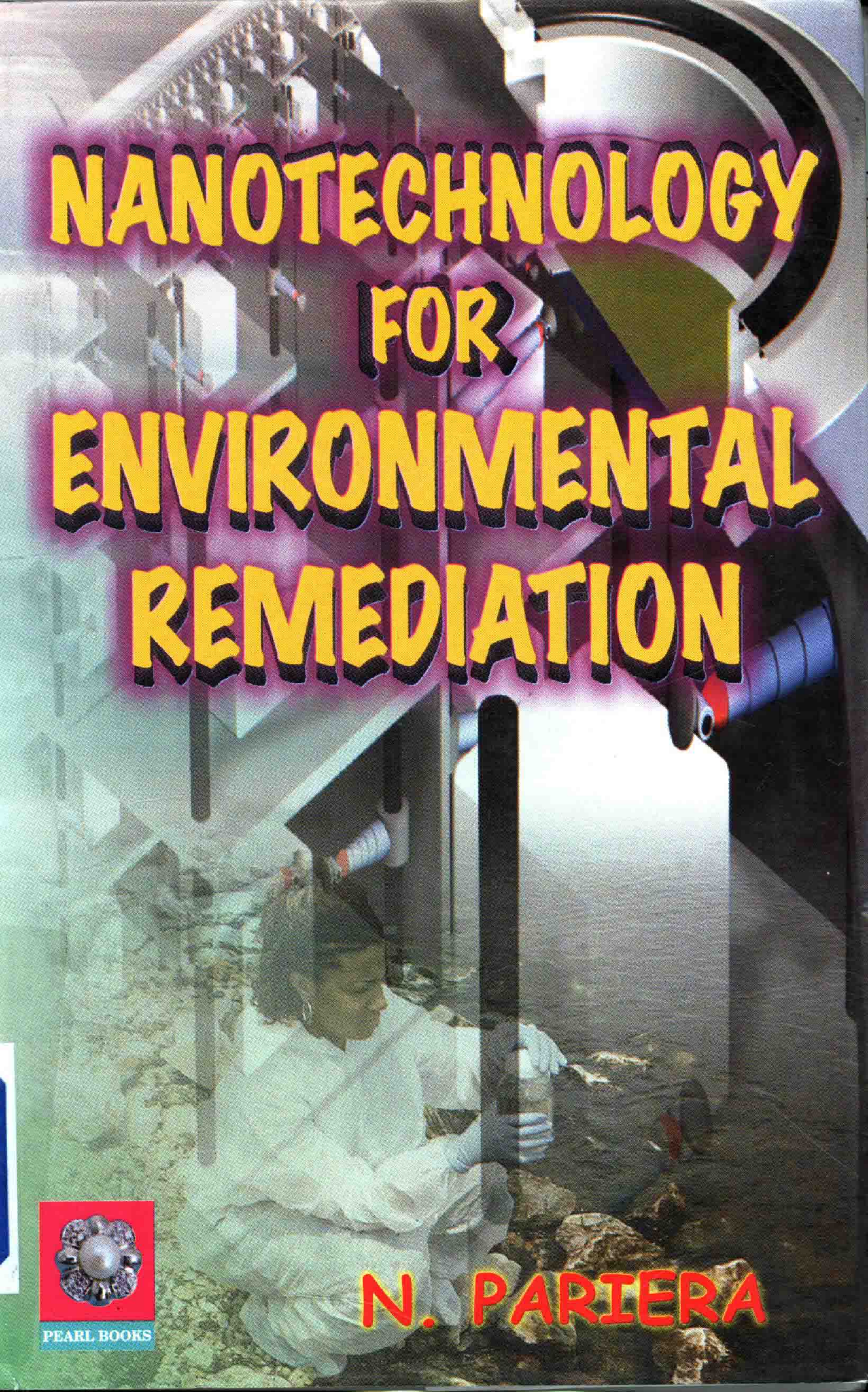
# NANOTECHNOLOGY FOR ENVIRONMENTAL REMEDIATION



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Dr. N. Pariera

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# Nanotechnology for Environmental Remediation

# Preface

A new generation of highly efficient environmental technologies from solar technologies and water-purification systems to sensors that detect pollution levels is becoming a reality as a result of nanotechnology's revolutionary properties and increased investment in this field. Not only are new, clean, energy efficient applications now incorporating nanotechnology, but also some researchers are beginning to integrate green engineering and chemistry principles early on into their production methods for nanomaterials and nanoproducts. Manufacturers have tremendous opportunities to design their production processes in ways that minimize environmental impact at the early stages of development in this nascent (albeit fast-growing) field.

