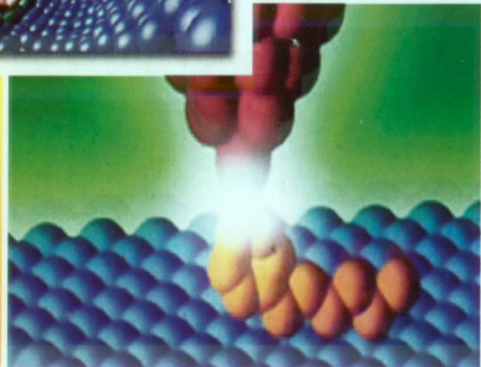
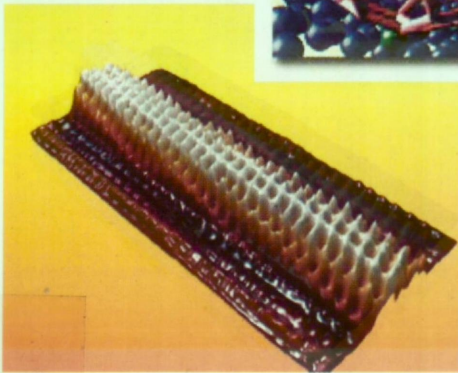
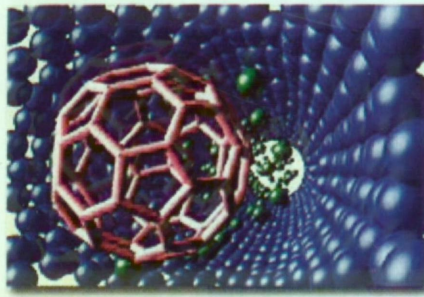


# NANO TECHNOLOGY INSIGHT

*General overview for Sri Lankan industrialists*



**A publication of  
the Technology Watch Centre,  
National Science Foundation**

**AUGUST 2006**



# The Scale of Things – Nanometer

## Things Natural



Dust mite  
200  $\mu\text{m}$

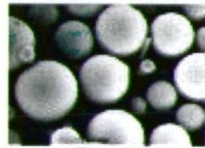


Human hair  
 $\sim 60\text{-}120 \mu\text{m}$  wide

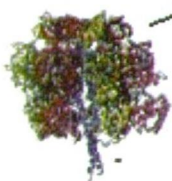
Red blood cells  
with white cell  
 $\sim 2\text{-}5 \mu\text{m}$



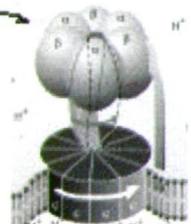
Ant  
 $\sim 5 \text{ mm}$



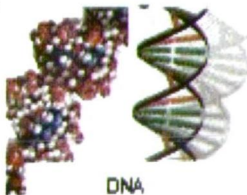
Fly ash  
 $\sim 10\text{-}20 \mu\text{m}$



