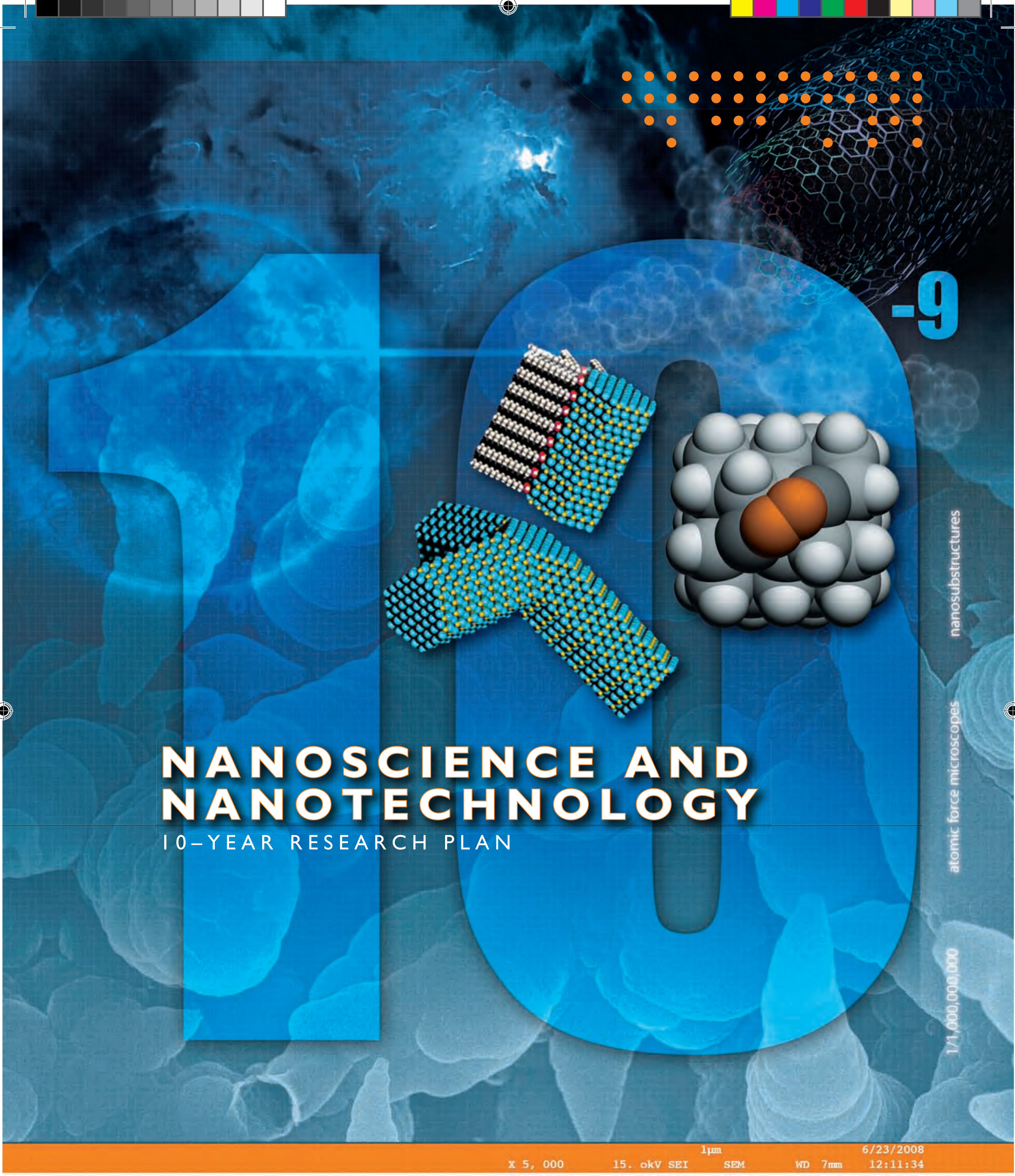

NANOSCIENCE AND NANOTECHNOLOGY

10–YEAR RESEARCH PLAN

science
& technology
Department:
Science and Technology
REPUBLIC OF SOUTH AFRICA

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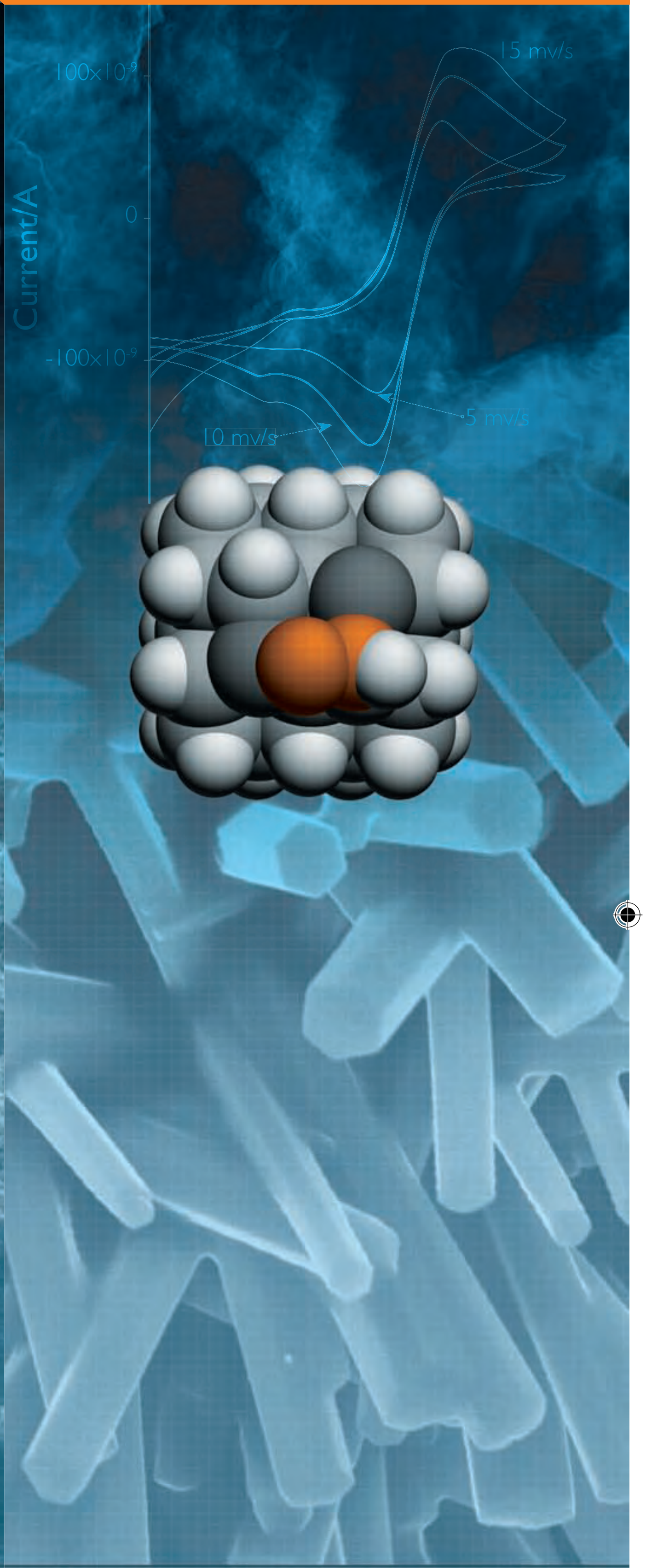
> “We believe that nanotech is the next great technology wave, the nexus of scientific innovation that revolutionizes most industries and indirectly affects the fabric of society. Historians will look back on the upcoming epoch with no less portent than the Industrial Revolution.”
>
> *Steve Jurvetson, Partner, Draper Fisher Jurvetson*



A nanometre is a unit of length in the metric system, equal to one billionth of a metre (i.e., 10^{-9} m or one millionth of a millimetre).