Nanotechnology for Environmental Remediation involves an approach to risk mitigation in an emerging and important set of industries. It involves three complementary goals: (a) advancing the development of clean technologies that use nanotechnology, (b) minimizing potential environmental and human health risks associated with the manufacture and use of nanotechnology products and (c) encouraging replacement of existing products with new nanoproducts that are more environmentally friendly throughout their life cycles. These approaches not only offer environmental benefits but also will help give us greater security and help us address public health crises, among other benefits. This critically important approach of nanotechnology needs further attention and integration into manufacturing processes, educational curricula and policy efforts.

The present book discusses about all them in greater detail. It is being hoped that the book will be equally important to the teachers and students. We are always eager of the valuable suggestions of the readers.

— *Author*

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# 1

# Nanotechnology and Nanotechnology Development

## INTRODUCTION

Nanotechnology is a powerful new technology for taking apart and reconstructing nature at the atomic and molecular level. It is being touted as the basis of the next industrial revolution and will be used to transform and construct a wide range of new materials, devices, technological systems and even living organisms. Nanotechnology will likely underpin and impact all industries and sectors of the economy, and is likely to facilitate far-reaching changes in social, economic and ecological relations. Opinion is sharply divided regarding whether these changes will be largely positive or negative.

Proponents suggest that nanotechnology will deliver gains in fields as diverse as manufacturing, medicine, environmental remediation and military applications. However critics argue that nanotechnology introduces serious new risks to human health and the environment, raises problematic ethical issues and is likely to result in large-scale socio-economic disruption. Governments are beginning to recognise the need for new laws to protect workers, the public and the environment from the risks of nanotoxicity.

However despite the commercial availability of over 720 products containing nanomaterials, not a single government world-wide has yet introduced regulations that require nanomaterials to be subject to new safety assessments prior to commercial release.

The failure of government regulators to take seriously the early warning signs surrounding nanotoxicity suggests that they have learnt nothing from any of the long list of disasters that resulted from the failure to respond to early warning signs about previous perceived "wonder" materials (like asbestos, DDT and PCBs).

Nanotechnology is being commercialised largely outside of general public awareness or debate, and without any serious attempt to involve the community in decision making about its introduction. Issues of ethics, democracy and nanotechnology's broader socio-economic impacts have yet to register in the debate.

## WHAT IS NANOTECHNOLOGY?

There is still not an internationally accepted nomenclature, set of definitions and measurement systems for nanotechnology, although work towards these has begun. The lack of a standardised nomenclature and measurement system has made it difficult to compare safety tests, exposure measurement and risk assessment carried out to date. However, the term 'nanotechnology' is now generally understood to encompass both nanoscience and the broad range of technologies that operate at the nanoscale.

- *Nanoscience:* The study of phenomena and materials at the atomic, molecular and macromolecular scales, where properties differ significantly from those at the larger scale
- *Nanotechnology:* Design, characterisation, production and application of structures, devices and systems by controlling shape and size at the nanoscale
- *Nanoscale:* Having one or more dimensions of the order of 100nm or less, or having at least one dimension that affects functional behaviour at this scale
- *Nanomaterials:* Particles, nanotubes, nanowires, quantum dots, fullerenes (buckyballs) etc that exist at a scale of 100nm or less, or that have at least one dimension that affects their functional behaviour at this scale

One nanometre (nm) is one thousandth of a micrometre (m), one millionth of a millimetre (mm) and one billionth of a metre (m).

To put 100 nanometres in context: a strand of DNA is 2.5nm wide, a protein molecule is 5nm, a virus particle 150nm, a red blood cell 7,000 nm and a human hair is 80, 000 nm wide and a flea is around 1,000,000nm in size.

