Light Emitting Diodes) colour screens, made of nanostructured polymer firms, for use in car stereos and mobile phones. OLEDs may enable thinner, lighter, more flexible, less power consuming displays, and other consumer products such as cameras, PDAs, Laptops, Televisions. This will impact all current makers of CRTs and liquid crystal display (LCDs), and other display types. [21]

**Load Balancing**

Load balancing is the balancing of calls between sites based on performance criteria. It involves the ability of a telecommunications network to route calls to the available agent, regardless of the physical location of the computers. In a virtual call centre, load balancing provides the ability to route to the available agent across an enterprise. As the hardware is miniaturised further through nanotechnology advances, and takes less physical space, more automation will relieve the agent of repetitive tasks and ease communication throughout a particular transaction. [22]

**Quantum Dot**

A Quantum Dot is the world’s smallest precision built transistor consisting of just seven atoms in a single silicon crystal. Despite its incredibly tiny size – a mere four billionths of a meter long – the quantum dot is a functioning electronic device and it can be used to regulate and control electrical current flow like a commercial transistor. As everything to do with communications (e.g. mobile phones) uses transistors, the smaller, more efficient and the faster they get, the quicker, cheaper and more powerful communications tools will become available to individuals. [23]

Reduction in one dimension to nano size, but keeping other two dimensions large, results in a structure known as quantum well. Reduction in two dimensions to nano size, while one remains large, results in a structure called quantum wire; and the reduction of all three dimensions to nano size results in the structure known as a quantum dot (QD). [24]

The use of QDs has revolutionized the optoelectronics area. QDs offer superior optical properties, high quantum efficiency (95%), and size-tuneable emission. The QDs fabricated through the colloidal synthesis of semiconductors have many applications such as optical sources and in flat-panel displays. [25]

These nanotechnology innovations, such as QDs, semiconductor nanoparticles, carbon nanotubes, and naoshells, have led to the fabrication of electronics hardware devices using the “bottom-up” approach” in contrast to present “top-down” approach.

**Quantum Mirage**
In 2000, IBM scientists discovered a way to transport information on the atomic scale that uses the wave nature of electrons instead of conventional wiring. This new phenomenon, called the “Quantum Mirage” effect, may enable data transfer within future nanoscale electronic circuits too small to use wires. It is called a mirage because information about one atom is projected to another spot where there is no atom. This is a fundamentally new way of guiding information through a solid.

This would help as computer circuit features shrink towards atomic dimensions – which they have for decades in accordance with Moore’s law – the behaviour of electrons changes from being like particles, described by classical physics, to being like waves, described by quantum mechanics. On such small scales, for example, tiny wires don’t conduct electrons as well as classical theory predicts. So quantum analogs for many traditional functions must be available if nanocircuits are to achieve the desired performance advantages of their small size. [26]

**Data Transmission Capability**

Nanotechnology has enabled manufacturing processes to yield smaller, faster, and more energy-efficient electronic, photonic, optoelectronic devices. The first generation of nanotechnology (1990s – early 2000s) dealt with improving the performance characteristics of existing micro materials; the second generation of nanomaterials (2006 onwards) is leading to the fabrication of devices that are cleaner, stronger, lighter and more precise. [27]

Researchers at Penn State and the University of Southampton have created a breakthrough in optical electronics by developing a technique to fill an optical fibre with micro- and nano-semiconductor structures. This structure enables the optical fibre to carry multiple wavelengths of light, and thus increases the data transmission capability tremendously. [28]

According to American Friends of Tel Aviv university (AFTAU), a new nano based technology that can make computers and the internet hundreds of times faster, a communications technology ‘enabler’, may be in use only five or ten years in the future. Dr. Koby Scheuer, from Tel Aviv University, has developed a new plastic based technology for the nanophotonics market, which manufactures optical devices and components. This plastic based filter is made from nanometer sized grooves embedded into the plastic. When used in fibre optics cable switches, the new device will make communication devices smaller, more flexible and more powerful. This new plastic based switch will be used a filter to make sense of the massive amounts of incoming communications data, replacing hard to fabricate and expensive semiconductors. [29]

**Sensors**

Micromechanical sensors became an elementary part of automotive technologies in mid-1990, roughly ten years later more miniaturised micromechanical sensors are enabling novel features for consumer electronics and mobile devices. Within the next ten years the development of truly embedded sensors based on nanostructures will become a part of our everyday intelligent environments.