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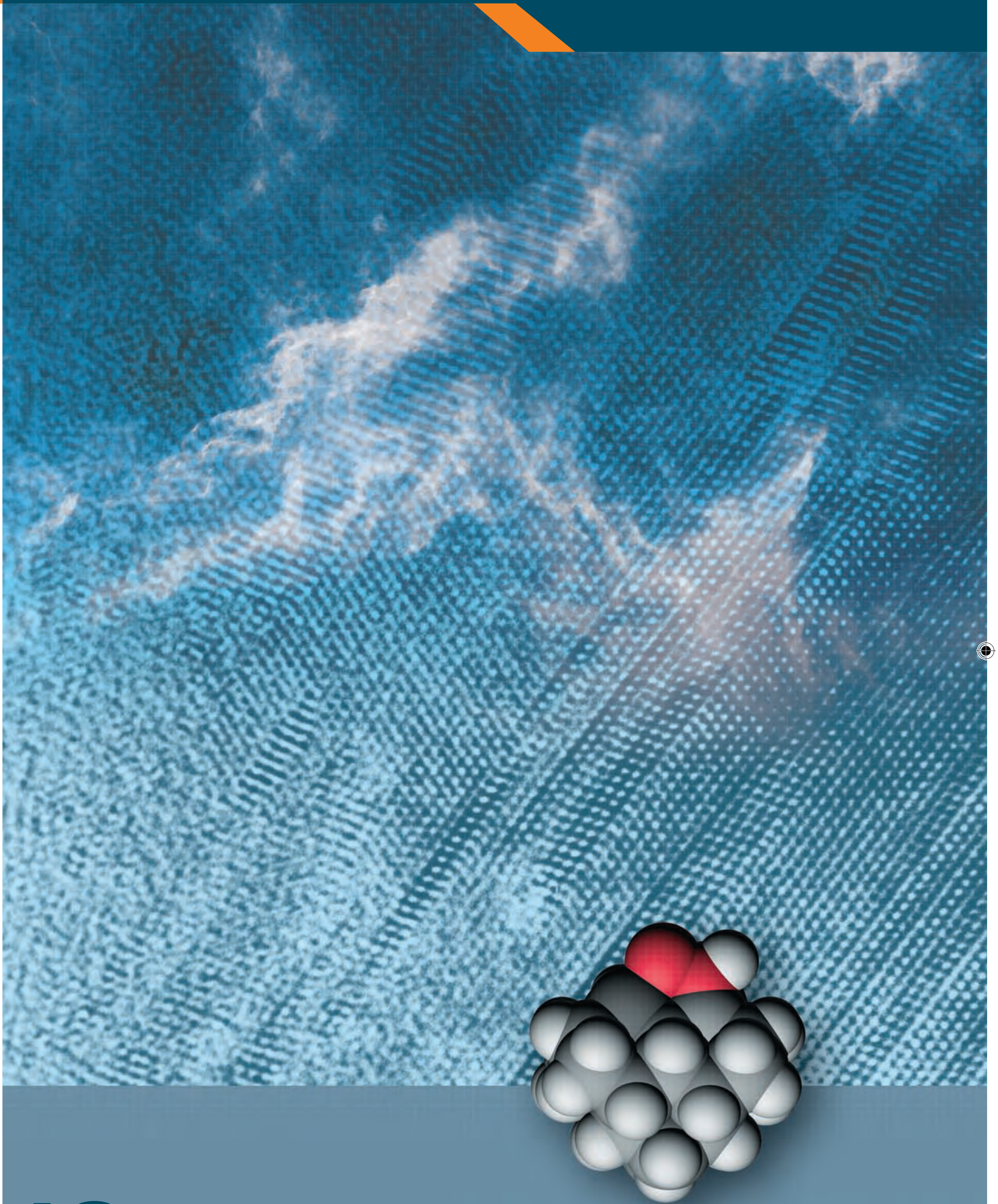

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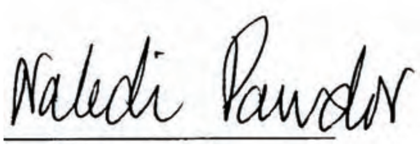
Foreword by the Minister of Science and Technology

Nanotechnology is a new multidisciplinary field that holds the potential to revolutionise the global economy in the 21st century. Our National Nanotechnology Strategy not only advances the national technology missions that were identified in the National R&D strategy, but also strengthens the integrated industrial focus of government. There is little doubt that nanotechnology has an extraordinarily important role to play in shaping our future.

This nanotechnology research plan will guide our development efforts, so that we will be able to improve access to affordable and quality primary health care by developing a nano-drug-delivery-system for TB and HIV/AIDS treatment, improve access to environment-friendly alternative energy sources by the development of an improved solar-energy technology, and establish at least two new nanotechnology industries.

I would like to appeal to every research institution to familiarise itself with the research plan and use it to inform its own nanotechnology research strategy.

It gives me great pleasure to present the Nanoscience and Nanotechnology 10-Year Research Plan.



Naledi Pandor

Minister of Science and Technology

Foreword by the Director-General of Science and Technology

I am delighted to present the Nanoscience and Nanotechnology 10-Year Research Plan.

The approval of the National Nanotechnology Strategy in 2005 was an important milestone in our quest to use nanotechnology to address a wide range of social and economic challenges in South Africa. Since then the Department has been hard at work establishing a series of programmes to help advance the objectives of the strategy. The establishment of the Nanotechnology Innovation Centres based at Mintek and the Council for Scientific and Industrial Research (CSIR) are the most significant steps taken to help advance nanotechnology innovation. These are complemented by programmes focusing on human capital development and on growing the nanoscience and nanotechnology research base.

South Africa's National Nanotechnology Strategy has been hailed by the science community as one of the best in the world, given its focus on socio-economic development. It aims to use nanotechnology to address the country's challenges in the areas of water, health and energy, as well as to give a competitive edge to some of the country's strategic industries (mining and minerals, advanced materials and manufacturing, and chemicals and bioprocessing). To effect the desired social and industrial development and expedite the realisation of the envisaged positive impact of nanotechnology, it has been necessary to identify the specific challenges nanotechnology is to address in each of these areas, enabling a solution-oriented research approach.

The Nanoscience and Nanotechnology 10-Year Research Plan has been developed to ensure the successful implementation of the National Nanotechnology Strategy by steering research efforts to deliver on the goals of the strategy, guiding and helping consolidate our efforts to ensure that we move expeditiously to harness the benefits of nanotechnology. It does this by identifying key challenges and relevant research questions in each of the strategic areas.

I encourage the nanoscience and nanotechnology research community to align their research efforts to this plan and forge further institutional collaborations to effect optimum results, and assure them that the Department will continue to support all endeavours aimed at realising the objectives of the National Nanotechnology Strategy.

Phil Mjwara

Director-General of Science and Technology

1. Background

The development of nanoscience and nanotechnology in South Africa is motivated by the potential advantages this emerging area of research holds for addressing some of the social and economic challenges the country faces. It is for this reason that the National Nanotechnology Strategy[1] focuses on the development of nanotechnology around two clusters, namely the Social Cluster and the Industrial Cluster.

The Social Cluster aims to take advantage of nanotechnology to address some of the country's social challenges in the areas of water, health and energy. The Industrial Cluster, on the other hand, focuses on taking advantage of this area of research to enhance the competitiveness of some of the country's industries. Industrial areas identified in the strategy are mining and minerals, chemical and bio-processing, and advanced materials and manufacturing.

This research plan, therefore, seeks to identify research questions that should be addressed for the research outputs, that are necessary to tackle challenges in the aforementioned areas, to be attained. In addition, the plan also seeks to help contribute to the creation of an enabling environment for the realisation of strategic objectives which include:

- supporting long-term nanoscience and nanotechnology research;
- developing human capital and supporting infrastructure;
- supporting the creation of new and novel devices for application in various areas;
- stimulating new developments in technology missions.

1 Please refer to page 22 for more information.

2. Nanoscience and Nanotechnology

2.1 Scope of Research: Nanoscience versus Nanotechnology

Nanoscience[2] is the fundamental study of phenomena at the nanoscale, typically, but not exclusively, below 100 nanometres in one or more dimensions where the onset of size-dependent phenomena often produces novel properties leading to novel applications. Nanotechnology is the ability to create and control objects on this same scale with the goal of preparing new materials that have specific properties and, therefore, functions. Nanotechnology[2], therefore, can be regarded as the engineering of functional systems at molecular scale; that is, using the properties of nanoscale materials that differ from the properties of individual atoms, molecules, and bulk matter, to create improved materials, devices and systems that exploit these new properties.

Although current nanotechnology research is primarily exploratory, and it may take years to realise many of the goals envisioned, the prospect of significant applications is high.

The research efforts as outlined in this research plan will contribute to all the components of the innovation value chain, from basic research through to product development and manufacturing. The basic and applied research will be conducted at higher education institutions, including both traditional universities and universities of technologies and, to some extent, at the national research facilities. This is expected to contribute significantly to the strategic objective of developing human capital. It is anticipated that the research outputs from these institutions will not be restricted only to publications and student theses, but will also result in the formulation and conceptualisation of products and processes for manufacturing and commercialisation.

The development and innovation component of the value chain will be addressed at nanotechnology innovation centres and science councils. Research activities at universities and innovation centres will not be mutually exclusive, but complementary in nature, each with a clear mandate.

2 Please refer to page 22 for more information.

2.2 Purpose of the Research Plan

To ensure the successful implementation of the strategy, a 10–year plan for implementation of the strategy has been developed. The plan identifies programmes to be pursued for the advancement of this area of research. Furthermore, it calls for the development of a research plan to focus research on the attainment of strategic goals. This research plan, therefore, is a key component of the implementation of the National Nanotechnology Strategy. Figure 1 shows the contextual relationship between the research plan, the implementation plan and the overall strategy.

