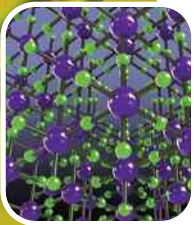
NANOTECHNOLOGY – BIG SCIENCE WITH TINY BUILDING BLOCKS




If you can picture dividing one millimetre into a million equal slices, you're at the infinitely miniscule scale of atoms and molecules. Scientists have discovered that materials behave very differently when they are made up of very small building blocks. Nanotechnology puts these discoveries to work by manipulating the basic building blocks of matter – one atom at a time – to produce unique materials and novel processes.

No wonder that "nano" is all the rage in research labs around the world. Boundaries between medicine, engineering, physics and chemistry fall away as scientists collaborate to realise the immense potential of this exciting new science. But, there may also be a downside.

- **Nano-optimists** believe that this technology will transform the world for the better. They look forward to clean and abundant energy, fantastically strong materials, environmentally friendly production processes, and smart drugs able to detect and treat diseases super-effectively.
- **Nano-sceptics** are worried about unpredictable health and environmental risks, as well as uncertainties around its socio-political consequences into the future.
- The **social response** to nanotechnology is important on both sides of the debate. Supporters of nanotechnology wish to guarantee that its development is not impeded by public opinion, while the negativists hope to ensure it is not too readily and blindly accepted (Wood, 2003).

NANO TERMINOLOGY

- The prefix 'nano' is derived from the Greek word for dwarf.
- The nanoscale refers to sizes at the level of atoms and molecules.
- A nanometre (nm) is one billionth of a metre (10^{-9} m).
- Six bonded carbon atoms is about 1 nm wide.
- A red blood cell is ~7 000 nm in diameter, and ~2 000 nm in height.
- A virus is ~100 nm in length.
- A human hair is between 50 000 and 80 000 nm thick.
- A sheet of normal office paper is about 100 000 nanometres thick.
- Materials can be produced that are nanoscale in one dimension (very thin surface coatings), in two dimensions (nanowires and nanotubes) or in three dimensions (nanoparticles).
- A nanoparticle is any chunk of material smaller than 100 nanometres.

Why do nanoscale materials have different properties?

1. Nanomaterials have a large surface area when compared to the same mass of material produced in a larger form. This can make materials more chemically reactive and affect their strength or electrical properties.
2. Quantum effects can begin to dominate the behaviour of matter at the nanoscale, changing its optical, electrical and magnetic behaviour.

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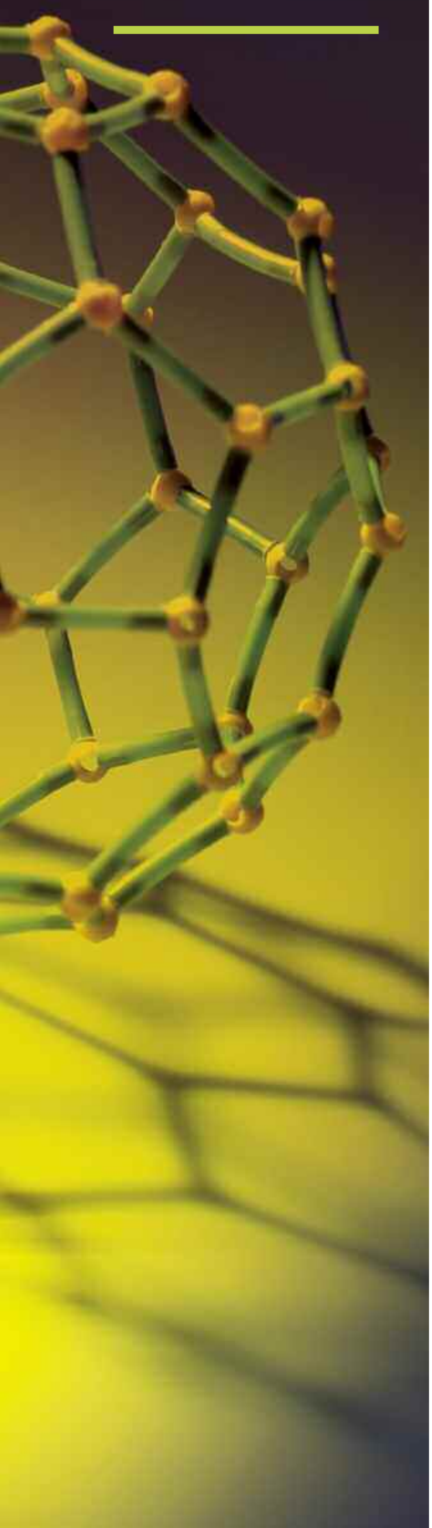
"Nanotechnology is likely to be particularly important ... because it involves little labour, land or maintenance; it is highly productive and inexpensive and it requires only modest amounts of materials and energy".