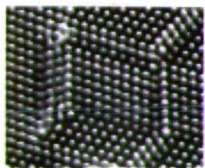
$\sim 10 \text{ nm}$  diameter



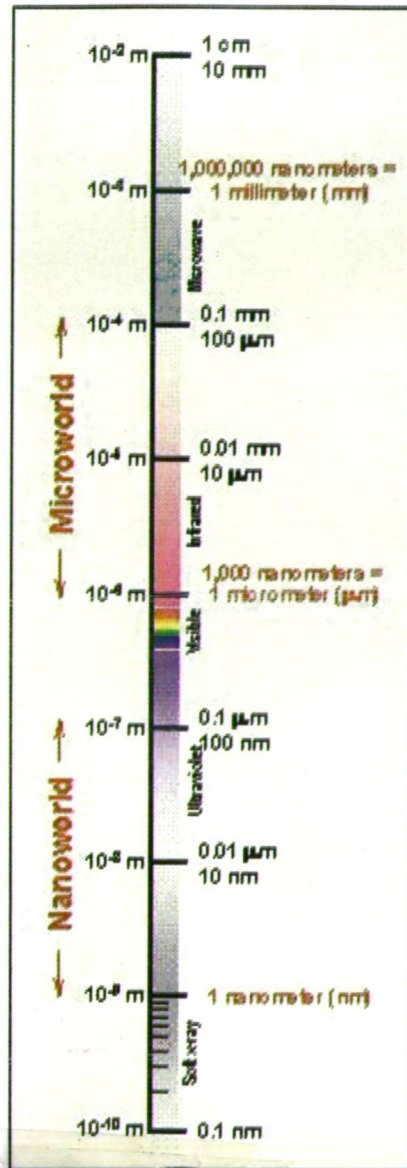
ATP synthase



DNA  
 $\sim 2\text{-}12 \text{ nm}$  diameter



Atoms of silicon  
spacing  $\sim$  tenths of nm



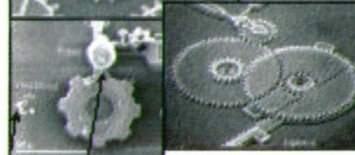
## Things Manmade



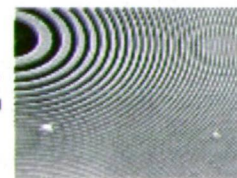
Head of a pin  
1-2 mm



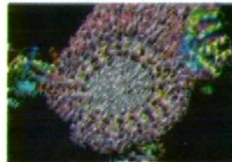
Micro Electro Mechanical (MEMS) devices  
10 - 100  $\mu\text{m}$  wide



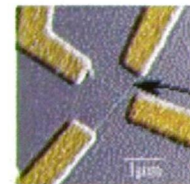
Pollen grain  
Red blood cells



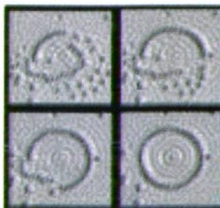
Zone plate x-ray "lens"  
Outer ring spacing  $\sim 35 \text{ nm}$



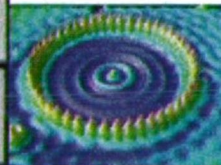
Self-assembled,  
Nature-inspired structure  
Many 10s of nm



Nanotube electrode

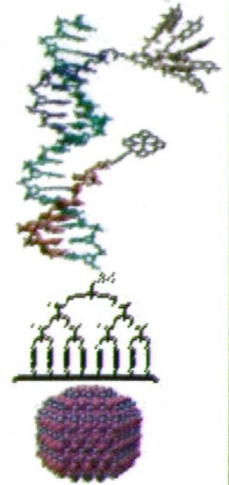


Quantum corral of 48 iron atoms on copper surface  
positioned one at a time with an STM tip  
Corral diameter 14 nm



Carbon nanotube  
 $\sim 1.3 \text{ nm}$  diameter

### The Challenge



Fabricate and combine  
nanoscale building  
blocks to make useful  
devices, e.g., a  
photosynthetic reaction  
center with integral  
semiconductor ferrite.

# WHAT IS NANOTECHNOLOGY

Nanotechnology is a relatively new field of research in scientific development, and involves manipulating and measuring rheological activities on a scale more than 800 times smaller than a human hair. Hence it is set to revolutionise science and technology. It has been speculated about for decades and the wonders and advantages of nanotechnology have been extolled by many. But not all.

Nanotechnology could be harmful to the environment or could be of benefit - depending on the priorities for research and development that are now being decided by Governments and companies. This booklet tries to explore the existing applications, and to analyse current trends and the associated incentives and risks.

Numerous existing technologies depend greatly on processes that take place on the nanometer scale.

Important nanomaterials used commercially include:

- ◆ Carbon tubes
- ◆ Titanium dioxide
- ◆ Silicon/germanium
- ◆ Calcium oxide-based materials
- ◆ Metal-cored coated particles
- ◆ Proteins or DNA

## A Definition of Nanotechnology

*Nanotechnology is the study, design, creation, synthesis, manipulation and application of functional materials, devices and systems through control of matter at the nanometer scale (1-100 nanometers, one nanometer being equal to  $1 \times 10^{-9}$  of a meter), that is at the atomic and molecular levels and the exploitation of novel phenomena and properties of matter at the scale.*

A National Science Foundation, USA official has more precisely defined nanotechnology as a science that deals with materials and systems that have the following key properties:

- ◆ *at least one dimension is from one 1 to 100 nanometres;*
- ◆ *the process of their design uses fundamental control over the physical and chemical attributes of molecular-scale structures; and*
- ◆ *they can be combined to form larger structures*

Since the properties of matter depend in part on size, the physical, chemical and biological properties of matter generally differ at the nanoscale when compared to larger quantities of the same material. This is due, in part, to the difference in surface area per unit of volume at the nanoscale. For a given material, increasing the number of nanoscale particles increases the proportion of atoms on the surface compared with the number of internal atoms.