The purpose of the research plan is to:

- provide strategic foresight for nanoscience and nanotechnology research in South Africa
- steer research efforts to deliver on the goals of the strategy;
- ensure high-impact research in nanoscience/nanotechnology in the areas identified in the strategy;
- help advance the goals of other national strategies, such as the metals sector development strategy, and the Department of Science and Technology's (DST) 10-year Innovation Plan;
- facilitate the development of human capital in nanotechnology and nanoscience;
- stimulate credible research outputs such as publications and patents; innovative products, and processes.

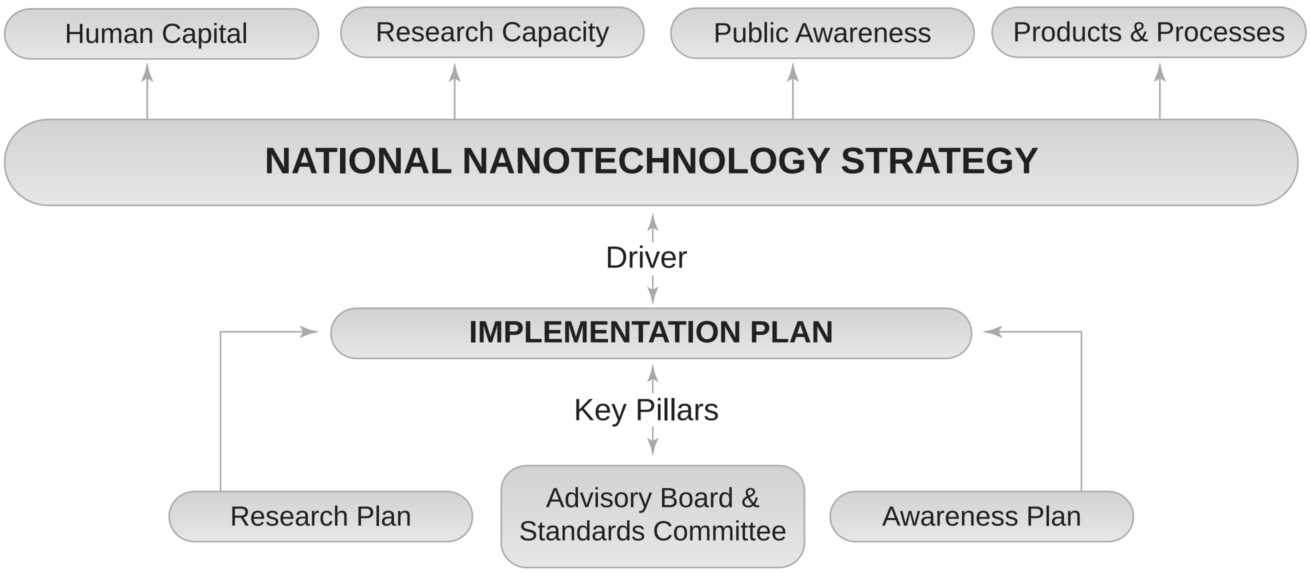
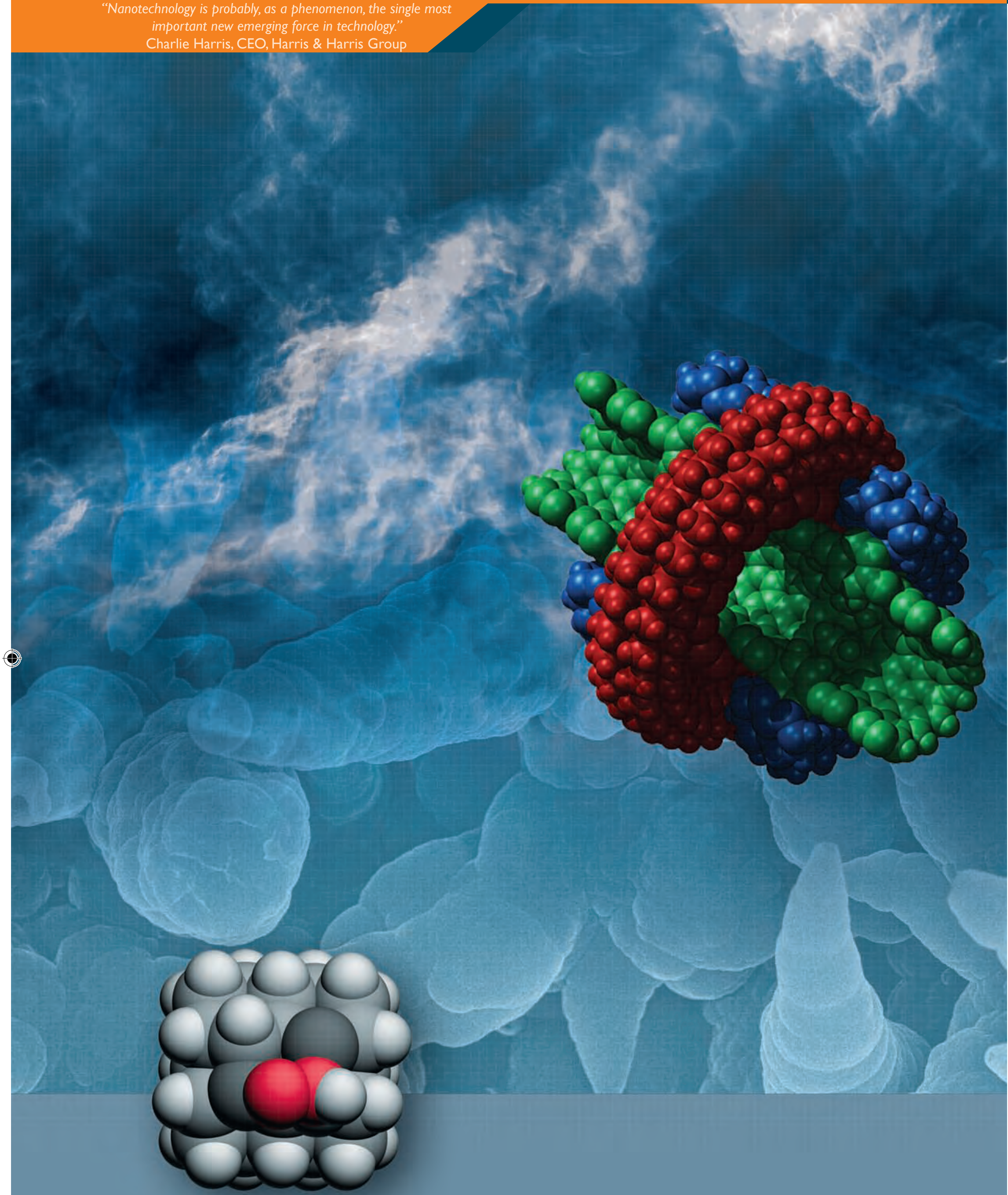


Figure 1. Schematic representation of the contextual relationship between the research plan, the implementation plan and the overall strategy.

"Nanotechnology is probably, as a phenomenon, the single most important new emerging force in technology."
Charlie Harris, CEO, Harris & Harris Group



3. Integration with Other Strategies and Initiatives

The implementation of the Nanotechnology Strategy should focus on making a significant contribution towards the realisation of the goals of South Africa's National System of Innovation (NSI). This necessitates the meaningful integration of nanotechnology research with relevant programmes developed to drive the NSI, including the five Grand Challenges identified in the 10-year Innovation Plan. Because it is multidisciplinary, nanotechnology has the potential to contribute to the advancement of each of the Grand Challenges.

3.1 Contribution to the Grand Challenges

3.1.1 Farmer to Pharma

Bio-nanotechnology (BioNano), which combines nanotechnology with biotechnology, can be used to develop the untapped potential of the biotechnology industry in South Africa. The 2003 National Biotechnology Survey indicated that only 10 percent of all South African biotechnology companies are estimated to be conducting innovative, cutting-edge research and development (R&D), with the majority being involved in new applications of low-technology modern biotechnology. Global developments in BioNano could encourage the advancement of current biotechnology R&D activities in South Africa. In addition to current applications of nanotechnology in such areas as pharmaceuticals and medicine, this novel and multidisciplinary science is benefiting food science and food technology.

3.1.2 Space Science and Technology

To date, South Africa has been primarily a consumer of space technologies. There is a need to develop systems and subsystems to support our requirements and to grow the local space-technology industry. The multidisciplinary nature of nanotechnology means it has the potential to make significant contributions to, and even achieve, technological breakthroughs in all the critical areas, namely the space sciences, earth observation, communication, navigation and engineering services.

The increasing use of satellite-based services requires the development of more efficient, more economical and more resilient space technologies and systems in future. The potential short- to medium-term applications of nanotechnology, which could lead to significant improvements in several areas of space technology, include lightweight construction and functional materials, improved systems and components for energy production and storage, data processing and transmission, sensor technology, as well as life-support systems.