2005 Report of the UN Millennium Project Task Force on Science, Technology and Innovation



The origins of nanotechnology

"There's plenty of room at the bottom" physicist Richard Feynman said half a century ago when he first spoke about the possibility of manipulating material at the scale of atoms and molecules (Feynman, 1959). The term 'nanotechnology' was first used in 1974, when Japanese researcher Norio Taniguchi used it to refer to the ability to engineer materials precisely at the nanometre level. Eric Drexler made the term popular in his 1986 book, *Engines of Creation*.

But, nanotechnologies are not entirely new. Nanoparticles have been used in glass and ceramics for centuries and materials scientists have been using nanoscale features of many chemicals for decades. The natural world also contains many examples of nanoscale structures.

The discovery of C60 in 1985 and carbon nanotubes in 1991 boosted the development of nanomaterials. Advances in computing power, materials modelling and microscopy gave scientists the tools to observe and handle individual atoms and to synthesise nanomaterials for specific purposes (Pitkethly, 2003). This ability to design materials at the nanoscale is what modern nanotechnology is all about.

Nanotechnology now and in the future

While much of the promise of nanotechnology is yet to be realised, current applications of nanotechnology include:

- nanosized particles in sunscreens, lipsticks and paints
- antibacterial nanosilver in wound dressings, plasters, catheters, and even socks
- breathable, waterproof, wear-resistant, wrinkle-resistant and stain-resistant textiles
- nanofilters for water purification
- nanomembranes in fuel cells and batteries
- nanoparticles in new generation solar cells
- nanoclays in plastics, tennis balls and many more
- stain-resistant fabrics
- self-cleaning, water-repellent and antibacterial glass
- tough, erosion-resistant cutting tools
- self-repairing, corrosion-resistant coatings.

Scientists are also working on:

- **Medicine:** nanorobots as vehicles for drug delivery; durable implants, prosthetics and heart valves; artificial retinas and cochleas, organ replacements
- **Food and nutrition:** atomically engineered food and crops that can be produced on less land and using less labour; nutritionally enhanced 'smart' foods
- **Energy:** more efficient fuel cells; lightweight, high-energy density batteries; lighting that uses very little energy
- **Environment:** self-cleaning filters to produce clean drinking water from waste water; techniques to clean up hazardous chemicals; sensors able to detect single molecules to monitor pollution; nanoscale traps to remove pollutants from the environment and remediation of toxic waste
- **Security:** new imaging, detection and personal identification systems; decontamination equipment; nanoforensics
- **Information technology:** smaller, lighter, more powerful and cheaper computers; miniature data storage systems that can store vast amounts of information; high resolution displays that can be rolled up like a poster
- **Manufacturing:** ultra-strong, durable materials that are very light and can be used, for example, to build aircraft; nanoceramics for more durable automotive components or high-temperature furnaces; wear-resistant tires; paints that can change colour by the flick of a switch.

"We are still in the initial wave of nanotechnology, in which most of the nanotechnology-based products on the market are linked to defence and national security applications or to sporting goods and consumer-convenience items. Within five to ten years, sophisticated electronic devices that use nanoscale circuitry and memory could be expected. After ten to fifteen years, the introduction of pharmaceutical products, drug delivery, and health-monitoring devices will begin. Beyond the scope of our current conception, perhaps thirty to forty years ahead, completely new forms of devices and processes will emerge."