The result is that chemical reactions can take place between atoms and molecules at surfaces. Essentially, nanoscale particles act as miniature chemical reactors.

In addition, other properties such as magnetism, hardness and electrical and heat conductivity can be changed substantially by modifying materials at the nanoscale. Atoms at the surface often behave differently from those located in the interior since they have a higher energy state.

## **CURRENT TRENDS – Applications**

These changes arise from surprising collective and quantum size effects that arise from confining electrons in nanometre-sized structures

While nanotechnology is in the “pre-competitive” stage (meaning its applied use is limited), nanoparticles are being used in a number of industries.

Nanoscale materials are used in

- ◆ electronic,
- ◆ magnetic and optoelectronic,
- ◆ biomedical, pharmaceutical,
- ◆ cosmetic, energy,
- ◆ catalytic and materials applications

Areas producing the greatest revenue for nanoparticles reportedly are chemical-mechanical polishing, magnetic recording tapes, sunscreens, automotive catalyst supports, biolabeling, electroconductive coatings and optical fibers.

### **Electronic applications**

Today most computer hard drives contain giant magnetoresistance (GMR) heads, that through nano-thin layers of magnetic materials, allow for an order of magnitude increase in storage capacity. Other electronic applications include non-volatile magnetic memory, automotive sensors, landmine detectors and solid-state compasses.

### **Catalytic and material applications**

Nanoparticles also are being used increasingly in catalysis, where the large surface area per unit volume of nanosized catalysts enhances reactions.

Greater reactivity of these smaller agents reduces the quantity of catalytic materials necessary to produce desired results. The oil industry relies on nanoscale catalysts for refining petroleum, while the automobile industry is saving large sums of money by using nanosized - in place of larger platinum particles in its catalytic converters.

Because of their size, filters made of nanoparticles also have been found to be excellent for liquid filtration. Several products are now available for large-scale water purification that can take out the tiniest bacteria and viruses from water systems, in addition to chemicals and particulate matter.

Nanomaterials, which can be purchased in dry powder form or in liquid dispersions, often are combined with other materials today to improve product functionality. Another example of rapid insertion of nanotechnology into useful applications is in the field of wear-resistant coatings. In the mid-1990s, nanoceramic coatings exhibiting much higher toughness than conventional coatings were first developed. In 2000, the first nanostructured coating was qualified for use on gears of air-conditioning units for U.S. Navy ships. It is estimated that use of the coatings on air valves will result in a \$20 million reduction in maintenance costs over 10 years. The development of wear-resistant coatings will lead to commercial applications that can extend the lifetime of moving parts in everything from personal cars to heavy machinery.

## **CURRENT TRENDS – Applications**

### **Nanotechnology is everywhere**

Nanotech is not just a lab experiment anymore. It is spreading fast and in some surprising ways. For that matter, one may probably slather nanotech all over the face in summer. It is in sunscreens and sun-blocking lotions. It is in quick-drying paint. It might be in your pants.

Perhaps most dazzling of all, nanotechnology can be used to manufacture diamonds that are all but indistinguishable from mined diamonds—a profound development that could eventually cut into traditional diamond sales the way Tylenol pushed aside aspirin.

Additional products available today that benefit from the unique properties of nanoscale materials, include:

- ◆ Step assists on vans and bumpers on cars
- ◆ Paints and coatings to protect against corrosion, scratches and radiation
- ◆ Protective and glare-reducing coatings for eyeglasses and cars
- ◆ Metal-cutting tools, ink and automobile catalytic converters.
- ◆ Sunscreens and cosmetics
- ◆ Longer-lasting tennis balls, light-weight, stronger tennis racquets
- ◆ Stain-free clothing and mattresses
- ◆ Dental-bonding agent, burn and wound dressings

## **THE FUTURE OF NANOTECHNOLOGY**

The future generations of nanotechnology will rely on being able to effectively arrange atoms. Molecular manufacturing and the use of molecular assemblers to hold and position molecules will be key to the future, and controlling how molecules react will allow scientists to build complex structures with atomically precise control.

The future of technology is sometimes easy to predict. Computers will compute faster, materials will become stronger, and medicine will cure more diseases. Nanotechnology, which works on the nanometer scale of molecules and atoms, will be a large part of this future, enabling great improvements in all these fields.