Nanotechnologies may also augment the sensory skills of human based on wearable or embedded sensors and the capabilities to aggregate this immense global sensory data into
meaningful information for our everyday life. Nanotechnology can help to develop novel kind of intelligent and autonomous devices that adapt to their environment and become a part of the network of devices surrounding them. Nanotechnologies may also help to open solutions for sensors that are robust in harsh environmental conditions and that are stable over a long period of time. These future embedded sensors will be inexpensive and ecologically sustainable so that they can be used in very large numbers. [30]

Nanotubes

Nanotube-based (carbon nanotubes as described before) transistors have been made that operate at room temperature and that are capable of digital switching using a single electron. They have already been used as wires to carry electricity and as transistors to control electric current.

Researchers have found that if they inject electrons that carry negative charges into one end of a nanotube and holes, or positive charges, into the other end, the two combine to emit light whose wavelength is inversely proportional to the tube’s diameter. Nanotechnology scientists have found a way to make the microscopic tubes emit light and have fashioned a nanotube transistor that emits 1.5 micron infrared light, a wavelength widely used in telecommunications. These light-emitting nanotubes could be used to form efficient communication devices and, eventually, all optical computer chips.

A group of researchers at the University of Texas have successfully demonstrated that mats of single-walled carbon nanotubes (SWCNTs) can communicate electrical signals to neurons. These results suggest that SWCN could be used as an electrical interface between neural prosthetics (devices used to replace damaged or missing nerves) and the human body.

Modern semiconductor chips that are dedicated to interconnect signals via wiring system have shown a limitation in terms of processing speed and memory. For this fact, the semiconductor industry has recently shifted from using aluminium to copper as interconnectors because copper carries electrical signals much faster than aluminium.

It has been demonstrated at the University of California that CNTs can send an electrical signal on a chip faster than traditional copper or aluminium wires, at speeds of up to 10 GHz. Such a breakthrough could lead to faster and more efficient computers and improved wireless network and mobile phone systems. This could lead to the industry being shifted from copper to nanotubes since it will provide an even larger performance advantage in terms of speed. However, for that to happen, nanotube technology would need to show it is more economical and requires precise assembly and packaging.

Spacecrafts and Satellites

Communications with spacecrafts and satellites depends on microwave devices. The currently used microwave devices are based on relatively inefficient thermionic electron devices that require heating and cannot be switched on instantaneously.

A microwave diode that uses the CNT’s cold-cathode electron source and operates at high frequency and high current densities has been developed by Teo et al. (2005). As such a nanotube based diode is very light, it can be switched on instantaneously and does not need a
heating source. Due to their tiny size and the ability to generate and modulate the beam simultaneously without the need for high temperatures, CNT cathodes hold promise for a new generation of lightweight, compact, and efficient microwave devices for satellites or spacecraft telecommunications.

Typically, conventional satellites carry 50 microwave amplifiers on board, each weighing about 1 kg and measuring about 30 cm in length. On average, it costs about £10,000 to send a single kilogram of payload into space. Using nanotube diode technology will help significantly in replacing conventional heavy, bulky, high temperature, microwave amplifiers thus resulting in the cost being reduced by half due to the weight and size reduction of up to 50% of the microwave devices. Additionally, such a technology will drive the industry toward very low cost microsatellites that weigh about 10kg. [31]

The Morph Concept

The Morph concept, by Nokia, suggests that future mobile devices might be stretchable and flexible, allowing the user to transform the gadget into radically different shapes. Nanotechnology would enable the ultimate functionality delivering flexible materials, transparent electronics and self-cleaning surfaces. Three years after the launch of its Morph concept, the Nokia research centre, which operates in conjunction with Cambridge University, revealed four projects based on nanotech concepts that “might be integrated into devices within the next 10 – 15 years”. It is believed that these conceptual ideas could make mobile devices more intelligent and cost-effective, allowing to interact with their environment in new and innovative ways. The four ideas are as follows:

**Stretchable electronic skin**

A stretchable, comfortable substrate can be used as an elastic touchpad to offer new possibilities for future device form factors. It can not only stretch and conform to fit the human body, but the integrated touch and pressure sensors enable new user interface options. The stretchable electronic skin includes a thin (50 nm depth) evaporated gold film to act as a conductor which is embedded in the rubber. The gold film stretches with the skin and reverts back into its original shape, while continuing to remain conductive.