Dr Suprakas Ray, National Centre for Nano-structured Materials, CSIR

Hopes and hazards

Along with optimism about the promise of nanotechnology, there are uncertainties about its potential impact on health, the environment and societies in general. Questions sparking debate include:

- **Nano-hype?** Some believe that scientists working in the field of nanotechnology are inflating the potential promise of nanotechnology and that many of the promised innovations will never become a reality.
- **Could nanoparticles be toxic?** Nanoparticles may be toxic simply because of the unique properties it has from being so incredibly small and therefore having a relatively large surface area. It is also likely that nanoparticles will penetrate cells more readily than larger particles. There is concern that carbon nanotubes, already commercially available to reinforce plastic materials, can affect the lungs in ways similar to asbestos (Kipen & Laskin, 2005; Poland 2008).
- **Food safety?** Do we really know enough about what happens to nanoparticles once they are ingested to allow its use in foods? In January 2008 the UK Soil Association adopted a nano-free policy for products certified as organic (Borm & Berubi, 2008).
- **Could nanotechnology spiral out of control?** In molecular nanotechnology, scientists are working towards minute nanorobots that can be programmed to manufacture things, atom by atom. These "nanofactories" could produce large and complex products, including more nanofactories. This could make cheap and rapid manufacturing a possibility, but could these nanorobots escape and reproduce uncontrollably? (Crichton, 2002).
- **Who will take responsibility?** A key question is how society can control the development and deployment of nanotechnologies and craft responsible policy to maximize benefits and reduce risks. Some are worried that nanotechnologies are advancing too fast for policies and regulations to keep up.
- **Who will benefit?** If nanotechnology is driven by an affluent agenda, it will widen the gap between rich and poor countries because of their different capacities to develop and exploit nanotechnologies, leading to a so-called 'nanodivide'. Producers in developing countries could also suffer if natural products (such as rubber, cotton, coffee and tea) are replaced by nano-equivalents.
- **Is nanotechnology ethically acceptable?** Some people are uneasy about the claim that nanotechnology (much like genetic modification) is 'messing' with the building blocks of nature and therefore 'unnatural' and even unethical.

Engaging the public

The successful introduction of a new technology requires careful attention to the interactions between the technology and society (Keller, 2007). Negative public opinion can obstruct the application of technological advances (Service, 2004). The public backlash against genetically modified foods effectively stalled a new industry in many parts of the world (Macoubrie, 2006).

Increasingly, scientists and policy makers are recognising the need to engage a wide variety of stakeholders on the promises and perils of nanotechnology. Instead of waiting for potential adverse reactions, the scientific community should engage in proactive dialogue to promote awareness, build trust and encourage informed decision making about the safety, ethics and regulation of nanotechnology. Researchers must take public concerns and the expectations of society seriously (Arnall, 2003; Rogers-Hayden & Pidgeon, 2007).

The mass media is at the interface between scientists, policy makers and the public. To use the mass media as an effective engagement tool, researchers need to understand their own role in news production, as well as how the media works (Petersen, 2008). It is also important to understand how scientists themselves perceive public discourse and media coverage of nanotechnology (Kramer, 2007).

An opportunity for social sciences?

Social and cultural differences come into play when people are faced with new technologies and this has specific implications for nanotechnology-related public outreach and risk communication efforts (Priest, 2006). The social sciences could play a key role in helping to shape the agenda of nanotechnology research and innovation (Lewenstein, 2005; Macnaghten, 2005). The role of social sciences in nanotechnology's development should be more than one of smoothing the path for its acceptance. Social science can help construct the lens through which we see nanotechnology, and understand its implications so these can be incorporated into development (Wood, 2003).

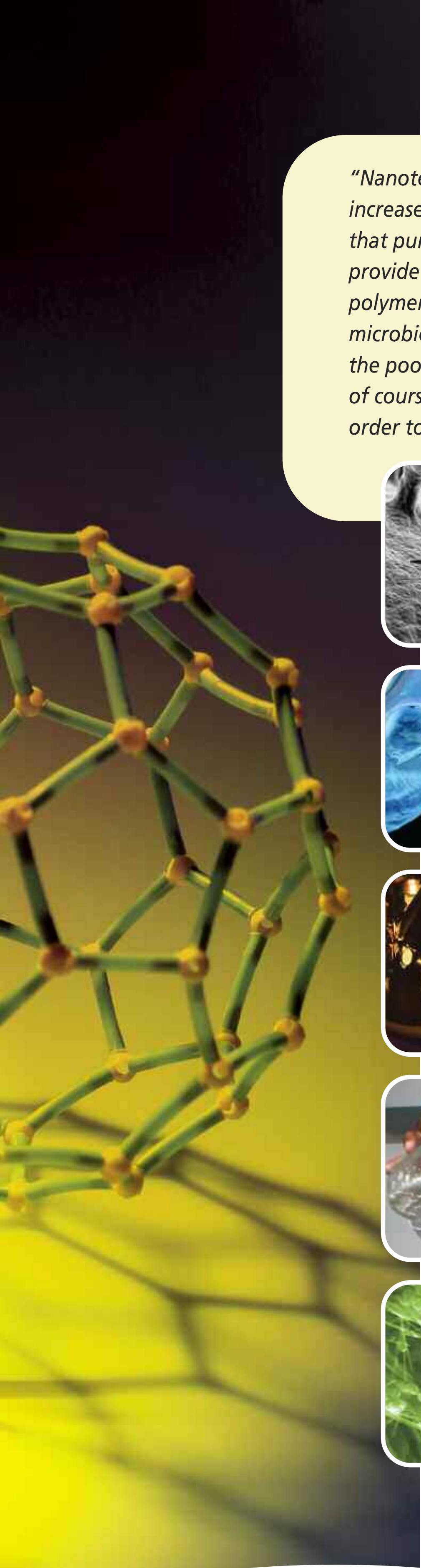
Key nanotechnology players in South Africa