On the other hand, space science research could also offer potential spin-offs as a nanotechnology research instrument, for example: particle interactions or self-organisation phenomena under-microgravity that could be used for the modelling and optimisation of terrestrial processes within the range of nanotechnology.

Examples of more visionary applications are those of molecular nanotechnology in space, the reclamation of other planets by raw-material extraction and material synthesis, and the establishment of a space elevator on the basis of ultra-strong nanomaterials, or the extreme miniaturisation and integration of space systems.

3.1.3 Energy Security

The greatest energy challenge in South Africa is access to affordable, safe, clean and reliable energy. By bringing together all the fundamental sciences such as physics and chemistry, for example, nanotechnology has already demonstrated possible solutions to this challenge.

Molecular nanotechnology (MNT), which is the design and construction of macroscopic materials at molecular level, will play a major part in solving the issues of both sustainable resource-extraction and by-product mitigation.

For energy, the broad categories of MNT application include:

- more efficient energy usage (non-thermal energy usage via nanostructured devices such as fuel cells; molecularly-tailored catalysts for selectivity and by-product elimination; high-strength materials for decreased transportation costs; electricity storage and electrosynthesis for portable power sources, and for chemical fuel generation; distributed fabrication to minimise transportation infrastructure);

- solid-state energy generation (solar power for photovoltaics and artificial photosynthesis; thermoelectric conversion for direct solid-state transformation of thermal gradients into electricity).

Nanotechnology may also hold the key to developing a viable hydrogen economy by establishing new technologies for the production and storage of hydrogen fuel using nanostructured materials, such as semiconductor, carbon-based or polymeric nano-materials.

3.1.4 Global Change Science

Worldwide, greenhouse gases and other emissions are believed to be responsible for altering the earth's climate. The projected effects of climate change in Africa include the increased occurrence of malaria, schistosomiasis (bilharzia) and other vector-borne diseases. Urgent responses are required, including research into prevention and early warning systems; field detection and treatment; public health infrastructure requirements and treatment regimes.

The major role that nanotechnology could play in global change science is to contribute to the reduction of greenhouse gas emissions.

3.1.5 Human and Social Sciences

With South Africa striving to become an innovative society, it is essential to support the public's understanding of, and engagement with, science. Science, engineering and technology (SET) practitioners need to be mindful that members of the public are not merely passive recipients of science and technology, but are important players in processes that shape the focus and patterns of science, technology and development[3].

As a new and, in some way, unknown field of science, nanotechnology has many challenges associated with it. The effects of certain applications and nanomaterials are unknown[3]. Ethical issues and risks might accompany the many benefits that nanotechnology promises.

Well-constructed awareness programmes that cover the benefits, risks and ethical issues ought to be implemented.

The Human and Social Sciences Grand Challenge may provide an excellent platform for scientists, lawyers, psychologists, etc. to come together and work through the challenges associated with nanotechnology- and nanoscience-related applications and materials.

3.2 Mechanisms for Integrating Nanotechnology with Other Strategies and Initiatives

Because of its multidisciplinary nature, nanotechnology is a stand-alone platform technology with the potential to revolutionise many research applications and industries. However, within the context of integrating nanotechnology with other national strategic initiatives, it can also be viewed as a cross-cutting technology platform.

It is evident therefore that a logical mechanism for integrating nanotechnology with other strategies and initiatives directed at promoting the objectives of the National System of Innovation (NSI) is the creation of 'nanotechnology platforms'. In this context, a

3 Please refer to page 22 for more information.

Technology Platform (TP) would be a collaborative research and development consortium comprising multi-disciplinary expertise to:

- foster effective public-private partnerships between research communities to deliver intellectual property (IP) that can be commercialised;
- support the development of local technological capabilities in general.

The mechanisms and instruments of the Technology Innovation Agency (TIA) will be used to achieve these goals. As a TP, nanotechnology will assume different roles for different technology-related goals.

The examples below are of different roles nanotechnology TPs can assume for different technology-related goals (Figure 2).

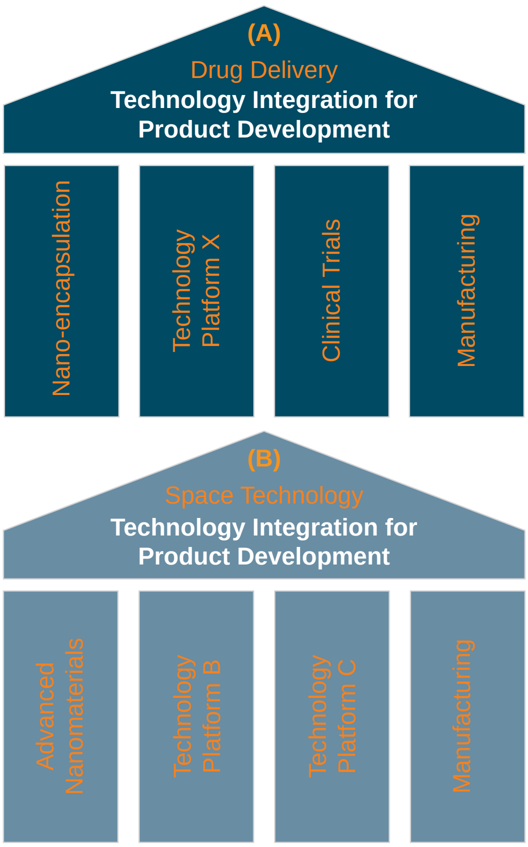


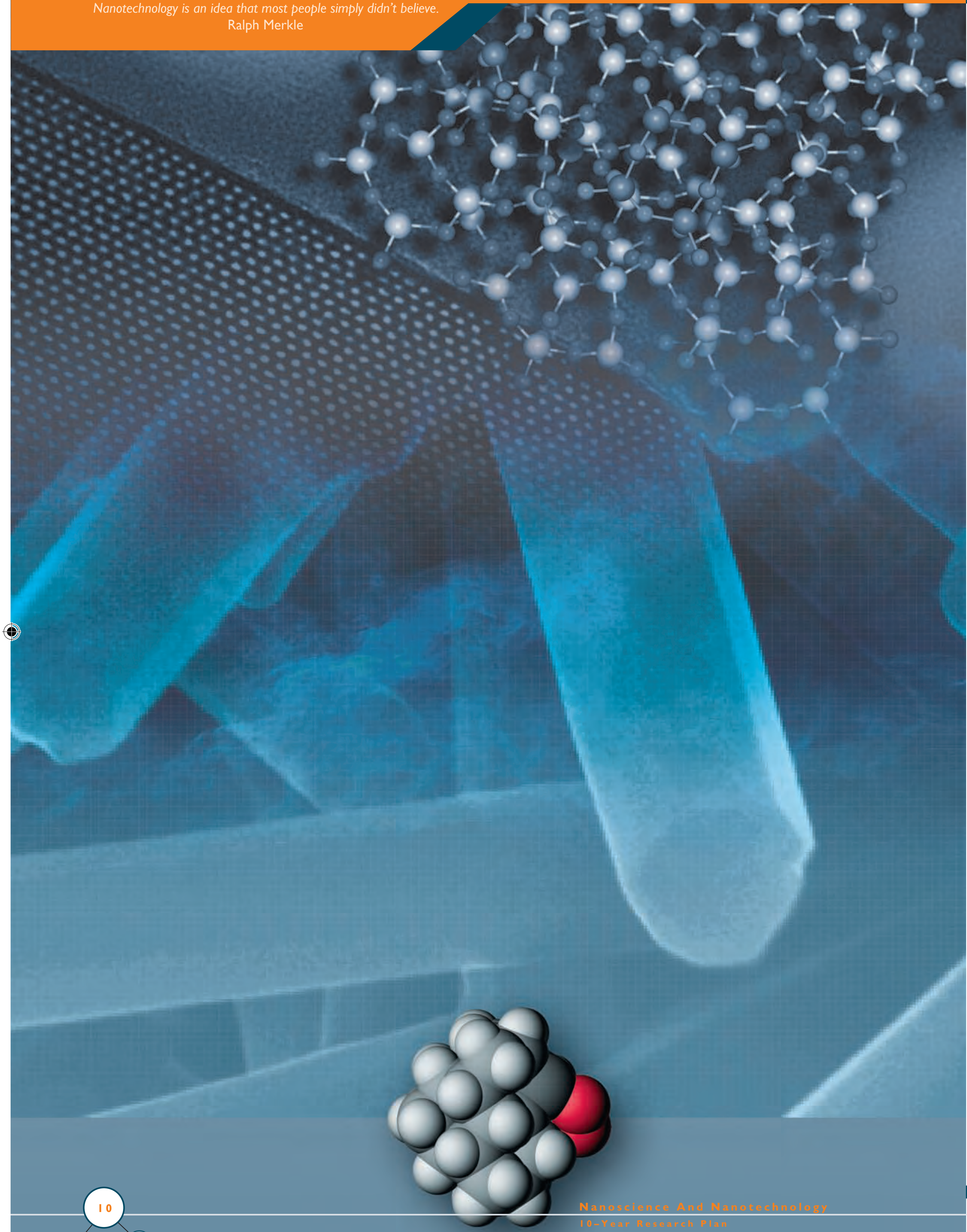
Figure 2: Conceptual model of the different roles nanotechnology can play as a Technology Platform (shaded) within a given centre of competence: (a) nano-encapsulation TP for a drug-delivery system, and (b) advanced materials TP for a space application, and for the manufacturing of satellites.