Advanced nanotechnology will work with molecular precision, making a wide range of products that are impossible to make today. Molecular manufacturing is the use of programmable chemistry to build exponential manufacturing systems and high-performance products. There are several ways in which this can be achieved, each with its own benefits and drawbacks. This technology is coming soon—almost certainly within 20 years, and perhaps in less than a decade. When it arrives, it will come quickly. Molecular manufacturing can be built into a self-contained, tabletop factory that makes cheap products efficiently at molecular scale.

# THE FUTURE OF NANOTECHNOLOGY

The time from the first assembler, to a flood of powerful and complex products may be less than a year. The potential benefits of such a technology are immense. Unfortunately, the risks are also immense.

## Why focus on molecular manufacturing?

Every manufacturing method is a method for arranging atoms. Most methods arrange atoms crudely; even the finest commercial microchips are grossly irregular at the atomic scale, and much of today's nanotechnology faces the same limit. Chemistry and biology however, make molecules defined by particular arrangements of atoms — always the same numbers, kinds, and linkages. Chemists use clever tricks that do not scale up well. Biology however, uses a more powerful method: cells contain molecular machines that read genetic data to guide the assembly of large molecules (proteins) that serve as parts of molecular machines. Molecular manufacturing will likewise use stored data to guide construction work done by molecular machines, greatly extending abilities in nanotechnology.

## The molecular assembler concept

The basic idea is simple: where chemists mix molecules in solution, allowing them to wander and bump together at random, molecular assemblers will instead position molecules, bringing them together to the specific location at the desired time. Letting molecules bump at random leads to unwanted reactions — a problem that grows worse as products get larger.

By holding and positioning molecules, assemblers will control how the molecules react, building up complex structures with atomically precise control. Picture an industrial robot arm standing next to an unfinished work piece. A conveyor belt supplies the arm with parts, each mounted on a handle. Step after step, the belt advances, the robot grips a fresh handle, plugs the attached part into the work piece, then puts the empty handle back on the belt. Eventually, the work piece is finished and another belt moves it away, shifting a new unfinished work piece into place.

To picture a molecular assembler in a manufacturing system, imagine that all the parts are measured in nanometers, and that the transferred parts are just a few atoms, shifting from handle to work piece through a chemical reaction at a specific site. An assembler works as part of a larger system that prepares tools, puts them on the conveyor, and controls the robotic positioning mechanism.

This will be a complex system that no one will build any time soon. Indeed, no one is even trying to build molecular assemblers today, because nanotechnology is still in its infancy. We can see a path to assemblers, just as the rocketry pioneers of the 1930s and 1940s could see a path to the Moon. But like those pioneers, we are not ready to attempt the final goal. They knew they must first launch many satellites, just as we must first build many molecular machines.

# THE FUTURE OF NANOTECHNOLOGY

## **Confusion and controversy: Developing assemblers**

While nano assembly has been described as “building things atom by atom,” an expression that has caught on in the press, this is a misconception. Molecular assemblers will build with atomic precision by mechanically guiding chemical reactions that typically add a few atoms at a time, but some researchers have criticized this misconception as if it were the actual proposal.

It is correct that assemblers can not build things by using tiny tweezers to pick up and put down atoms one at a time, but even from the start this was never the idea. The apparent controversy over “molecular assemblers” is thus an illusion: the critics are talking about something else. The idea of building things by mechanically guiding chemical reactions has withstood scientific scrutiny for over twenty years, and seems sound. It is time to move on, to consider the consequences of molecular assemblers and what they will be able to build.

## **Understanding advanced capabilities**

One can catch a glimpse of future technologies because it is possible to understand things that we can't yet build. Chemistry, biology, engineering, and applied physics all provide useful perspectives. Chemistry shows what can happen when reactive molecules meet. By using molecular machinery to guide reactive molecules, similar structures can be built at larger scales.

The products can be stronger, tougher, and more capable than the delicate structures found in living cells.

Biology shows that molecular machines can exist, can be programmed with genetic data, and can build more molecular machines. Biology shows that the products of molecular machine systems can be as cheap as potatoes. Molecular manufacturing will make a far wider range of products for similarly low costs.

These glimpses of future technologies are enough to establish the potential for molecular manufacturing. Engineering shows that strong, precise parts can be combined to make computers, robots, and a host of useful gadgets. Applied physics, aided by computer modeling, shows that these sorts of devices can be built from atomically precise parts of nanometer scale.