**Nanowire Sensing**

This idea shows how nanotechnology can cheaply and effectively enable environmental sensing, such as the continuous monitoring and measuring of many things from air pollution, food-based contaminants to bio-chemical processes.

By employing a network of nanoscale wires, a compact and potentially low cost “artificial nose” has been created which can accurately detect or “smell” difference substances. The nanowires, which are fixed on top of the chip effectively act as a chemical sensor and distinguish different substances which are placed close to the sensing surface. As molecules from substances stick to the nanowire surface inside the device, they cause a change in the electrical current flowing through the nanowire, which then detect and identify traced amounts of contaminants in the environment.
Flexible Printing Supercapacitors

Supercapacitors are used to deliver current bursts for device functions which require high power transients such as camera flash and audio/RF amplifiers. Compact, flexible supercapacitors enable the creation of significantly thinner capacitors than those in use today with significantly greater power. With a flexible printed circuit board it would be possible to enable flash photography at much greater distances. As the supercapacitor is fully flexible, it can be incorporated into a device in many different ways and the device design and form is not limited.

Electroctactile Experience

Electroctactile experience enables users to feel different surface textures on the screen of a mobile phone which can correspond to an image or menu shown on the screen. It works by providing an alternating potential between the surface of device and the user’s finger when in contact with and sliding over the screen. This gives a tactile sensation known as electrovibration, which uses low voltages and does not stimulate the skin until it is moved across the surface of the screen. According to Nokia, this type of interaction could enable genuine 3D interaction. [32]

Nanotechnology in Telecommunications – feasibility

Strengths

Nanotechnology will enable manufacturers to produce computer chips and sensors that are considerably smaller, faster more energy efficient, and cheaper to manufacture than their present-day counterparts.

Current advances in nanotechnology have resulted in new approaches for improvements in telecommunications and information processing. Traditional electronic devices are increasingly being replaced by optoelectronic devices such as photonic crystals and quantum dots.

The use of Quantum Dots has revolutionized the optoelectronics area. QDs offer superior optical properties, high quantum efficiency (95%), and size-tuneable emission.

Nanotechnology has enabled manufacturing processes to yield smaller, faster, and more energy efficient electronic, photonic, and optoelectronic devices.

New developments in nanotechnology sensors have generated new interest in MEMS-based systems. Such devices have applications in communications, medical diagnosis, commerce, the military, aerospace, satellite systems, and wireless communications.

The major advantages of MEMS devices are miniaturization, multiplicity, and the ability to directly integrate the devices into microelectronics.

Weaknesses
Time between research and commercialization is estimated to be 3-10 years. Venture capitalists find this time factor to be a detriment.

There is a serious gap between research and commercialization that must be addressed by government agencies and the venture capitalists. The scientists may publish their research and not be interested in commercialization. A common notion is that for every dollar invested in basic research, an investment of almost $100 is required to produce a competitive product.

There is a lack of effective mechanisms to facilitate the technology transfer from academic institutions and laboratories to the commercial sector.

**Opportunities**

Components based on the microelectromechanical system (MEMS) and nanoelectromechanical system (NEMS) hold significant promise for future developments in wireless communication.

Nanotechnology can be used to achieve Gigabit networks, which will be helpful in handling vast amounts of voice, image, and video data being created.

Nanotechnology is leading to the fabrication of devices that are cleaner, stronger, lighter and more precise.

Improved storage devices as IBM has been working on the Millipede project which is designed to produce an experimental prototype of a new storage medium with 20 times the density of current hard drives, but inexpensive to manufacture.

Hewlett Packard is presently using a chemical process to make grids of nanowires, only a few atoms thick, and manipulating molecules to function like a microprocessor, which could lead to incredibly small storage devices.

The impact of nanotechnology on telecommunications is, in many ways, enabling communications across not only physical borders but also across the cultural curtains of long-established economic, political, cultural, and even religious barriers.