In Figure 2, the individual pillars represent TPs and the triangular sections represent the technology-integration-for-product-development mechanism. The apex is the actual product. The nanotechnology TPs are the shaded pillars. In both (a) and (b) one of the TPs would be a manufacturing platform, whereas in (a) another the TP would be a clinical trials platform.

A nanotechnology platform will be established in consultation with stakeholders such as: the Department of Science and Technology (DST) Programme 2 - Research, Development and Innovation (RDI); the National Nanotechnology Innovation Centres (NICs); national facilities; universities; and industry. Once established, the Nanotechnology TP will be an enabling entity within a given centre of competence (COC) to commercialise any TP-generated IP. Again, the instruments and mechanisms of the TIA will be implemented to achieve this goal.

In this context, a COC is defined as a collaborative network/consortium for the commercialisation of technology comprising participants with multi-disciplinary expertise, and each with a specific role, but relying on harnessing the resources, capabilities and synergies of all, in pursuit of a clear research objective and product/service with commercial and/or public-good potential.

Nanotechnology is an idea that most people simply didn't believe.
Ralph Merkle



4. Key Initiatives: Capacity Development and Innovation

In creating an enabling environment for the development of this field of science, the DST has put in place a series of programmes focused on positioning universities and other research institutions to conduct world-class nanoscience and nanotechnology research and enhance capacity-building. The programmes include the acquisition of equipment, institutional arrangement for research and innovation, human capital development, and nanotechnology flagship projects.

4.1 Equipment Acquisition

The National Nanotechnology Equipment Programme (NNEP) focuses on the acquisition of equipment and facilities necessary for research into nanoscience and nanotechnology. In addition, researchers can also access funding through the National Equipment Programme. The National Research Foundation (NRF) manages these programmes.

4.2 Institutional Arrangement for Research and Innovation

To advance nanotechnology research, Nanotechnology Innovation Centres have been established at Mintek and at the CSIR. These multi-user national facilities are expected to play a significant role in promoting nanotechnology research, with their primary focus leaning more towards the higher end of the innovation value chain, namely the development of commercial products and processes. They will house some of the advanced equipment necessary for advanced research in the field and conduct research in line with the focus of the National Nanotechnology Strategy. Being national facilities, these Centres are accessible to all stakeholders.

Focusing on the lower end of the innovation value chain, and in creating a platform for the generation of knowledge in the field of nanoscience, it is necessary that nanoscience, as a prerequisite to nanotechnology, be given long-term sustainable support. This will be done through the establishment of Nanoscience Centres. Such centres will be equipped with basic and necessary infrastructure and provide final-year undergraduate, honours, master's and doctoral students with basic teaching and training in nanoscience to prepare them adequately to pursue research careers in nanotechnology, or find employment in related industries. The Centres' critical contribution will be the development, initially, of nanoscience curricula and, subsequently, accredited qualifications in this field, with the focus being on the areas identified in the National Nanotechnology Strategy.

4.3 Human Capital Development

As part of the DST's research-chairs initiative (South African Research Chairs Initiative), targeted research chairs in the field of nanoscience have been established. Among others, the research chairs will focus on increasing the level of research activity in the field, thus contributing significantly to the development of human capital.

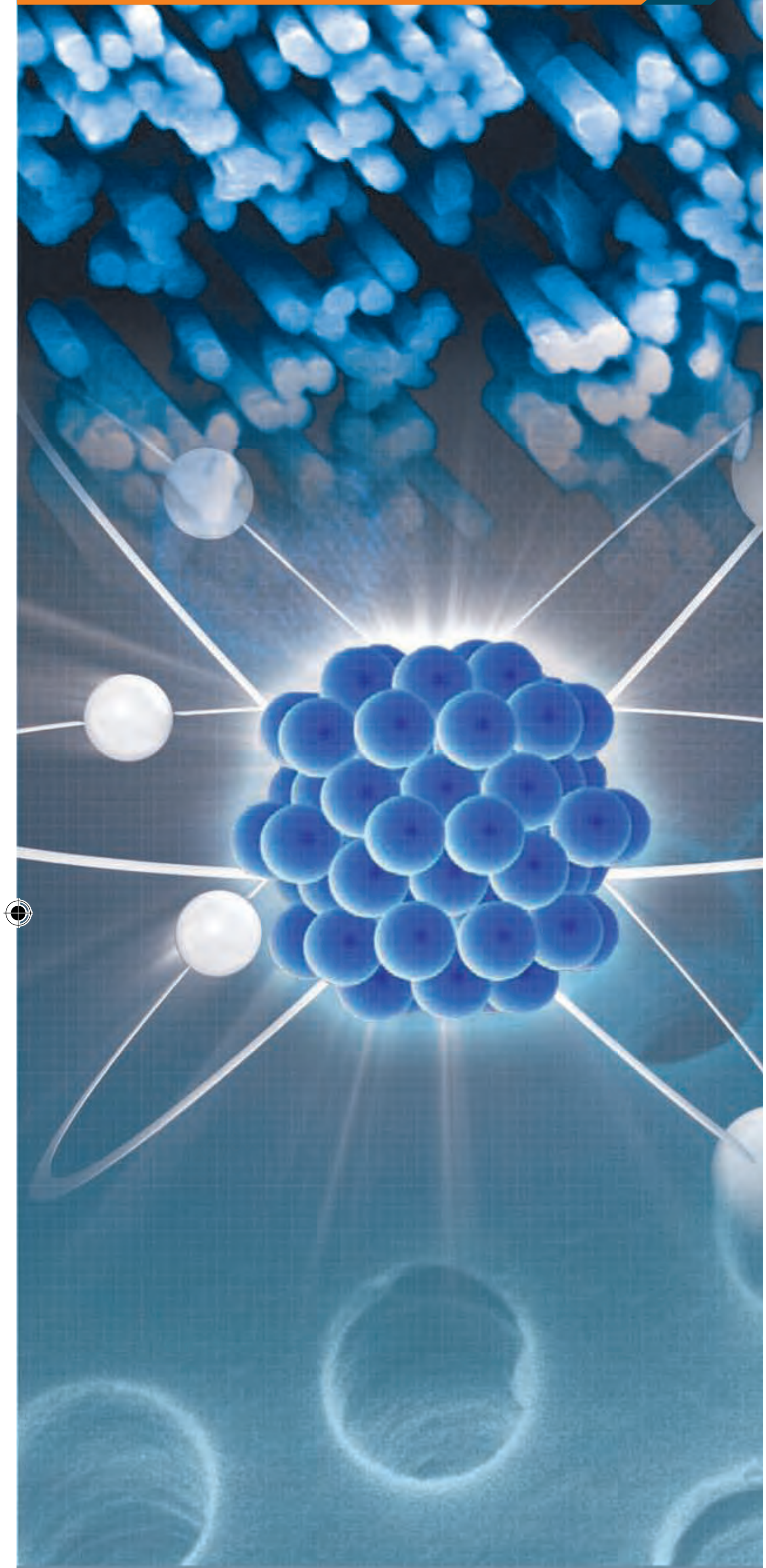
The Bilateral and Multilateral Collaborations on Nanotechnology, such as the India-Brazil-South Africa forum (IBSA), South Africa-France, and South Africa-Argentina collaborations, will be exploited for the development of expertise and skills training in the identified research areas.

Other DST initiatives are also used, such as *Student Support Programmes* to advance the development of human capital by fast-tracking high-end skills development in nanoscience and nanotechnology.

4.4 Nanotechnology Flagship Projects

Nanotechnology flagship projects serve to demonstrate the benefits of nanotechnology within a reasonable timeframe. Implemented through the NRF, the nanotechnology Flagship Programme offers researchers the opportunity to formulate and pursue projects from the broad clusters identified in the strategy. Examples of these projects include the use of nanotechnology in water treatment, super capacitors and fuel-cell development, and nano-architecture in the beneficiation of platinum-group metals.