## **Directions and applications**

Molecular manufacturing will bring both great opportunities and great dangers. Nanocomputers will extend desktop computational power by a factor of a billion or more. Nanoscale sensors, computers, and tools will bring surgical control to the molecular level, enabling a revolution in medicine. Light, strong, and inexpensive aerospace structures will make space flight easy. But the future's faster, cheaper, cleaner production of better products will also bring disruption. Advanced lethal and nonlethal weapons, deployed quickly and cheaply, could make the world a more dangerous place. The list of consequences is long.

# THE FUTURE OF NANOTECHNOLOGY

The tools required to develop nanotechnologies are typically small and unobtrusive. The pace of research is accelerating worldwide. Some suggest stopping it, but it is hard to imagine how. Thus, it seems that this technology, with all its challenges and opportunities, is an unavoidable part of our future.

Industry can cooperate with governmental and educational institutions, professional societies and standards organizations to (a) focus research priorities appropriately, (b) ensure adequate training of scientists, engineers, and technologists, (c) address public safety and environmental concerns, and (d) address national security concerns. Policy formulation will be an ongoing challenge, although new tools can improve the process of critical discussion and debate.

Within a few decades, healthcare will be revolutionized by combining nanotechnology with biotechnology to produce ingestible systems that will be harmlessly flushed from the body if the patient is healthy but will notify a physician of the type and location of diseased cells and organs if there are problems. Nanometer-scale traps will be constructed that will be able to remove pollutants from the environment and deactivate chemical warfare agents. Computers with the capabilities of current workstations will be the size of a grain of sand and will be able to operate for decades with the equivalent of a single wristwatch battery. Robotic spacecraft that weigh only a few pounds will be sent out to explore the solar system, and perhaps even the nearest stars.

The total societal impact of nanotechnology is expected to be greater than the combined influences that the silicon integrated circuit, medical imaging, computer-aided engineering, and man-made polymers have had in this (past) century." See what is Nanotechnology?

*Which companies will adopt and grow with this new field? and which will be out-competed by new players?*

Far from being a dream, nanotechnology will materially impact many of our economies largest markets during the next 10 years, and will be a common thread in many of the emerging businesses during this time.

While medicine will lag other industries due to the multi-year average time for new medical technologies to emerge from clinical trials, it may be the most profoundly impacted within the next two decades. The NanoHouse "Imagine windows that clean themselves. Or bathroom tiles that will not, and cannot, build up soap scum. Imagine piping sunlight around the house like water, or rolling on paint that can change colour whenever you want it. Perhaps best of all, consider receiving a quarterly cheque from the electricity company because your house is producing more power than it is consuming." Brave New Nanoworld Aircraft wings made of lightweight, high-strength carbon nanotubes only a few billionths of a meter in diameter. Magnetic storage disks that could hold 100,000 times more data than current disks. These are some possible applications of new nanoscience research.

## **FUTURE APPLICATIONS**

In the long term we can expect major applications in telecommunications, computing, pharmaceuticals, warfare and energy sectors. Nanotechnology could be harmful to the environment or could be of benefit - depending on the priorities for research and development that are now being decided by Governments and companies. Research indicates that the first products of nanotechnology are likely to be faster computers and diagnostic aids in medicine.

It is hard to predict what products will move from the laboratory to the marketplace over longer periods, but it is believed that nanotechnology will facilitate the production of ever-smaller computers that store vastly greater amounts of information, and process data much more quickly than those available today. Computing elements are expected to be so inexpensive that they can be in fabrics (for smoke detection, for instance) and other materials. The pharmaceutical and chemical industries are being impacted greatly by nanotechnology.

New commercial applications of nanotechnology that are expected in two to five years in these and other industries include:

- ◆ Advanced drug delivery systems, including implantable devices that automatically administer drugs and sensor drug levels;
- ◆ Medical diagnostic tools, such as cancer tagging mechanisms and lab-on-a-chip, real time diagnostics for physicians;
- ◆ Cooling chips or wafers to replace compressors in cars, refrigerators, air conditioners and multiple other devices, utilizing no chemicals or moving parts;
- ◆ Sensors for airborne chemicals or other toxins;
- ◆ Photovoltaics (solar cells), fuel cells and portable power to provide inexpensive, clean energy, and
- ◆ New high-performance materials.