The Department of Science and Technology (DST) outlined the country's vision for nanotechnology in the National Nanotechnology Strategy, launched in 2006. It positions nanotechnology as a tool to address development challenges and provide solutions to local development needs, such as safe drinking water and innovative delivery of health services.

The DST supports the South African Nanotechnology Initiative (SANI), a network of researchers, policy makers and other stakeholders interested in promoting South Africa's competitiveness in nanotechnology. More information about members and current research priorities is available at www.sani.org.za.

Two centres in South Africa provide a dedicated platform for nanotechnology research, innovation and capacity building:

1. The National Centre for Nano-structured Materials at the CSIR focuses on the design and modelling of novel nano-structured materials, with an emphasis on developing materials relevant to South Africa's needs. The group collaborates locally and globally with universities, science councils, the private and public sector.
2. The DST/Mintek Nanotechnology Innovation Centre at Mintek focuses on water, health, mining and minerals. The Medical Research Council, the Water Research Commission and several universities participate in the Mintek consortium. Mintek is also home to Project AuTEK, a joint venture between Mintek, local universities, and the three major South African gold mining houses - AngloGold Ashanti, Gold Fields and Harmony Gold. It focuses on creating gold-based chemo-therapeutics for diseases where there is a need for improved medicine, such as cancer, malaria and HIV/Aids.



"Nanotechnology has the potential to develop a range of applications to, for example, increase soil fertility and crop production. It could provide rural villages with portable systems that purify, detoxify and desalinate water through 'intelligent membranes'. It can certainly provide solutions for improved drug delivery through the development of biodegradable polymers that ensure sustained and gradual release treatments. Furthermore, nanotech microbiocides could substantially reduce the risk of HIV infection in women. It is therefore the poor that stand to benefit most from existing and emerging nanotechnologies, provided of course that public funding and policies are aimed at effectively spreading these benefits in order to balance social and economic development priorities."

Derek Hanekom, Deputy Minister of Science and Technology, at the launch of the South African National Nanotechnology Strategy, 13 April 2006, Mintek

Image courtesy of the CSIR

In an 'Emerging Issues Paper' on nanotechnology, published March 2008, South Africa's Department of Environmental Affairs and Tourism calls for a South African research strategy to address the safety, health and environmental aspects of nanotechnology, and increase public awareness related to the issue (Oosthuizen & Binedell, 2008).

Useful internet resources on nanotechnology

- Big things from a tiny world, US Nanotechnology Initiative (**www.nano.gov**)
- European Nanotechnology Gateway (**www.nanoforum.org**)
- Foresight Nanotech Institute (**www.foresight.org/nano**)
- Safe production and use of nanomaterials (**www.nanosafe.org**)
- Small talk: Discussing nanotechnologies (**www.smalltalk.org.uk**)
- The Universities of Sheffield and Leeds Nanotechnology Education Portfolio (**www.nanofolio.org**)
- UK Royal Society and the Royal Academy of Engineering working group on nanotechnology (**www.nanotec.org.uk**).
- Nanotechnology games that encourage debate:
  - DECIDE nanotechnology game (downloadable card game kit) **www.playdecide.org/download/nano/Nanotech_kit_uk.pdf**
  - DEMOCS nanotechnology game (online game): Register at **www.neweconomics.org**

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The **South African National Nanotechnology Strategy** was approved by Cabinet and launched in April 2006. It aims to ensure that South Africa is ready to optimally use nanotechnology to enhance the country's global competitiveness, and to achieve its social development and economic growth targets.

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