"We think that the biggest breakthroughs in nanotechnology are going to be in the new materials that are developed."
Troy Kirkpatrick, GE Global Research



All these programmes have enabled a significant amount of nanoscience research to be done in South Africa and they continue to generate human capital with the necessary skills to conduct research in this field. The programmes have created a climate that is conducive to the undertaking of focused research, aimed at delivering solutions to the challenges the country faces, as identified in the strategy. Based on that, this research plan was developed to articulate research questions to be pursued in directing research in this field to focus on delivering on identified strategic areas in the Social and Industrial Clusters. For each of these clusters, many research questions are to be pursued.

5. Challenges and Research Questions for the Social Cluster

Challenges specific to the Social Cluster and hence research questions aimed at addressing those challenges have been identified as follows:

5.1 Water

Many different water treatment technologies (chemical and biological, active and passive) already exist for removing various contaminants from water and achieving different levels of quality, depending on the technology used and the water quality that is required. Each treatment technology, however, has its own limitations, such as being energy intensive and generating by-products with unintended impacts on the environment and human health.

Nanotechnology could assist in meeting the need for safe and affordable water through relatively inexpensive water purification and the rapid and low-cost detection of impurities[4]. The application of nanotechnology in water treatment may vary depending on the scale (local portable systems for central regional treatment facilities) and the quality of water required.

5.1.1 Supply of Clean Water

One of the very significant challenges is that a large number of South Africa's rural communities and informal settlements located near industrial areas need to have access to clean water. In most instances, the water to which the community has access is heavily contaminated, resulting in water-borne diseases such as cholera being widespread. This makes the provision of clean water, particularly to rural and arid areas, a real and serious challenge. This necessitates the development of low-cost and portable filters and purifiers. Addressing this challenge could be assisted by nanotechnology research into the:

- development of water purification modules;
- development of biodegradable, stimuli-dependent nanoparticles for the delivery of agents that are used in water treatment;
- development of sensors for the detection of pathogens/chemical pollutants in water;
- development of techniques to remove pathogens/chemical pollutants and particulate matter in water;
- preservation of water cleanliness to ensure that water treated in bulk can remain uncontaminated for a long time.

5.1.2 Water Scarcity and Access to Water

As do most countries in the world, South Africa faces the challenge of diminishing water resources. Therefore, it is necessary to explore other means of getting potable water, such as the desalination of sea water. The cost of desalinating sea water using existing technologies is very high, therefore the challenge is to take advantage of nanotechnology in developing alternative and cost-effective means of doing so.

To enable the exploration of other possible sources of drinking water, we need to explore how nano-technology can help to:

- develop alternative and cost-effective systems for the desalination of sea water;
- create appropriate conditions for rain (such as cloud seeding);
- develop techniques for the maintenance of water levels in dams and rivers (i.e. prevent or minimise water evaporation);
- develop techniques for harvesting and pre-serving rain water (including excess rain);
- develop systems for water recycling at a point of usage;
- effect an improvement in the portability of water.

4 Please refer to page 22 for more information.

5.1.3 Water Pollution

Industrial effluent has been the main source of destruction of wetlands. To protect the environment, including the country's wetlands, it has become necessary to investigate cost-effective and efficient means of treating industrial effluent. The challenge is to ensure the sustainable protection of the environment.

In addition, industrial waste streams such as those from mines, are responsible for, among other things, the contamination of ground water. With some communities relying on ground water as their source of water, it is necessary to ensure the remediation of such water sources by using nanoparticles. The remediation of waste streams would not only stop ground water contamination, but also ensure environmental protection.

The research focus in this area should be on how nanotechnology can be used to:

- develop sensors for the detection of pollutants;
- develop systems for the removal of pollutants (for recovery and/or inactivation);
- beneficiate effluent;
- minimise contaminants through the use of nanoparticles;
- recover water from diluted mine effluent.

5.2 Energy

Ongoing developments around the country have put a great deal of strain on existing energy sources. It has become necessary therefore to look elsewhere for alternative sources of energy. In addition, the effective and efficient distribution of energy is also a major challenge. As such, research questions in the area of energy should aim to address these challenges.

Research could possibly focus on the following things:

5.2.1 Alternative Sources of Energy

To determine how nanotechnology can help address this challenge, research should explore:

- How nanotechnology can be used to develop new sources of energy;
- How nanotechnology can be used to develop/improve existing renewable sources of energy;
- How nanotechnology can be used to effect the production of cleaner and environmentally-friendly energy;
- How nanotechnology can be used to effect an improvement in the generation and use of energy;
- How nanotechnology can be used to develop high-capacity energy storage devices;
- How solar energy can be applied to produce hydrogen fuel;
- The use of nanotechnology in the efficient production of hydrogen by water electrolysis;
- How nanotechnology can be used for hydrogen purification;
- How nanotechnology can be used in both catalysis and fuel cell research. In South Africa, the development of the Pebble Bed Modular Reactor (PBMR) technology will benefit significantly from nanotechnology research and applications.

5.2.2 Effective Distribution of Energy

Energy distribution, particularly to rural communities, has become a serious challenge. A lack of adequate infrastructure is one of the primary reasons for there being difficulty in distributing energy to such parts of the country. Therefore, it is necessary to investigate the possibility of nanotechnology providing other (and of more effective) means of distributing energy or distributed onsite power generation. This is the basic research question in this area.

Specifically, the research questions would include the use of nanotechnology to develop portable and efficient energy sources.

5.3 Health

South Africa is facing serious challenges regarding the health of its people. The country has a high rate of HIV-infection, which is accompanied by opportunistic infections such as tuberculosis TB. This is placing a tremendous burden on the national health infrastructure and is draining resources that ought to be used in addressing other diseases that are also important and growing in urgency. These diseases include diabetes, cancer, heart disease, malaria, arthritis, and asthma. New solutions are urgently needed to adequately manage these diseases.

Relevant research questions in this area would explore the following, among other things:

- The use of nanotechnology in the development of point-of-care diagnostic kits. Point-of-care diagnostic tools are necessary when medical practitioners need to confirm diagnosis during a consultation, thus enabling the rapid identification of pathogens and application of appropriate therapy. Such instances include cases where patients are suffering from infectious diseases that have a rapid disease progression such as meningitis (which can lead to fatality or disability in infants and children), and Ebola (which causes quick and painful death in its patients). Point-of-care diagnostics are also crucial in the management of HIV and TB, because these conditions require rapid detection and treatment to improve the life of the infected patient, and prevent the spread of these infectious agents. Rapid diagnostic kits for HIV are currently available; however, they have proved not to be selective as they sometimes give false results. Therefore, selective/specific diagnostic tools for HIV are urgently needed. In the case of TB, the current testing methods have a long turn-around time, which makes it difficult for doctors to provide timely and appropriate therapy. In addition, specialised technicians are needed to perform the tests and specialised pathologists to interpret the results. The development of rapid diagnostic kits for TB would enable doctors to quickly confirm the diagnosis of TB and therefore administer timely treatment. Therefore, rapid diagnostic kits that are simple and 'user friendly' would be beneficial in several instances in the management of infectious diseases.
  Point-of-care diagnostic kits are also important for the early detection of cancers as this would improve chances of successful therapy;

- The use of nanotechnology in the development of new forms of therapy. HIV-positive patients as well as patients who suffer from TB normally take large doses of many tablets regularly and over extended periods. The pills have toxic side-effects. This sometimes leads to therapy fatigue among patients and therefore non-compliance with the treatment regimen. This results in the emergence of multi-drug-resistant organisms. Therefore, new drug formulations that would reduce drug dosage as well as the frequency of consumption are needed. Drug delivery systems that would allow the targeted release of therapeutic agents to the diseased site would further reduce the general toxicity that is caused by the systemic circulation of drugs. Drug-delivery systems that would allow drugs to cross the physiological barriers (such as the blood-brain barrier, and the blood-ocular barrier) are also needed. These would enable treatment of, for example, cerebral TB, cerebral malaria, meningitis, as well as other diseases that are localised in the brain, and neurodegenerative diseases that are localised in the eye. The CSIR is developing a nanoparticle-encapsulated drug-delivery system for TB treatment.
  New materials that would be used as implants in tissue replacement also need to be developed. They must be bio-compatible to minimise injury to the patient. The mechanism of tissue regeneration also needs to be explored;

“Solar cells and most modern displays are examples of organic hybrids. But as we move to a renaissance in medicine with nanotech, matter becomes code.”
Steve Jurvetson, Managing Director, Draper Fisher Jurvetson

- Using nanotechnology to improve surgical procedures. Current methods of performing surgery are invasive and cause most patients a great deal of pain during the recovery period. Highly specialised surgeons are required to perform them. New surgical tools need to be developed to improve on current surgical procedures, and new procedures need to be developed to reduce the invasiveness of surgery, and reduce the complexity of surgical procedures;
- The development of nano-biosensors for *in situ* detection of glucose levels in diabetes therapy;
- The ability to functionalise nano-particles in a simple and efficient manner to confer versatility for biomedical applications.