## **ANTICIPATED FUTURE OPPORTUNITIES**

### **Nanotechnology predictions**

Things that become practical with mature Nanotechnology

- ◆ Nearly free consumer products
- ◆ PC's billions of times faster than today
- ◆ Safe and affordable space travel
- ◆ Virtual end to illness, aging, (and theoretical even death)

- ◆ No more pollution and automatic cleanup of existing pollution
- ◆ End of famine and starvation
- ◆ Superior education for every child on Earth
- ◆ Reintroduction of many extinct plants and animals
- ◆ Terraforming Earth and the Solar System

Above current and future nanotechnology industry applications can be summarised as follows:

| <b>Applications of Nanotechnology</b>             | <b>Examples</b>  |
|---|--|
| Energy storage, production, and conversion        | Novel hydrogen storage systems based on carbon nanotubes and other lightweight nanomaterials<br>Photovoltaic cells and organic light-emitting based on quantum dots<br>Carbon nanotubes in composite film coatings for solar cells<br>Nanocatalysts for hydrogen generation<br>Hybrid-protein-polymer biomimetic membranes   |
| Agricultural productivity enhancement             | Nanoporous zeolites for slow-release and efficient dosage of water and fertilizers for plants, and of nutrients and drugs for livestock<br>Nanocapsules for herbicide delivery<br>Nanosensors for soil quality and for plant health monitoring<br>Nanomagnets for removal of soil contaminants   |
| Water treatment and remediation                   | Nanomembranes for water purification, desalination, and detoxification<br>Nanosensors for the detection of contaminants and pathogens<br>Nanoporous zeolites, nanoporous polymers, and attapulgite clays for water purification<br>Magnetic nanoparticles for water treatment and remediation<br>TiO <sub>2</sub> nanoparticles for the catalytic degradation of water pollutants                                |
| Disease diagnosis and screening                   | Nanoliter systems (Lab-on-a-chip)<br>Nanosensor arrays based on carbon nanotubes<br>Quantum dots for disease diagnosis<br>Magnetic nanoparticles as nanosensors<br>Antibody-dendrimer conjugates for diagnosis of HIV-1 and cancer<br>Nanowire and nanobelt nanosensors for disease diagnosis<br>Nanoparticles as medical image enhancers  |
| Drug delivery systems Food processing and storage | Nanocapsules, liposomes, dendrimers, buckyballs, nanobiomagnets, and attapulgite clays for slow and sustained drug release systems<br>Nanocomposites for plastic film coatings used in food packaging<br>Antimicrobial nanoemulsions for applications in decontamination of food equipment, packaging, or food<br>Nanotechnology-based antigen detecting biosensors for identification of pathogen contamination |
| Air pollution and remediation                     | TiO <sub>2</sub> nanoparticle-based photocatalytic degradation of air pollutants in self-cleaning systems<br>Nanocatalysts for more efficient, cheaper, and better-controlled catalytic converters<br>Nanosensors for detection of toxic materials and leaks<br>Gas separation nanodevices   |
| Construction                                      | Nanomolecular structures to make asphalt and concrete more robust to water seepage<br>Heat-resistant nanomaterials to block ultraviolet and infrared radiation<br>Nanomaterials for cheaper and durable housing, surfaces, coatings, glues, concrete, and heat and light exclusion<br>Self-cleaning surfaces (e.g. windows, mirrors, toilets) with bioactive coating   |
| Health monitoring                                 | Nanotubes and nanoparticles for glucose, CO <sub>2</sub> , and cholesterol sensors and for in-situ monitoring of homeostasis   |
| Vector and pest detection and control             | Nanosensors for pest detection<br>Nanoparticles for new pesticides, insecticides, and insect repellents  |

# PRESENT INDUSTRY STATUS SRI LANKA

It is certain that nanotechnology is set to revolutionise science and technology as we know of it today though acquisition of nanotechnology in our industrial sector is currently at the zero baseline. Yet, if our products are to compete with those produced in our competitor countries, we can not escape from the current trends in product development, i.e., nanotechnology.

Sri Lanka is gifted with many natural resources, including a wide range of endemic flora and fauna. Sri Lanka is also reasonably endowed with industrial minerals such as apatite, calcite, dolomite, quartz, feldspar, mica, graphite, ilmenite, rutile, zircon and secondary weathering products like laterite, kaolin, clay and silica sand. Except for graphite, apatite and mineral sands which are under state control, the mineral industry is handled mostly by the private sector. Our graphite is 99 +% pure carbon, while the quartz we have is more than 99% pure silica. The Eppawela apatite resource is yet another heritage we have. Time has come for us to rethink on the effective and sustainable use of our resources keeping in mind not to exhaust all what we have within our lifetime. Most attractive way out would be to go for advanced materials, devices and new products. For example, the quality of raw materials for the local clay based industries are:

- ◆ Pottery, tile and brick, cement etc, which use low grade high iron clays,
- ◆ Ceramic and porcelain industry using high grade low iron clays,
- ◆ Industries such as tire re-treading, paint, paper, pencil etc. where clays are used as inert fillers/pigments,
- ◆ Few other industries with specialized uses, e.g. Asbestos, pharmaceuticals.