As nanotechnology makes computing capabilities increasingly smaller and more efficient, collecting, storing, sharing and processing large amounts of information will become easier and cheaper. [33]

Nanotechnology has the capability of dramatically improving surveillance devices, thus leading to an increase in incentives to private companies producing security nanotechnology. [34]

**Threats/risks**

Regulatory agencies do not yet exist to oversee the characterization of nanoproducts, or their action in a nanodimension. [35]

No thought process regarding the handling of nanowaste. [36]
Nanotechnology in telecommunications also poses the risk of breaching security applications in general as they are so small that detection (possible bugging of building/mobile phones) would almost be impossible. Again industry standards and government standards/laws need to be applied to reduce this risk.

**Discussion**

In this paper a SWOT analysis of the applications of nanotechnology covered in this paper has been carried out. The strength of the recommendation of an investment in one of these areas of nanotechnology will be based on current advancements in that area, investment patterns and the amount of risks involved. All these aspects will determine how feasible and beneficial it would be for a company, institute or shareholder to invest in that area of nanotechnology.

**Biological Engineering**

*Current State of Technology*

As discussed in the feasibility section of nanotechnology in Biological Engineering, there are many proven working applications in the lab environment:

- Identifying cancerous molecules and in addition nucleic acids belonging to specific strains of cancer (such as different types of breast cancer) [6]
- In addition this can be applied to diagnostics tailored to an individual by identifying particular nucleic acids or identified genes
- Use of gold as a catalyst to remove a step in the production of pharmaceutical drugs – therefore leading to a higher yield of product [36]
- Synthetic peptides (Antimicrobial peptides) that kills bacteria while destroying less blood cells – advancement in suppressing bacteria while leaving healthy cells intact [37]
- Drug delivery has already been improved in the lab environment via nanocapsules and also nanotubes – this would allow the treatment of cancer without damaging healthy cells [38]

*Financial Trends*

From figure 1 of the financial graphs it can be seen that in the past that nanobiotechnology along with Nanodevices has shown to take up the largest shares of investment in the world market and specific areas of nanotechnology in bioengineering are predicted to take up some of the most largest shares in investment. In addition, figure 3 shows that the expectations in the past of the investment in drug delivery in nanotechnology increases greatly every year. What this shows is that nanotechnology in bio engineering has shown enough promise that investment predictions are high and in result shows greater potential in development.

*Weight of risks*
As was stated before the risk in general in nanotechnology is the results of the application outside of a controlled environment. In specific to Biological Engineering the manipulation of biological molecules and applications of this to genes/DNA could present potential mutations or accidental creation of out of control “super bug”.

However this type of risk is present in most bioengineering and medical areas in general and careful trials and analysis of results will most likely highlight dangers and threats that could potentially be caused by nanotechnology in Bioengineering.

**Medical electronics**

*Current state of technology*

Advancements in the application of nano electronics in the medical field is looked to in the future to provide implantable medical sensors and the ability to replay information to a PC wirelessly and quickly. Nano electronics has not advanced as much as bioengineering as the problem of overcoming the potential problem of electronic interference and the ability to connect nano structures to structures of a higher scales were difficult. However, recently there has been such progress as:

- Self-powered devices that can transmit wirelessly over long distances [39]
- Transmission of signals when a particular nucleic acid is sensed by nanosensors
- Sensors that can transmit the amount of a particular molecule is contained in an chemical compound

*Weight of Risks*

Nanotechnology applied to medical electronics poses the risk of interfering with the electrical signals in the human body and poisoning due to nanomaterials/nanoparticle build up. Continued application of nanoelectronics in the medical is said to risk people experiencing a build-up of nanoparticles with could potentially poison the patient. In addition cylindrical fullerenes (carbon nanotubes and nanowires) have killed and poisoned creatures in a lab environment. [40]

*Financial trends*

The investment financially in medical electronics would benefit in the analysis in bioengineering and other areas of nanotechnology. This potential has been identified and from figure 4 it can be seen that from 2004 to 2006 there was great increase compared to the increase of other areas of investment in R & D in nanotechnology. In addition to this financial evidence figure 1 shows that the predicted investment in nano electronics is the second highest in the world market. Therefore nanotechnology in medical electronics can be seen to have increased investment over the years and in the near future.