## ENGINEERED VS. INCIDENTAL NANOPARTICLES

Engineered nanoparticles are deliberately manufactured and can be distinguished from nanoparticles that 'exist in nature', or are by-products of other human activities. 'Incidental' nanoparticles (also called ultrafine particles in the study of air pollution and its epidemiology) are a by-product of forest fires and volcanoes, and high-temperature industrial processes including combustion, welding, grinding and vehicle combustion. It is the manufactured or engineered nanotechnological products and processes that are the primary focus of the issues raised in this briefing paper. However many of the safety and regulatory issues relating to manufactured nanoparticles are also relevant to incidentally produced nanoparticles (e.g. the need to establish safe workplace exposure limits for all types of nanoparticles).

### Nanotechniques

A number of forms of nano-techniques can be distinguished, including:

- *Nanoparticle Production:* This includes production of carbon nanotubes, "buckyballs", quantum dots, and the nano-scale manufacture of previously larger scale materials and chemical compounds (including metal oxides such as titanium, zinc, aluminium, manganese, iron, silver, gold and more)
- *Nanofabrication and Molecular Manufacturing:* these include a range of existing and hypothetical techniques and processes for assembling systems and structures from the atom up. The goal of molecular manufacturing is to create independent small-scale nanofactories that will enable efficient, decentralised industrial manufacture with atomic level precision

- *Nanobiotechnology:* This includes the use of nanotechnology to manipulate living organisms and to enable the merging of biological and non-biological materials Why is nanotechnology attracting so much interest?

## What is Novel about Nanotechnology?

The fundamental properties of matter change at the nanoscale. The properties of atoms and molecules are not governed by the same physical laws as larger objects or even larger particles, but by "quantum mechanics". The physical and chemical properties of nanoparticles can therefore be quite different from those of larger particles of the same substance. Altered properties can include but are not limited to colour, solubility, material strength, electrical conductivity, magnetic behaviour, mobility (within the environment and within the human body), chemical reactivity and biological activity.

The altered properties of nano-sized particles have created new possibilities for profitable products and applications. The use of nanoparticles, the potential of nanofabrication and molecular manufacturing, and new breakthroughs associated with synthetic biology and the melding of living and non-living organisms, has generated a lot of excitement in the research and business communities. Oxford University Professor George Smith has been quoted as joking that "nano is from the Greek verb meaning 'to attract research funding'"

## Why are People Touting nano as the Next Industrial Revolution?

Nanotechnology embodies the dream of controlling the building blocks of both living and non- living things, and the ability to remake the world from the atom up. The excitement around nano is building because people believe that it will bring changes as significant or potentially more far reaching than those that accompanied the European Industrial revolution. Proponents and critics alike suggest that nanotechnology will enable break throughs in a wide number of different fields- communications, agriculture, cognitive science, medicines, military and environmental remediation to name a few...

*"Convergence of diverse technologies is based on material unity at the nanoscale and on technology integration from that scale... [Nanoscience and nanotechnology] will allow us to understand and, when desirable, to control the behavior both of complex microsystems, such as neurons and computer components, and macrosystems, such as human metabolism and transportation vehicles"*

*"The real power of nanoscale science is the potential to converge disparate technologies that can operate at this scale. With applications spanning all industry sectors, technological convergence at the nanoscale is poised to become the strategic platform for global control of manufacturing, food, agriculture and health in the immediate years ahead"*

Why should we be sceptical about nanotechnology's ability to solve our problems?

Nanotechnology proponents suggest that it may provide a panacea for growing problems of climate chaos, water shortages, pollution, poverty, disease and social unrest. Nano optimists see nanotechnology providing: universal clean water supplies; greater productivity in agriculture and nutritionally enhanced foods; cheap and powerful solar energy generation; clean and highly efficient manufacturing; and radically improved formulation of drugs, delivery modes, diagnostics and effective vaccines for most diseases. However industrial-technological solutions alone cannot fix problems stemming from socio-economic inequity or the unequal distribution of power. Nanotechnology, like other new echnologies, does not exist in isolation from its economic or political context. Nano investment and applications to date remain driven by the less altruistic economic and political realities of the 'real world'.

The first nanoproducts to be released commercially are targeted squarely at wealthy consumers in the global north, including: anti-wrinkle cosmetics; odour-eating socks; superior display screens for computers, televisions and mobile phones; premium coatings for luxury cars; and self-cleaning windows and bathrooms.