There are however, many other types of clay minerals in nature and of these the so-called expanding or swelling clays have a number of interesting chemical and physical properties which in turn offer many potential industrial uses. Exploitation of such clays for industrial processes is gaining currency in developed countries. In Sri Lanka, however, probably due to the fact that no deposits have been identified, little thought has been given to this possibility. Preparation of high-tech ceramics from our local minerals is another area to be exploited. The nanoparticles of these materials would combine all the advantages associated with high surface area to volume ratio and improve activities. The most exciting application of new ceramics is in heat engines such as the advanced gas turbine and the turbo-compound diesel engine. The main attraction of ceramics in heat engine applications is the ability to operate at higher temperatures without forced cooling. This results in a greater efficiency, and hence reduces fuel consumption. Ceramic seals are currently being manufactured world wide in large quantities in different sizes, types and shapes.



Almost all the ceramic materials have high compressive strength and resistance to abrasion. Therefore they are excellent as abrasive powders and for incorporating in grinding wheels. MgO, Al<sub>2</sub>O<sub>3</sub> and diamond powders are used for metallurgical polishing. Silica particles are used in sandstones and sandpaper. SiC and diamond are superior for these purposes. Locally available hard minerals such as corundum, zircon, silica, etc. have been used successfully in manufacturing grinding wheels, in Professor B.S.B. Karunasratne's laboratory in the Department of Physics, University of Peradeniya.

The extreme hardness, wear resistance and low contact friction of ceramics, have also been utilised in the manufacture of bearings. For example, Si<sub>3</sub>N<sub>4</sub> sliding on Si<sub>3</sub>N<sub>4</sub> has a coefficient of friction about 0.27 without addition of a lubricant, whereas steel sliding on steel has a coefficient of friction about 0.12 with oil lubrication and 0.54 without lubrication. However, the lubrication properties of ceramics depend on the chemical composition, temperature and operating condition of the environment. In particular, these ceramic bearings are useful where lubrication is either limited or not possible (vacuum environment) or the temperature is beyond the limits of metal bearings. An example in a low-load situation is the use of ruby or sapphire (single crystal Al<sub>2</sub>O<sub>3</sub>) bearings in watches. Ceramics have an advantage over steel, because of lower density which reduces the centrifugal force on the balls. This in turn reduces the excessive wear of the bearings.

Apart from this, the contact area between ceramic balls and the ring is smaller due to the high elastic modulus of ceramics, and therefore a lower amount of heat is generated. Hot-pressed Si<sub>3</sub>N<sub>4</sub> has shown success in high-load, high speed bearing applications.

### **New Industries based on Graphite**

Excellent lubricants may be prepared by dispersing graphite nanoparticles in a viscous organic liquid. This would benefit the graphite industry enormously. Even gaskets could be manufactured. Graphite nanoparticles with a suitable binder may be pressed to form electrodes. The alkaline-manganese dioxide (Zinc/KOH/MnO<sub>2</sub>) primary battery has become the dominant battery system in the portable battery market after introducing these type of batteries in 1960. Zn is the most popular anode material and Manganese dioxide is an abundant natural oxide, inexpensive and non-polluting material used as cathode in alkaline primary batteries. MnO<sub>2</sub> is also an electronic conductor. Although it is a poor electrical conductor, the electronic conductivity can be improved by addition of carbon black or graphite. Graphite is a good additive to MnO<sub>2</sub> but a trace amount of impurities in natural graphite affects adversely to electrical conductivity.

Therefore the morphology and occurrence of Sri Lanka natural graphite has to be selected very carefully in such applications. Then again the most suitable form will be the nanoparticles.

## **New Industries based on solid polymer batteries**

The lead-acid battery developed in 1859 is still used for ignition in motor vehicles and for propulsion in electrically powered vehicles. Most common types of batteries used for portable electronic devices are Carbon-Zinc, Alkaline, Ni-Cd, Ni-MH etc. However, these batteries do not meet the power requirements demanded by the electric vehicle industry and the consumer electronic industry due to limited specific capacity (ampere hour per gram of active material) giving rise to low energy densities (watt hour per kg). Although microelectronic industry has gone through an unprecedented development during the last few decades, the portable electrochemical power sources have shown only a very slow progress.