6. Challenges and Research Questions for the Industrial Cluster

The focus of the Industrial Cluster is on enhancing the competitiveness of some of South Africa's industries. Identified industries include those of (i) mining and minerals, (ii) chemical and bio-processing and (iii) advanced materials and manufacturing.

6.1 Chemical and Bio-Processing

The Sector Development Strategy: Chemicals[5] identify key strategic challenges that the chemical sector faces. Of the key action programmes identified to address these challenges, the following are where nanotechnology research can assist:

6.1.1 Titanium Beneficiation Initiative

The goal of this initiative is to convert an initial target of 20 percent of exported titanium-based minerals and by-product feedstock such as zircon to high-value-added products (e.g. TiO_2).

To help advance this goal, the following research questions will be pursued:

- The use of nanotechnology to convert titanium-based minerals to titanium dioxide;
- The use of nanotechnology in the cost-effective production of ultra-pure zirconia for application in various areas (e.g. ceramic tiles).

6.1.2 Flouro-chemical Expansion Initiative

The goal of this initiative is to expand the size of the fluoro-chemical industry in South Africa by building a world-class, high value-added fluorine-based industry with associated down-stream fine-chemical synthesis operations. This goal can be achieved largely through the beneficiation of fluorspar (CaF_2), the primary mineral feedstock for fluorine chemistry.

5 Please refer to page 22 for more information.

To help advance this goal, the following research focus areas will be pursued:

- the use of nanotechnology in the development of fluorine-based fine-chemical products for various applications (e.g. electronic chemicals, medical, cosmetics, etc.);
- the use of nanotechnology in the beneficiation of fluorspar to crude and pure hydrogen fluoride (HF), fluorine (F_2) and fluoro-chemical products.

Furthermore, the competitiveness of our chemical industries can be enhanced through the improvement of some of the processes, such as cleaner production. Also, functionalisation of some of the products (e.g. catalysts) to effect better performance can serve to confer much-needed competitiveness. As such, research questions in this area should be geared towards addressing these issues. Examples of such research questions include the use of nanotechnology in the synthesis of nanocatalysts necessary for cleaner production (in chemicals manufacturing).

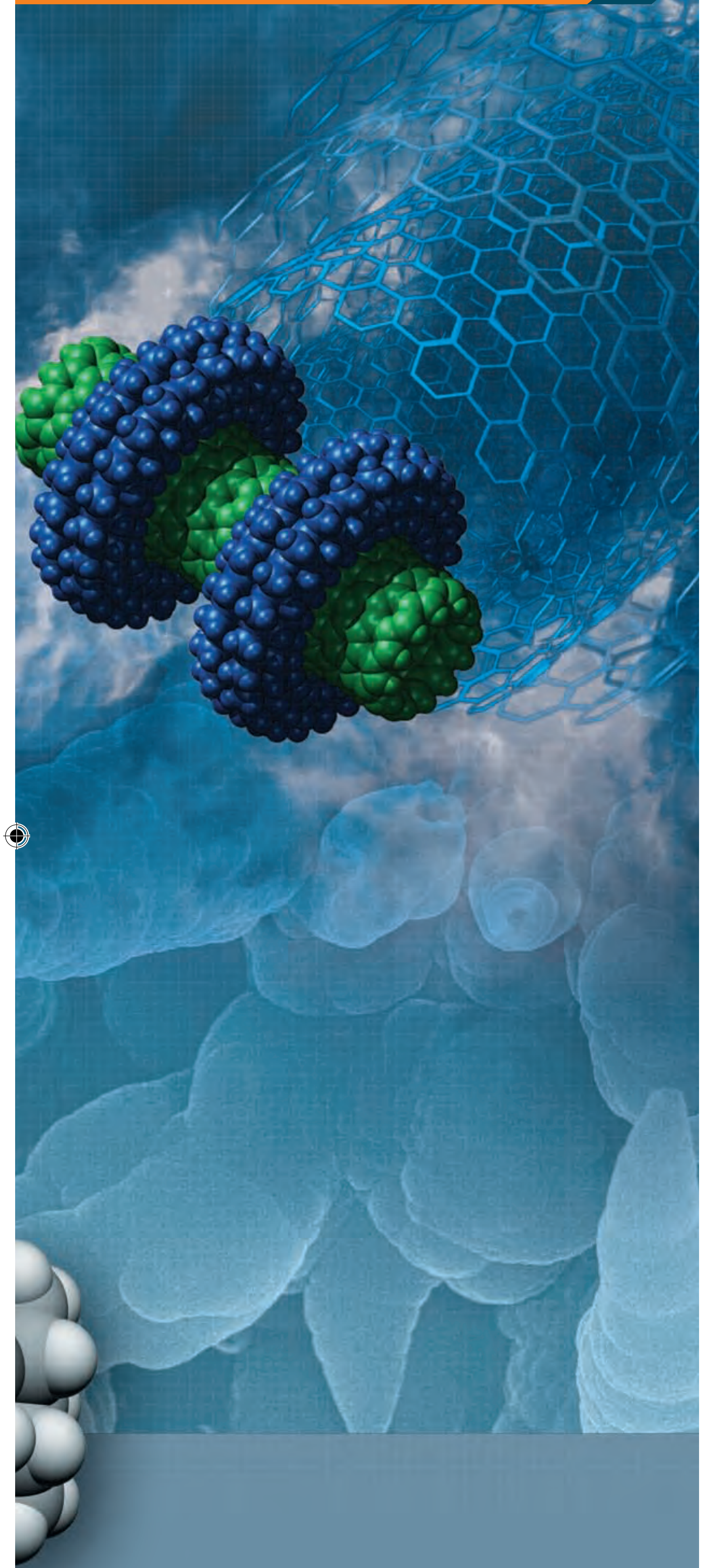
6.2 Advanced Materials and Manufacturing

The Advanced Manufacturing Technology Strategy (AMTS)[6] identifies the following as potential lead projects for the advancement of its strategic goals and objectives. To effect synergy, nanotechnology research in this area will also focus on advancing delivery on these lead projects, which include the following:

- aluminium, magnesium and titanium light metals development;
- coating technology innovation, including paints and thin films;
- platinum beneficiation;
- high-performance magnesium alloys;
- high-performance textiles;

6 Please refer to page 22 for more information.

"We're very optimistic that nanotechnology can markedly improve cancer therapy."
James Baker



- the optimisation of the three current processes used to extract Al and other by-products from coal ash;
- the production of TiO_2 sponge recovered from slag with new technology.

Research in these areas would also serve to advance the objectives of the Metals Sector Development Strategy 7 of the Department of Trade and Industry, particularly with regard to the promotion of the beneficiation of metals, which is one of the identified key action programmes.

In addition to the beneficiation of metals for industrial applications, the development of advanced materials will also address drug delivery and space industries, as already noted.

6.3 Mining and Minerals

6.3.1 Mineral Beneficiation

Insufficient beneficiation along the value chain, particularly on downstream industries[7], has been identified as one of the key strategic challenges within the metals sector that retard the economic aspirations of government. To address this challenge, a key action programme that has been identified is the promotion of the beneficiation of metals. In line with this key action plan, research questions aimed at mineral beneficiation will be pursued. Such research should explore:

- the preparation of high-value end-products (such as catalysts and electrocatalysts) using the platinum group metals (PGMs);
- how to convert mined silicon into nano-particles directly from the extracted mineral in a cost-effective process;
- how bio-compatible minerals can be used to provide health solutions.

7 Please refer to page 22 for more information.

7. Expected Outcomes

Whilst most of the research would have a long-term focus, it is anticipated that, within a 10-year timeframe, this research plan will guide research in nanoscience and nanotechnology in order for it to make a significant contribution to: (i) social development; (ii) economic growth; and (iii) human capacity development. Table 1 lists some of the expected contributions in these areas. Progress in identified research projects will be monitored on an ongoing basis through annual progress reports.

Table 1: Expected Outcomes

	EXPECTED OUTCOMES
Social Development	Improve access to affordable and quality primary health care by the development of a: • point-of-care diagnostic kit for the diagnosis of TB and HIV/AIDS • nano-drug-delivery-system for TB and HIV/AIDS treatment. Access to safe, affordable good quality water by the development of a low-cost: • water filter • and portable water-pollutant sensor. Access to environment-friendly alternative energy sources by the development of: • an improved solar energy technology.
Economic Growth	Development of a knowledge-based economy, contribution to job creation, increased foreign investment in nano-technology R&D, in particular the health as well as the mining and minerals sectors: • mass production and export of gold nanoparticles • at least one improved exportable process for the beneficiation of metals and minerals, in particular the platinum-group metals • establishment of at least two new nanotechnology industries • significant job creation within the nanotechnology sector • 10 patents • at least three TPs.
Human Capital Development	Human capital development will be required for the sustainable development and growth of nanotechnology in South Africa. This will be achieved by an indirect contribution via the implementation of nanoscience and nanotechnology research across the entire value chain, which will deliver: • 400 master's degree and 50 doctoral students • 150 publications.