The US government, which is the world's biggest funder of nano research, directs the largest portion of its funding to military applications. In 2006, the US defence program received a third of the total US$1.3billion investment in nanotechnology, which was a greater share than that received by the National Science Foundation

Our experience of the European Industrial revolution, and other periods of rapid industrial and technological change, tells us that the benefits of nanotechnology will not be shared equally. Very little attention has been paid to studies of the likely disruptive impacts for the world's poorest people if and when nanomaterials displace existing commodity markets (eg for rubber, cotton or copper) and cause massive job loss

Now, as during the previous industrial revolution, it will be the world's poorest people who are least able to adapt quickly in the face of technological change.

## Overview of Investment and Commercial Value

Investment in nanotechnology is growing rapidly. Combined investment in nanotechnology by the government and private sectors is growing rapidly from year to year. About US$10 billion was spent on nanotechnology research and development in 2004, which is almost double the money spent in 2003. At least 60 countries have established national nanotechnology research programmes, about half of which are in Europe.

In 2004, Japan led the way, investing almost US$4 billion, with the US not far behind at US$3.4 billion. The combined investment from Germany, the UK, France and Italy was about half this. Following that in order of descending investment, was: Taiwan, South Korea, China and Australia. In Australia, about US$200 million was invested, with about equal proportions coming from government and the private sector.

The growth of private sector investment in nanotechnology is now outpacing that of government. 2003 was the first year that private sector funding about equalled public funding, but in 2004 the corporate sector's investment was more like two-thirds of the total money invested. Nanotechnology cuts across all industry sectors and investment reflects this. Virtually all the Fortune 500 companies now run nano-programmes. To put the scale of nanotech investment in context, the US government's US$5 billion for nano research and development between 2001 and 2006 makes it the biggest publicly funded science endeavour since the Apollo moon landing.

Nanotechnology is already making a commercial impact In 2004, global sales of nanotechnology products totalled US$10 billion. The overwhelming majority of this revenue came from sales of nanoscale materials, with a very small amount coming from nanodevices. Industry analysts Lux Research estimated that products incorporating nanomaterials constituted around 0.1% of global manufacturing output.

Future predictions of industry growth are necessarily speculative and vary widely. In 2001, the US National Science Foundation estimated that by 2015 the global nano industry would be worth US$1trillion, employ 2 million workers directly, and contribute to the production of half the world's new manufactured products. However growth figures continue to be revised upwards, with some recent comments indicating the NSF believes the US$1trillion figure may be reached as early as 2011.

In 2004 industry analysts Lux Research estimated that by 2014 products incorporating nanomaterials would constitute around 15% of global manufactured goods, with a total value of as much as US$2.6trillion. To put this into context, that would approach the size of the information technology and communication industries combined. Nanoproducts- what's available now and what can we expect in the future Products containing nanomaterials already on the market

Although some people still describe this phase of nano's commercialisation as being "pre-competitive", more than 720 products containing nanomaterials are already available.

Products containing nanomaterials have been released commercially in the absence of regulatory oversight. There is no legal requirement anywhere in the world for manufacturers to conduct new safety tests on nano-scale ingredients to ensure that the people who use these products and the workers involved in product manufacture, packaging and transport, are not exposed to unacceptable risks. There is similarly no requirement for manufacturers to demonstrate that the novel properties of nano-scale ingredients, nano-processing, or product manufacture do not present an increased negative impact to the environment. There is no requirement for manufacturers to indicate the inclusion of nanoscale ingredients on product labels.

The following list represents just a fraction of the products that are already on the market:

- Transparent sunscreens
- Cosmetics including lipsticks, face powders, hair conditioners, moisturizers and anti-ageing creams
- Temperature moderating, stain, moisture and odour-repellent clothing
- Food additives
- Food packaging
- Agricultural fertilisers
- Long-lasting paints furniture varnishes and car coatings
- Self-cleaning windows and building surfaces
- Computer chips and mobile phones
- Inks
- Magnetic recording tapes and memory storage devices
- Optical fibres
- Chemical-mechanical polishing
- Land-mine detectors
- Solid-state compasses
- Fuel cells
- Industrial catalysts
- Specialist automotive and aerospace components
- Broad range of military applications
- Display technology for laptops, mobile phones, digital cameras
- Football stadium lights

- Metal-cutting tools
- Self-cleaning surfaces for glass and building surfaces
- Glare-reducing coatings for eyeglasses and car windscreens
- Automatic catalysts converters
- Bumper bars and step assists for cars
- Tennis balls and racquets
- Dental-binding agents
- Burn and wound dressings
- Bio-imaging products
- Nanomaterials for environmental remediation
- Disinfectants and anti-bacterial products
- Anti-graffiti coatings for walls

## What will Nanotechnology look like in the Future?

It is difficult to imagine exactly how nanotechnology development is likely to unfold and what its timeline may be. Even the industry experts revise their forecasts every few years. We know that the use and production of nanomaterials will expand significantly over the coming years, with implications for human health, the environment and broader trade relations. However it is hard to know how many of the hypothetical higher-tech applications of nanotechnology will actually come to fruition, and when. Some of the current and hypothetical applications of nanotechnology are described briefly below.