**Nanorobotics**

*Current state of technology*
At the moment Nanorobotics has shown the least development out of all the applications of nanotechnology discussed in this paper. Currently there has been development of:

- A nanocar powered by an external light source
- A DNA nanowalker – DNA that can split and walk a section and then reattach themselves [41]

This is a great advancement in the field of Nanorobotics and the next steps would be to get this nanowalker to carry a load. However this area of nanotechnology has shown slow progress.

**Weight of Risks**

It is difficult to state and predict the risks of an area in nanotechnology that has yet to be fully realised however the most obvious risks are; the lack of control, wrong molecules being targeted by the Nanorobotics and out of control self-replication. However these risks are mostly based on speculation and fear of what cannot be seen.

**Financial trends**

There is not much financial evidence that is specific to Nanorobotics but nano devices in general haven’t shown great interest investment wise over the years. In figure 1 it does show that in the 1990’s to the early 2000’s there was the most investment in Nanodevices in the world market. However figure 3 and 4 reveal that the potential in the change in investment was minimal and compared to other areas was not the greatest predicted are of investment.

Therefore it can be concluded that Nanorobotics is showing a trend to not be the most popular area of nanotechnology to invest in.

**Nanotechnology in Telecommunications**

**Current state of technology**

Nanotechnology in Telecommunications shows a trend in replacing traditional electronic devices with photonic crystals and quantum dots and current technology such as Kodak producing OLED (Organic Light Emitting Diodes) colour screens, made of nanostructured polymer firms, for use in car stereos and mobile phones reveals a growing and potential market.

**Weight of Risks**

The growth and potential of nanotechnology in telecommunication flags up the threat of a lack of regulations overseen by governing bodies. This is particularly dangerous when what types of nanomaterials are used and in what quantity; as it has been discussed that this lack of regulation can pose as health risks. Therefore the risks in telecommunication are of a general nature that would most likely apply to most areas of nanotechnology; depending on the attitudes of governing bodies and industry standards.
Financial trends

Again financially there is not much specific information in this area of nanotechnology. However, figure 1 shows that in general nanoelectronics was and is predicted to be a big investment in the world market of nanotechnology.

Therefore the recognised potential in nanoelectronics reflects overall that nanotechnology in telecommunications would yield greater breakthroughs and products like is already currently being development.

Financial graphs

Figure 1

![Graph showing financial trends in nanotechnology](image)

The figure shows that in the today’s market for nanotechnology products, nanodevices and nanobiotechnology are estimated to be responsible for the largest shares of around 420 and 415 million US Dollar. Materials and tools play a minor role with 145 and 50 million US Dollar. Compared to the forecasts for 2015, all areas are expected to undergo significant increases, e.g., for materials from 145 million up to 340 billion US Dollar. Nanoelectronics will amount to 300 billion US Dollars, followed by pharmaceuticals, chemical processing and aerospace.

Figure 2

However, any comparisons of actual numbers and forecasts from different sources and with different breakdowns have to be interpreted carefully. The forecast exercise undertaken by Fecht et al. (2003) in their ‘Finding hidden pearls’ report is more reliable because more focused on the near time horizon, i.e. 2002 to 2006 (Figure 3)

![Graph showing financial trends in nanotechnology](image)

In these estimates, nanotools play the most prominent role on the world market, though with smallest growth rates. Nanodevices and nanomaterials start on a slightly lower level, but nanodevices increase with a much higher rate. Contrarily to the above observations of Lux Research, nanobiotechnology is only marginal, but increases substantially during the period of reference. Overall increases are at an average of 15% annually, which does not yet reflect a real breakthrough. From these figures, it is obvious to conclude that nanotechnology is not yet on the take off point of revolutionising the world economy. So, which
Conclusion

From the above discussion of each application of nanotechnology covered in this paper, the best recommendation of investment in nanotechnology would be Bioengineering. This is due to the already and predicted interest financially of the world market in this area of nanotechnology, which truly reveals it to be the most feasible area. In addition, bioengineering already shows developments that work efficiently and beyond the capabilities
of currently traditional techniques of diagnostics, molecular imaging, treatment and drug delivery.
[23] Poole and Owens 2006


[27] Nanotechnology for Telecommunications


[30] Nanotechnology for Telecommunications


[34] http://epic.org/privacy/nano/default.html