As indicated in Figure 1, this Research Plan is an enabler of the Implementation Plan, which provides a detailed listing of the timelines and projected outcomes of the National Nanotechnology Strategy over the next 10 years.

8. Summary and Conclusion

The Research Plan provides guidance in terms of research focus. The identified research questions therefore are by no means exhaustive. Furthermore, whilst this research plan focuses on the research necessary for the advancement of some of the national goals, research aimed at knowledge generation would also be highly encouraged. As such, the focus of nanoscience and nanotechnology research will not be exclusively confined to research identified herein.

Furthermore, the DST will put in place mechanisms for determining health, safety, environmental and risk issues associated with nanotechnology research and application using internationally-accepted best practice[3]. This effort will be aimed at ensuring that nanotechnology research, including that prescribed in this document, is done in accordance with international best practice.

The following (Table 2) is the summary of research questions identified and discussed herein:

Table 2: Summary of Research Questions

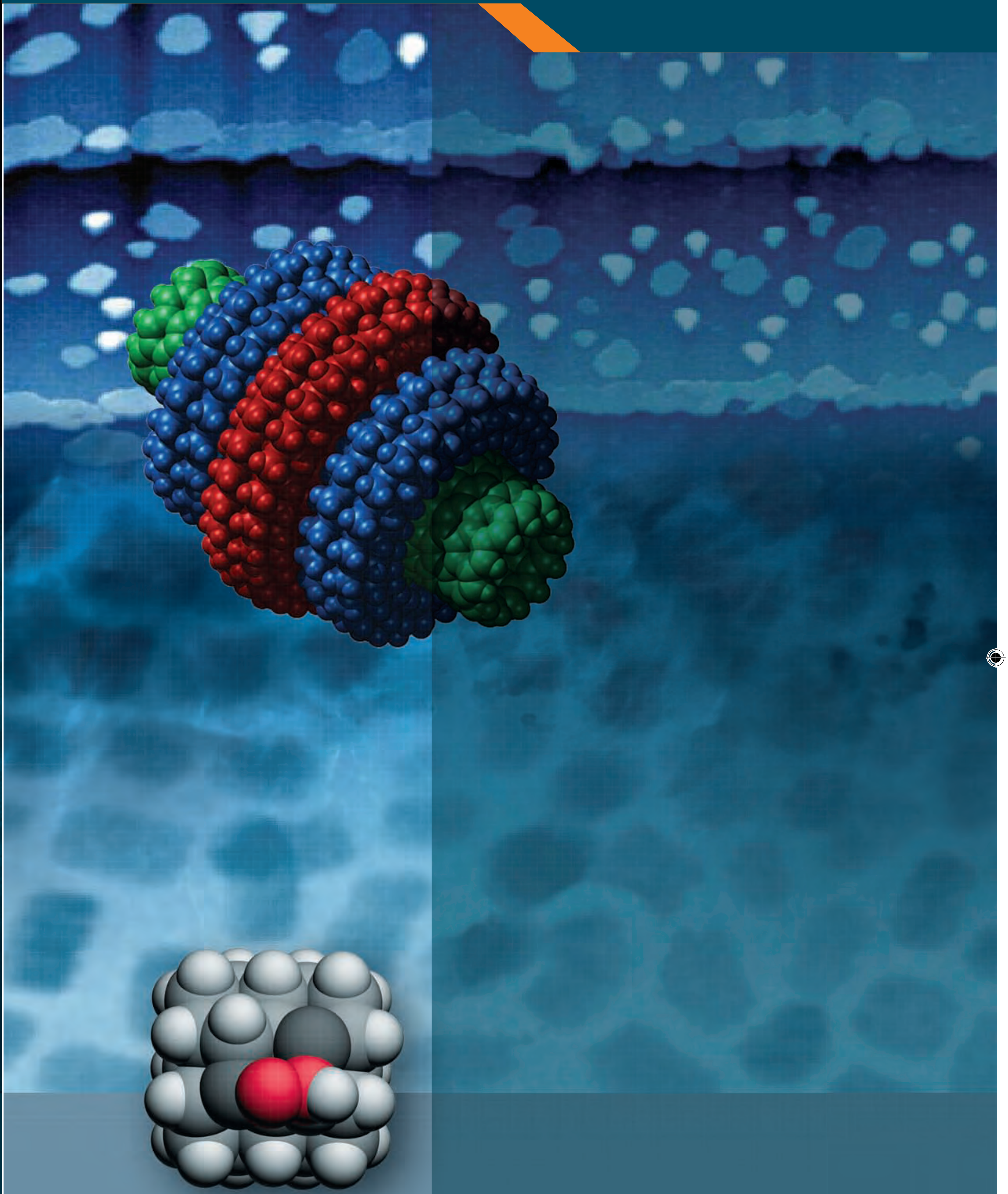
STRATEGIC FOCUS AREA	SPECIFIC OPPORTUNITY/ CHALLENGE	FOCUS OF RESEARCH QUESTIONS
Water	Supply of clean water	• The development of water purification modules • The development of biodegradable, stimuli-dependent nanoparticles for the delivery of agents that are used in water treatment • The development of sensors for detection of pathogens/chemical pollutants in water • The development of techniques to remove pathogens/chemical pollutants and particulate matter in water • Preservation of water cleanliness
	Water scarcity and access to water	• Development of techniques and processes for water desalination • Creation of appropriate conditions for rain (such as cloud seeding) • Development of techniques for maintenance of water levels in dams and rivers (i.e. prevention or minimisation of water evaporation) • Development of techniques for rain water harvesting • Development of systems for water recycling at a point of usage • Effect improvement in water portability
	Water pollution/effluent treatment	• Development of sensors for pollutant-detection • Development of systems for removal of pollutants • Industrial effluent beneficiation • Minimisation of contaminants through the use of nanoparticles • Recovery of water from dilute mine streams
Energy	Alternative sources of energy	• Development of new sources of energy • Development or improvement of existing renewable sources of energy • Production of cleaner and environmentally-friendly energy • Improvement in generation and use of energy • Development of high-capacity energy-storage devices • Using solar energy to produce hydrogen fuel • Efficient production of hydrogen by water electrolysis • Hydrogen purification • Catalysis and fuel cells research
	Effective distribution of energy	• Development of mobile energy sources

3 Please refer to page 22 for more information.

STRATEGIC FOCUS AREA	SPECIFIC OPPORTUNITY/ CHALLENGE	FOCUS OF RESEARCH QUESTIONS
Health		• Development of point-of-care diagnostic kits • Development of new forms of therapy • Improvement of surgical procedures • Development of nanosensors for in situ detection of glucose levels in diabetes therapy • Functionalisation of nanoparticles to confer versatility for biomedical applications
Chemical and Bio-Processing	Titanium Beneficiation Initiative	• Conversion of titanium-based minerals to titanium dioxide • Cost-effective production of ultra-pure zirconia for application in various areas
	Fluoro-chemical Expansion Initiative	• Production of fluorine-based fine chemical products for various applications • Beneficiation of fluorspar to crude and pure hydrogen fluoride (HF), fluorine and fluoro-chemical products
		• Improvement of catalysts to achieve supported narrow metal crystallite-size distribution, which can be varied over wide crystallite-size range • Synthesis of nanocatalysts necessary for cleaner production (in manufacturing of chemicals) • Application of meso- and micro-porous materials as nanostructure catalyst-carriers for cleaner processing
Advanced Materials and Manufacturing	Advancing strategic goals of AMTS	• Aluminium, magnesium and titanium light-metals development • Coating technology innovation • Platinum beneficiation • Production of high performance magnesium alloys • Production of high performance textiles • Optimisation of three processes to extract aluminium in other by-products from coal ash • Production of TiO2 sponge recovered from slag with new technology
Mining and Minerals	Mineral beneficiation	• Preparation of high-value end-products using PGMs • Conversion of South Africa-mined silicon into nanoparticles directly from the extracted metal in a cost effective process • The use of bio-compatible metals to provide health solutions

9. References

1. The National Nanotechnology Strategy; *Department of Science and Technology.*
2. Working Definition TC/229, *International Standards Organization.*
3. Nanoscience and Nanotechnologies (2004). *The Royal Society & The Royal Academy of Engineering.*
4. National Science and Technology Council (2007). The National Nanotechnology Initiative: Strategic Plan. United. States of America, Subcommittee on Nanoscale Science, Engineering and Technology.
5. Sector Development Strategy: Chemicals (2005). *Department of Trade and Industry.*
6. A National Advanced Manufacturing Technology Strategy for South Africa; *Department of Science and Technology.*
7. Metals Sector Development Strategy (Draft) (2006). *Department of Trade and Industry.*



NANOSCIENCE AND NANOTECHNOLOGY

10–YEAR RESEARCH PLAN

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