Present day: Applications based primarily on the use of passive and active nanomaterials for their novel properties. This draws on well-established branches of applied science including materials science. Key applications are in coatings, pigments, electronics and photonics and biotechnology.

Medium-term (2015): Half of all newly designed advanced materials and manufacturing processes may be built using control at the nanoscale, with increased used of nanoscale devices. Creation of three-dimensional nanosystems and the development of precise molecular assembly. Healthcare and life sciences applications become significant as nano-enabled pharmaceuticals and medical devices emerge from lengthy human trials. Technology convergence enables vastly superior treatment of disease (including an effective treatment for cancer) and life extension, including via the production of synthetic organs. 'Smart' foods interact with consumers to 'personalise' food, changing colour, flavour or nutrients on demand or in response to an individual's allergies or nutrient needs.

Longer term (2015-2050): Development of molecular assembly-based nanofactories capable of decentralised, atomically-precise manufacture of everything from bicycles to supercomputers to weapons. Atomic-level genetic control of crops, plants and animals; use of ubiquitous nano surveillance and monitoring systems on farms increases productivity and reduces labour needs. Fast, broadband interfaces directly between the human brain and machines that transform work in factories, control automobiles, ensure military superiority to its early developers, and enable new sports, art forms and modes of interaction between people. "Instead of harvesting grain and cattle for carbohydrates and protein, nanobots could assemble the desired steak or flour from carbon, hydrogen and oxygen atoms present in the air as water and carbon dioxide"

## Why the Science of the Small Brings huge Problems?

The expectations and hype surrounding nanotechnology have fuelled a nano gold rush. Governments and corporations world-wide have scrambled to be part of the 'next industrial revolution', not wanting to be left on the wrong side of a future divide between 'nano-haves' and 'nano-have nots'. In the midst of this race to boost research, seek patents and commercialise as quickly as possible, serious questions regarding ethics, human and environmental safety, socio-economic disruption and democracy have been ignored. Some key areas where unresolved questions remain include:

## SERIOUS ETHICAL PROBLEMS

Ethical problems underlie nanotechnology's quest to manipulate the very building blocks of life; its aggressive commercialization enabled by research carried out with public monies, but driven by commercial and military interests; and the failure of governments to halt the rapid introduction of nanoproducts and nanomaterials until serious public interest issues are addressed adequately. Nanobiotechnology raises significant ethical concerns in its quest to engineer organisms and manufactured products containing both biological and human-made components. The US National Science Foundation's work to use convergent nanotechnology, biotechnology, information technology and cognitive science to improve human performance beyond species-typical boundaries is also particularly ethically problematic. This work has drawn strong criticism from disabilities and human rights advocates concerned that it will create new inequities and further marginalise existing disadvantaged groups.

**Risks to Human and Environmental Safety**

There is a growing body of toxicological evidence that nanoparticles present serious new risks to human and environmental health. Leading scientific organisations, including the United Kingdom's Royal Society, have warned that the risks of nanotoxicity are serious. In 2004 the Royal Society recommended that nanomaterials should be treated as new chemicals and be subject to new safety assessments prior to their inclusion in consumer products. The Royal

Society further recommended that factories and research laboratories should treat nanomaterials as if they were hazardous, and until the environmental impacts of nanomaterials are better known, their release into the environment should be avoided as far as possible. And yet no government world-wide has introduced a regulatory system to protect the health of workers, the public and the environment from the risks associated with nanotoxicity. The Royal Society clearly recommended prohibiting the deliberate release of nanomaterials for bioremediation until its ecological implications were better understood, and yet this is already taking place. Concerns surrounding the potential for deliberate or unintentional release of self-replicating organisms that could cause ecological damage cannot be ruled out.