Lead-acid and Ni-Cd batteries have 30-100 Wh/Kg (and 50-150 Wh/litre). High energy density and power density, long cycle life and shelf life, reliability and safety are some of the key features expected from a battery. Lithium based rechargeable polymer batteries are emerging as the electrochemical power source of the future. There are several different types of rechargeable Li-polymer batteries that are being commercially developed:

*Systems with Li anodes:* Li / SPE /  $\text{TiS}_2$   
(Intercalation cathode)

*Other cathode materials:*  $\text{V}_2\text{O}_5$ ,  $\text{V}_6\text{O}_{13}$ ,  $\text{LiV}_3\text{O}_8$ ,  $\text{LiMn}_2\text{O}_4$ ,...

*Recent developments:*  $\text{LiNiO}_2$ ,  $\text{LiCoO}_2$   
These cathodes can have potentials 4V against Li metal.

Typically, a Li/SPE/ $\text{LiCoO}_2$  battery can have energy densities of 440 Wh/kg

## **New Industries based on active carbon:**

### **Electrochemical supercapacitors**

Electrochemical capacitors are devices capable of higher storage, several hundred times more than conventional capacitors. There are no chemical changes and unlimited cyclability compared to batteries. The critical components of supercapacitors include the electrodes, electrolyte and the separator. The characteristics of electrode materials for supercapacitors include high cyclability, long-term stability, high surface areas and resistance to electrochemical oxidation/reduction.

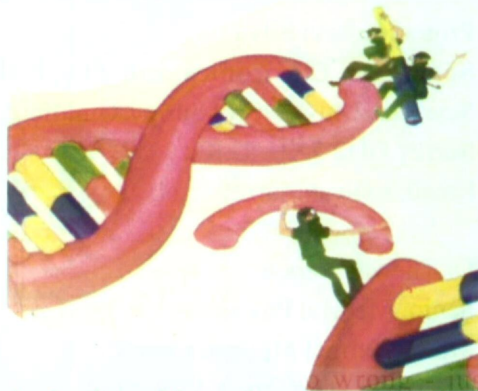
Carbonaceous materials have been particularly popular owing to their large surface areas. High temperature heat-treated active carbons such as coconut shells, wood powders, coal tar and resins are active electrode materials with surfaces ranging between 1000 and 500  $\text{m}^2/\text{g}$ , that results in capacities as high as 500 F/g in alkaline electrolytes.

Discussed above are only a few possibilities but of course, the potential for new industries based on locally available raw materials is limitless. The variety of properties and uses for these myriad materials fashioned into remarkable products is truly remarkable in itself. That such apparently mundane and plentiful minerals could be fashioned into materials with properties so diverse, is a testament both to the wonders of nature and to the agility of the human mind.

## CONCLUDING REMARKS

“This is not to say that nanotechnology is a far-off, fuzzy, futuristic technology. It is not. It has already established a beachhead in the economy. The clothing industry is starting to feel the effects of nanotech. Eddie Bauer, for example, is currently using embedded nanoparticles to create stain-repellent khakis. This seemingly simple innovation will impact not only khaki-wearers, but dry cleaners, who will find their business declining; detergent makers, who will find less of their product moving off the shelf; and stain-removal makers, who will experience a sharp decrease in customers. This modest, fairly low-tech application of nanotechnology is just the small tip of a vast iceberg—an iceberg that threatens to sink even the “unsinkable” companies.”

In this respect, nanotechnology is not different from other new disciplines. We, as humans, do not seem to have the capacity to really learn to understand something before we start to mess with it on a big scale.



And when things do go wrong - just imagine an autodidactic nano-intelligence on the loose - we end up fighting the symptoms, pointing fingers at each other, and deny any or all culpability.

Forethought of possible consequences is usually far from our minds as we are caught up, or pushed by superiors, to make the research investment profitable as soon as possible. Money seems to be all that matters these days, and so it is with nanotechnology. It will need to prove itself in the boardroom as much as the laboratory otherwise it will go the way of other developments that failed the “money test” and disappear into the archives and filing cabinets of the world.

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**“STRIDE INTO THE FUTURE BEFORE IT ARRIVES”  
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